Evaluating alternatives for extending the drinking water supply in Uganda

CIE4061-09 Multidisciplinary Project

Roos Besseling, Josine van Marrewijk,
Marloes Slokker, Ilse van der Zwet

Delft University of Technology

Evaluating alternatives for extending the drinking water supply in Uganda

A multidisciplinary project

by

Roos Besseling, Josine van Marrewijk, Marloes Slokker, Ilse van der Zwet

Roos Besseling	4692551
Josine van Marrewijk	4675878
Marloes Slokker	4708849
Ilse van der Zwet	4698940

Delft University of Technology
Faculty of Civil Engineering and Geosciences
January 2023

VEi
Dutch Water Operators

TU Delft

Preface

This report is written as part of a multidisciplinary project for the master program of Civil Engineering at Delft University of Technology. The aim of the project was to learn about working together with different stakeholders in a multidisciplinary team. During the past eight weeks, we have been working on one of the most complex and interesting challenges we have come across in our study program. It was a completely new experience to work on a research regarding the drinking water supply in Uganda. During the meetings with people from the National Water & Sewerage Corporation (NWSC) and the Ministry of Water and Environment (MWE) we have learned about the sometimes conflicting interests and the challenge of obtaining data.

During the second week of our stay in Uganda, we have assisted with a training on the basics of hydraulics for engineers from NWSC and MWE. The training was given by one of our colleagues from Vitens Evides International (VEI), Leo Meijer. We would like to thank him for giving us this opportunity. More information about this interesting week can be found in Appendix A.

There are many people we would like to thank for their useful insights and the information they have provided. First of all, Martin Nijsse from VEI and Jan Dirk Smidt from Witteveen+Bos, who have invited us to come to Uganda and provided us the topic of our project. Martin Nijsse has made us feel very welcome and made sure that our stay in Kampala was perfect. He also introduced us to a lot of interesting people that have helped us with the project. Jan Dirk Smidt has supervised us throughout the project and was always very helpful finding our way in Uganda and providing us a lot of feedback.

Next to that, we would like to thank Ron Sloots for sharing his geological expertise in the field of groundwater in Uganda. Then, we would also like to thank François van Ekkendonk for his insights in the risk analysis and the setup of the multi-criteria analysis tool. We are also very thankful for Dammie Hillary Atuhairwe, who joined the fieldwork trips and has taught us a lot about groundwater and boreholes in Uganda.

Besides, we are very grateful for the hospitality and transparency of the area managers and engineers of Hoima and Bugiri (Tom Mbaziira, Denis Otto, Mable Abaho and Abias Twinamatsiko) and for making sure our stay during the fieldwork trips was perfect.

We want to thank Marcas Ahimbisibwe who provided us a place to work in his office at the Ministry of Water and Environment and giving us a lot of insights in the drinking water supply system in Uganda. Zainab Mpakiraba gave us useful feedback on our multi-criteria analysis tool from her point of view, so we would like to thank her as well. We would like to thank Damian Mugisha for his time to provide us with a lot of information on the financial analysis.

We would like to give a special thanks to Mark Williams Lumala for driving us around in Kampala as well as taking us to every borehole in Hoima and Bugiri. Also for teaching us a lot about this country and its culture, checking in on us all the time and making us feel very safe.

Of course, we would also like to thank our supervisors of the TU Delft: Edo Abraham, Henk Jonkers and Juan Aguilar Lopez, who have been sincerely involved and provided us with useful feedback and advise.

We are very grateful for the opportunity to perform this research in Uganda. It was interesting to meet so many new interesting people and learn about this beautiful country. We are proud of the result and we hope that it will be useful for the decision makers at the Ministry of Water and Environment and the National Water & Sewerage Corporation.

Roos Besseling, Josine van Marrewijk, Marloes Slokker, Ilse van der Zwet
Kampala, Uganda, January 2023

Abstract

In many places in Uganda, people do not have a connection to the drinking water supply system and there is a lack of treated water supply, meaning that people only have access to water a certain part of the day. As a result many people rely on springs, handpumps, rivers or lakes, of which the quality cannot be monitored or controlled.

National Water & Sewerage Corporation (NWSC) provides water mainly in the bigger cities and towns in the country and is extending the number of connections every year. The Ministry of Water and Environment (MWE) is managing the water in the more rural areas and hands over certain regions to NWSC and aims to have the whole urban population served with safe and affordable drinking water by 2030. To achieve this goal, the water supply system needs to be extended, which can be done by using surface water, groundwater or both.

It is required to extend the water supply system using the best alternative considering the specific location. In this research the different alternatives for the extension of the water supply system in two project areas, Hoima City and Bugiri District, are evaluated using a multi-criteria analysis (MCA). The criteria of the MCA are set up using visits to both areas as references. The MCA-tool consists of a financial analysis, a performance analysis and a risk analysis. By evaluating the different options using an MCA, the decision-making process can become less complicated.

The three main categories of the MCA can be divided into multiple criteria that are important for the evaluation of different alternatives. The financial aspects include the different costs of an alternative regarding both the investment and the operation. The performance aspects describe how well the alternative performs during the construction as well as its lifespan while looking at the sustainability, durability, society and feasibility of the design. Lastly, the risk analysis focuses on different kind of important risks during both the construction of the system and its lifespan. The categories that are considered are economics, politics, society, organization, technology and environment. The performance criteria as well as the risks, can be weighted according to the objective and stakeholders to distinguish the contribution of all criteria. It is important that the defined criteria should be unambiguous and independent and that the final multi-criteria analysis should be comprehensive and carefully weighted.

For Hoima City, the different long-term alternatives are extending the groundwater supply system or using surface water. For surface water there were 3 alternatives according to the baseline study: Kafu River, Masindi Port and Lake Albert. The best long-term alternatives according to the multi-criteria analysis are using Lake Albert as a source and using groundwater with 80% coverage as a source. Lake Albert can provide 100% coverage, the performance of this alternative scores relatively high and it is also classified with a low risk. If the financial aspects are very important, the groundwater alternative with 80% coverage is a good option, because it covers most of the gap, has a relatively high performance score and is much cheaper than the Lake Albert alternative. However, it has a higher risks, which is something to keep in mind by choosing this alternative.

The fieldwork in Bugiri District showed that the boreholes give relatively low yield in this area, so groundwater cannot be a long-term solution in this area. For Bugiri District the four alternatives all use the water from Lake Victoria as a source. The first two options consider the extension of an existing treatment plant in Jinja (Masese) and Majanji. The other two alternatives, Bugadde and Wakawaka, consider the construction of a new treatment plant. The result of the comparison using the MCA is that Bugadde and Wakawaka are the most favorable when considering the long-term, because the coverage and the performance are high. The drawback of these options is that the costs are very high in comparison to the other two alternatives.

For both project areas, it is recommended to improve the operational performance of the already existing groundwater supply system for the short term. This can be done by for example improving the maintenance and monitoring of the pumps and boreholes, improving the power supply and drilling extra boreholes in areas with a high groundwater potential.

The result of the research has its uncertainties and limitations, which means there are many recommendations for further research. The most important ones concerning the MCA-tool are given, it should be kept in mind that the MCA-tool is created for an early stage of designing an extension of the Ugandan drinking water supply system. For the financial analysis, the pump prices are not extensively researched and the unpaid water is not included in the analysis, which can unfavorably influence the profit ratio. For a later stage in the design process it is recommended to include different treatment costs depending on the state of pollution of the water. For the risk analysis, a limitation is that the legal risks are not yet included due to a lack of time to study the legal aspects of the drinking water supply system. Besides legal risks, there could be other risks that might be important for the evaluation of a water supply extension. It is therefore recommended to perform further studies regarding potential legal issues and besides, to conduct multiple baseline studies to other areas in Uganda. It is also recommended to study which mitigation measures can be taken to eventually reduce the risk of certain alternatives. A very important aspect when evaluating alternatives with the MCA, is to keep in mind who filled out the MCA and that this is done by the same person for all alternatives, to be able to compare the results. This is the most objective way to use an MCA-tool.

List of Figures

List of Tables

Table of Contents

List of Abbreviations

Abbreviation	Definition
AfDB	African Development Bank
CBO	Community Based Organisation
CEO	Chief Executive Officer
CFU	Colony-forming unit
DIP	Ductile Iron Pipe
DN	Diametre nominal
DWD	Directorate of Water Development
DWTP	Drinking Water Treatment Plant
EC	Electrical Conductivity
FID	Financial Investment Decision
GDP	Gross Domestic Product
GIS	Geographic Information System
HDEP	High-density polyethylene
JPF	Joint Partnership Fund
KWA	Kampala Water Area
MCA	Multi-criteria analysis
MoES	Ministry of Education and Sports
MoH	Ministry of Health
MoLG	Ministry of Local Government
MoLHUD	Ministry of Lands, Housing and Urban Development
MWE	Ministry of Water and Environment
NGO	Non-Governmental Organisation
NPA	National Planning Authority
NRW	Non-revenue water
NWSC	National Water & Sewerage Corporation
OCHA	Office for the Coordination of Humanitarian Affairs
OD	Outer diameter
OP	Operational Policies
RMC	Regional Member Country
TCU	True Color Unit
TSS	Total suspended solids
UBOS	Uganda Bureau of Statistics
UGX	Ugandan Shilling
UNRA	Uganda National Roads Authority
uPVC	un-plasticised Poly Vinyl Chloride
UWSSS	Urban Water Supply and Sanitation Sector
VEI	Vitens Evides International
WB	World Bank
WOP	Water Operators’ partnership
WSDF	Water and Sanitation Development Facility
WWX	WaterWorX program

1 Introduction

In this introduction, the motivation for this multidisciplinary project is explained, followed by the problem statement. In the objective, the goal of this project is given and the research questions are formulated. In the approach, the methodology for answering the research questions is described. After that, some background information on Uganda is given. Lastly, in the report outline, the layout of the report is summarized.

1.1. Motivation

There are several challenges that threaten the water availability of many people in the world. In Uganda the lack of water infrastructure and treatment facilities are causing the scarcity of good quality drinking water. Uganda is a fast growing country, which means that the water demand increases. Also, due to the population growth and intensification of the agricultural and industrial production, the ground and surface water becomes more and more polluted.

This multidisciplinary project is executed in collaboration with Vitens Evides International (VEI) and it contributes to the goals of the WaterWorX program that VEI carries out in Uganda. The WaterWorX project aims to strengthen the National Water & Sewerage Corporation (NWSC) in the sustainable delivery of cost-effective water services to a rapid growing urban population. The project objectives are implemented both in Kampala and small to large towns in the rest of Uganda.

1.2. Problem statement

The drinking water supply network of Uganda is not widely expanded. According to a spatial map developed by the Uganda Bureau of Statistics (UBOS), 11 million people live without access to clean water. The number of people connected to a sewerage network is even way less. Most people use a protected or unprotected spring as a water source Marks et al., 2020. According to Marks et al., 2020, about 20 percent of the households has access to water at home, which means at a distance of maximum one minute walking distance. Unfortunately, the lack of adequate filtration systems and loss of vegetation, acting as a natural filtration system, leads to various health problems in Uganda. Because this unsafe water is one of the largest barriers to eradicating extreme poverty, the Ministry of Water and Environment aims to have clean water for everyone by 2030.

It is important to research how the current drinking water supply network of Uganda can be extended, taking into account environmental, societal, technical and financial factors. For each extension, different alternatives can be considered. Nowadays, the decision process between different stakeholders is not very transparent and sometimes there are conflicting interests. It is important to compare all alternatives on different criteria to make a well-thought decision. The decision making process can be more insightful and quicker if a multi-criteria analysis (MCA) is used, which is based on making decisions for the extension of drinking water supply system in Uganda. The different alternatives that are filled out for a specific region should be researched beforehand, i.e. the gap between water demand and treated water supply gap should be determined as well as other factors.

1.3. Objective

The overall goal of this multidisciplinary project is to set up an accessible tool to evaluate different alternatives for extending the drinking water supply system of an area in Uganda. A multi-criteria analysis improves the decision making process, since it gives insights in the main criteria that need to be considered when choosing for an alternative. To use the MCA-tool, different design alternatives within a Ugandan area should be evaluated and compared. Therefore, the research question of the project is:

How can a multi-criteria analysis be set up to become an accessible tool for the evaluation of different alternatives for an extension of the drinking water supply system in a Ugandan area?

Multiple sub-questions are composed, in order to support the main research question:

- Which area specific water sources can be used in order to become feasible alternatives to extend the current water supply system?
- What research should be done on the alternatives in order to determine its minimizing effect on the future water demand-supply gap?
- What criteria should be considered to evaluate different design alternatives?
- How can the criteria be weighted and scored to ensure a valuable result for the decision making?

To test this tool, two water-critical areas within Uganda will be researched and evaluated, which are Hoima City and Bugiri District.

1.4. Approach

The composed main research question and the sub-questions serve as a guideline to reach the stated objective of this project. To answer the first sub-question, a study should be performed within the specific water-critical area. This study could consist of an extensive fieldwork research in case there is not much information available about the different water sources of the area. It can also be possible that the water-critical area has already been researched extensively recently, which means a literature study on feasibility reports is recommended. On top of that, it is useful to interview local experts and talk with many stakeholders to get insights in the system and the available sources.

In order to answer the second sub-question, the current and future water demand for the safe drinking water limited area should be defined. Another requirement is to determine the current treated water supply. Based on the future water demand and the current treated water supply, the future gap between the demand and treated water supply ('demand-supply gap') can be calculated. Based on this 'demand-supply gap', the daily amount of water needed in the future for the safe drinking water limited area can be defined. As a next step, for each of the alternatives it should be determined if a complete new water supply system should be built or that it can become an extension of an existing system, so existing future plans should be considered as well. Therefore, it should be evaluated whether extraction from the water source is limited and likewise, whether the 'demand-supply gap' can be covered with this source. Other aspects to investigate are non-revenue water, water quality, the distance and height difference between the water source and the transmission and distribution network.

The third sub-question can be answered by evaluating all aspects of the safe drinking water limited area in Uganda. Aspects such as costs, risks, society, sustainability, durability, feasibility etc. could be considered. This evaluation should result into a summation of criteria. It is important to create distinct criteria, to make the evaluation unambiguous.

For the fourth and last sub-question, it depends on the location and area which criteria are considered most important and which criteria are weighted as less important. It should be taken into account that not all criteria can be scored on the same scale. Therefore, multiple analyses could be performed, with distinct weighting scales.

1.5. Report outline

This section highlights the outline of the report. The next chapter, chapter 2, focuses on the stakeholder analysis of the Ugandan water system. Also the contact persons are listed. After this, the report is divided into 4 different parts: the case study in Hoima City, the case study in Bugiri district, the multi-criteria analysis tool - including the results for the different case studies - and the final part containing the conclusion, discussion and recommendations.

Part I and part II are case studies and both follow the same report structure. Part I focuses on the case study in Hoima City, whereas part II is about the case study in Bugiri District. The first chapter (chapters 3 and 7 respectively) of both parts contains the background information on the area. The second chapter (chapters 4 and 8 respectively) consists of the baseline study, which explains the gap between the current and future demand and treated water supply, as well as the resulting 'demand-supply gaps'. After the baseline study, a water source analysis is performed in the third chapter (chapters 5 and 9 respectively) with different alternatives for extension for the long term and short term. Next to that, the water sources are analysed looking at the water quality. The next chapter of this part I and part II (chapters 6 and 10 respectively) contains the water supply system designs for the transmission and distribution network for both the short term and long term.

Part III consists of the multi-criteria analysis. The first chapter of this part (chapter 11) contains some general information about the MCA-tool. This chapter consists of three analyses: a financial analysis, a performance analysis and a risk analysis. In the last paragraph of this chapter the results of a fictitious case are presented to explain how the tool can be used for decision making. In the other two chapters of this part, the MCA-tool is applied to the cases of Hoima City and Bugiri District (chapters 12 and 13 respectively).

The final part, part IV, contains the conclusions and recommendations of the research and report. Chapter 14 contains the conclusions and the discussion and recommendations are given in chapter 15. The recommendations are split up in two main parts, one for the water supply system and one section focusing on the multi-criteria analysis tool.

2

Stakeholders

In this chapter an overview of all the stakeholders that are involved in the water supply system of Uganda are presented. Furthermore, it is explained who is funding the projects and how the process generally goes. An overview and explanation of all the contact persons is presented in Appendix B.

The institutional framework of the Ugandan water system comprises of the Government of Uganda and the funding agency. An overview of all organisations which are involved in the project scope are explained below.

2.1. Ministries

Ministries focus on policy formulation and providing guidance to lower level governments. The Ministry of Health (MoH) is assisting lower level governments through their National Health Policy and other aids to support service delivery. Their Environmental Health Department is responsible for the implementation of safe water, sanitation and hygiene initiatives of the Ministry. Another Ministry that is involved is the Ministry of Education and Sports (MoES). They encourage the provision of safe water and sanitation facilities in both government and privately owned schools, because it promotes the learning ability (Gauff Consultants, 2017).

2.1.1. Ministry of Water and Environment

The Ministry that is the most important to the project scope is the Ministry of Water and Environment (MWE). The MWE has prepared a National Water Policy and is still active as a provider of services. However, it prefers to work according to the devolution strategy. For e.g. Hoima District, this strategy implies that the Directorate of Water Development has constructed water supply and sanitation facilities in several areas and that these are now managed at local level (Gauff Consultants, 2017). The Directorate of Water Development (DWD) provides overall technical insight for the planning, implementation and supervision of the delivery of urban and rural water and sanitation services (Ministry of Water and Environment, 2018). Within the DWD is the Urban Water and Sewerage Department from the Urban Water Supply and Sanitation Sector (UWSSS), with the following policy objectives:

- Service Coverage: 100% clean water service coverage of the urban population by 2040.
- Sustainability: Sustainability of service delivery.
- Affordability: Subsidy and tariff framework that is beneficial to the poor, to ensure a basic adequate level of service which is financially affordable.

2.2. Other relevant high-level agencies

Other high-level agencies which are relevant during a drinking water project are the Ministry of Lands, Housing and Urban Development (MoLHUD), to survey and valuate the affected land and properties within the project. The Ministry of Local Government (MoLG) provides policy direction, compensation rates and guidance on the planning of the municipalities and towns hosting the project. To improve the synchronised development approaches and coordination with other agencies, The National Planning Authority (NPA) offers guidance when a drinking water project is implemented. The Uganda National Roads Authority (UNRA) has requirements regarding user permissions of the corridor to be shared between water distributors and the roads authority (World Bank, 2018). Road reserves could be used for other utilities, like water supply lines. Finally, Local Council 1 (LC1) provides information about affected populations, mobilization, sensitization and guidance of the project team on pertinent issues as well as witnessing the enumeration of property and resolving boundary conflicts (World Bank, 2018).

2.3. District Local Governments

Uganda has the thrust of the Local Government Act, which means that the main providers of government services are the District Local Governments and lower governments (Division Councils in cities and Sub-County Councils in Districts) (Gauff Consultants, 2017). The Directorate of Health and Environment carries out the functional requirements related to safe water and sanitation, while the monitoring and policy aspects are overseen by councillors of the Health and Environment Committee. The Health and Environment Services departments are responsible for the service delivery.

2.4. National Water and Sewerage Corporation

National Water and Sewerage Corporation (NWSC) predates the Local Governments Act and provides water supply and sewerage services in any area appointed by the Minister. The corporation was formed in 1972 to serve urban areas of Kampala, Entebbe and Jinja. The corporation was given more authority and autonomy and a mandate to operate and provide water and sewerage services on a sound commercial and viable basis, all under the NWSC Statute of 1995 (NWSC, 2021a). As of 2021, NWSC is operating 258 towns, serving 15 million people with 700,000 water connections. The drinking water supply network of Hoima City and part of Bugiri town are covered by NWSC. The investment is done by the Ministry of Water and Environment, but the operational costs are for NWSC which should be balanced by the revenues from the water connections according to The Ministry of Water and Environment.

2.5. WaterWorX project

The overall project objective of the WaterWorX project is to strengthen the National Water and Sewerage Corporation (NWSC) in the sustainable delivery of cost-effective water services to a rapid growing urban population. The project objectives are implemented both in Kampala and small to large towns in the rest of Uganda. Within the WaterWorX project, National Water and Sewerage Corporation (NWSC) and Vitens Evides International (VEI) have signed a Partnership Agreement intended to engage in a Water Operators' Partner-ship (WOP) between NWSC and VEI regarding the exchange of knowledge and operational experience in the field of drinking water supply and sanitation. The first phase of the project was completed in December 2021. The second phase of five years started in 2022.

2.5.1. Vitens Evides International

Vitens Evides International aims at sharing knowledge and skills to make the partner water operators stronger, financially sustainable and more (climate) resilient. VEI creates improved access to water and sanitation services in mostly low-income areas in Africa, Asia and Latin-America, for approximately 350,000 people every year.

Standing side by side as water operators, VEI strives to continuously increase the impact for people living in poverty, by systemically improving the maturity of working processes of the WOP partners, supported by peer-to-peer collaboration, training, technical assistance and smart investments (VEI Dutch Water Operator, 2022). VEI is a full subsidiary of Vitens N.V. and Evides N.V. and implements their international Corporate Social Responsibility policy on behalf of the following seven Dutch drinking water partners: Vitens N.V.; Evides Waterbedrijf N.V.; WML; Waterbedrijf Groningen; Brabant Water; WLN and PWN.

VEI has two mission objectives (VEI Dutch Water Operator, 2022):

- To contribute to Sustainable Development Goal number 6: achieving universal and sustainable access to water and sanitation by 2030. VEI wants to help 11.5 million people directly or indirectly to benefit from sustainable water services over the period 2015 - 2030.
- To strengthen the internal and external reputation of the partner water operators: leading in the drinking water sector, and an attractive employer for talented employees.

2.6. NGOs and CBOs

In Uganda around 180 Non-Governmental Organisations (NGOs) and Community Based Organisations (CBOs) are active which are involved in providing water. To improve the coordination and collaboration amongst stakeholders, the Uganda Water and Sanitation Network (UWASNET) was established in 2000 under the Ministry of Water and Environment. One of the NGOs is GOAL, GOAL has been very active in the Bugiri District.

2.6.1. GOAL

GOAL is, among other countries, located in Uganda with a water supply focus on community engagement (hygiene and sanitation) and infrastructure (handpumps, boreholes etc.). GOAL initiates a project (e.g. building a hand pump), then a private contractor (Gemma) makes sure it is built properly within 6 months, then GOAL monitors and maintains the project and later on it is handed over to the District Water Office or Umbrella organisation. This NGO has been working in Bugiri for 10 years and covered 80% of the whole district, which means the project is finished in Bugiri and that the same kind of project is continued in the surrounding districts according to GOAL NGO.

2.7. Funding

Since most large scale drinking water project investments are financed by funding, the banks who are providing this funding are important stakeholders as well. Their values and policies must be taken into account. The World Bank (WB) and African Development Bank (AfDB) are the most common funds for Ugandan drinking water projects. The Water and Sanitation Development Facility (WSDF) provides funding for rural areas, which is usually more complicated.

2.7.1. World Bank

The primary objective of the World Bank is to ensure that the Bank funded operations do not cause adverse social and environmental impacts and that they “do no harm”. This means that water projects funded by the World Bank must comply with these requirements. The World Bank’s environmental and social safeguard policies is to prevent and mitigate excessive harm to people and their environment during the development process (World Bank, 2018). The safeguard policies provide a platform for the participation of stakeholders in project design and consist of the following Operational Policies (OP):

- Environmental Assessment (OP 4.01)
- Natural Habitats (OP 4.04)
- Pest Management (OP 4.09)
- Indigenous People (OP 4.10)
- Physical Cultural Resources (OP 4.11)
- Involuntary Resettlement (OP 4.12)
- Forestry (OP 4.36)
- Safety of Dams (OP 4.37)
- Projects on International Waterways (OP 7.50)

The World Bank and Uganda are not necessarily on the same line, especially when it comes to resettlement. The World Bank prefers resettlement assistance and compensation for replacement: ”land for land”. However, according to Uganda’s law the project proponents are not legally bound to procure alternative land or assistance if they provided fair financial compensation based on a legally accepted valuation process. Furthermore, Uganda’s Land Act allows depreciated replacement cost in rural areas while the World bank does not recognise ’depreciated value’ for replacement assets (World Bank, 2018).

2.7.2. African Development Bank Group

The African Development Bank Group wants to support sustainable economic development and social progress and so reducing poverty. Uganda is a regional member country (RMC) of the AfDB, which means Uganda can receive resources for investment providing policy advice and technical assistance to support development efforts (African Development Bank Group, 2022). 17 Sustainable Development Goals are formed between all multilateral development institutions, the goals which are relevant for Ugandan drinking water projects can be found at www.afdb.org/en/about/mission-strategy.

2.7.3. Water and Sanitation Development Facility

The Water and Sanitation Development Facility (WSDF) provides funding for water and sanitation investments in Small Towns, Town Boards and Rural Growth Centres in Uganda. The WSDF carries out design and construction of water supply and sanitation facilities and is funded under the Joint Partnership Fund (JPF): a basket fund under the Joint Water and Environment Sector Support Program. This program receives funding from various sources and Development Partners, for the purpose of implementing Water & Sanitation interventions in the country (Ministry of Water and Environment, 2022).

2.8. WE Consult

WE Consult consists of several companies and provides advise and management for several projects in Eastern and Southern Africa on Water resources, environment and geographic information system (GIS). The company was founded by Ron Sloots in 1997 in Uganda and now WE Consult is part of the WE group and has several offices in Kampala (Uganda), Maputo (Mozambique), and Lusaka (Zambia). In 2000 WE Consult did a research in Hoima City and constructed 2 boreholes. Including boreholes which are not in use yet.

Part I

Case study: Hoima City

3

Background Hoima City

In this chapter, some information is provided on the project area, the current water supply system and why this area is chosen as a case study. For example the location of the case study is described and the districts' Mission and Vision. Then some information on the climate, vegetation, geology and topography is given.

3.1. Description of project area

The project area of this case study covers Hoima City. It is a city in one of the oldest districts of Uganda, Hoima, and after being a municipality from 2010, it is pronounced as a city since 2020 (Hoima District, 2022a). In Figure 3.1 Hoima District and the location of Hoima City are shown. The total area of the district is 5735.3 km^2 (Hoima District, 2022a) and the area of the city is equal to 227.3 km^2.

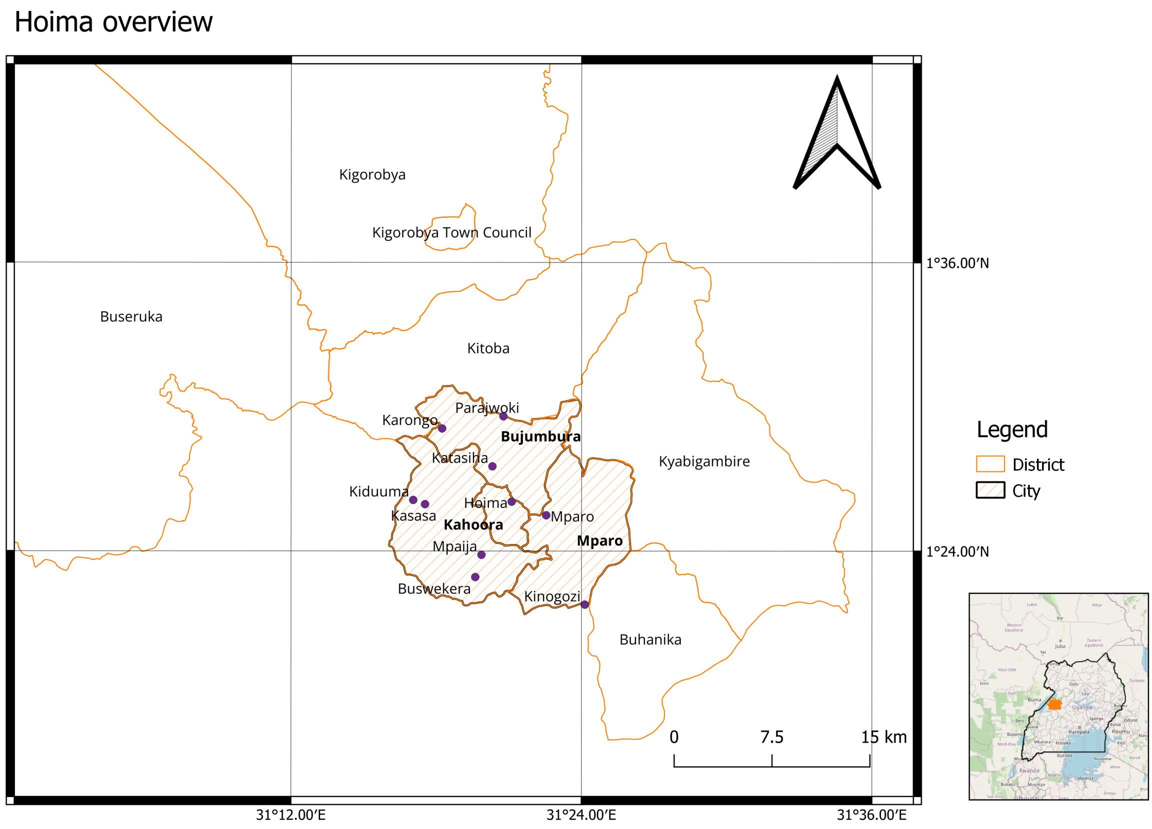


Figure 3.1: Hoima City project area

3.1.1. Vision and Mission

The Vision and Mission of Hoima district is described on the website as follows:

Vision:
A healthy, well educated productive society with a high quality of life by 2040.
Mission:
To serve the community through the coordinated delivery of services formed on national priorities and significant local needs in order to promote sustainable development of the district.
Goal:
Increased household incomes and improved Quality of life of Ugandans.

(Hoima District, 2022b)

3.2. Climate and vegetation

Hoima is a district with significant rainfall and a tropical climate. The precipitation is around 2,685 mm per year, of which the most precipitation falls in October (381mm) and the driest month is February (67 mm of precipitation) (Climate Data, 2022). Furthermore, the warmest month of the year is February, with an average temperature of 24.8 °C and the coldest month is August, with temperatures averaging 21.8 °C (Climate Data, 2022).

The vegetation of the area mostly consists of trees, crops and scrub as can be seen in Figure 3.2. The swamp vegetation as well as the quality of the rivers/streams are threatened by car washing, brick making, untreated sewerage deposits and cultivation (Gauff Consultants, 2017, pp. 1.6–1.8).

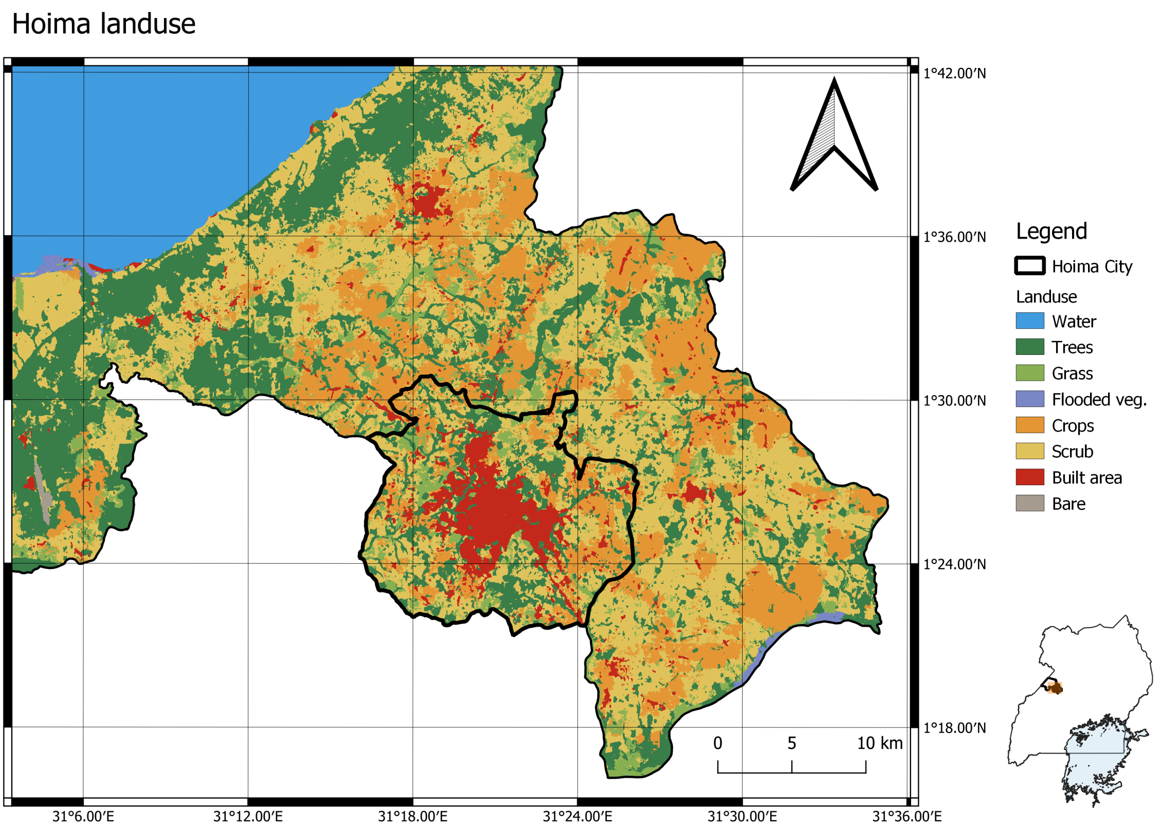


Figure 3.2: Land use Hoima City (QGis, 2022)

3.3. Geological environment, vegetation and the oil discovery

The geology of Uganda is quite complex. The land is mainly underlain by pre-Cambian rocks like granites, gneisses, migatities, meta-sediments, mudstones and argillites. In Hoima City the sediments are predominantely clay stones, shales and high permeable and porous sandstones and siltstones (Hoima District, 2022a). The hilltops are covered with reddish clay (lateritic soils), while parts of the City consist of harder material like granitite, quartzite schists and phyllites (gneisses) (Gauff Consultants, 2017).

Hoima is one of the six sedimentary basins within Uganda and is opened up for petroleum exploration (Directorate of Petroleum - Uganda, 2022). All discoveries around Albertine Graben are shown in Figure 3.3. Pouyanné, chairman and Chief Executive Officer (CEO) of TotalEnergies, calls the development of Lake Albert resources a major project for Uganda and Tanzania and Ruth Nankabirwa, the Minister for Energy and Mineral Development, says: "The planned 15-20 billion-dollar (52-70 trillion Uganda shillings) investment after the Financial Investment Decision (FID) will facilitate Uganda's Gross Domestic Product (GDP) growth by 22 per cent and also unlock over 60,000 jobs where over 57 per cent will be given to Ugandans, attracting 4.8 billion dollars (About 16.8 trillion Uganda shillings)" (The Independent, 2022). The petroleum exploration is an interesting aspect of Hoima City regarding population growth and therefore also the increasing water demand.

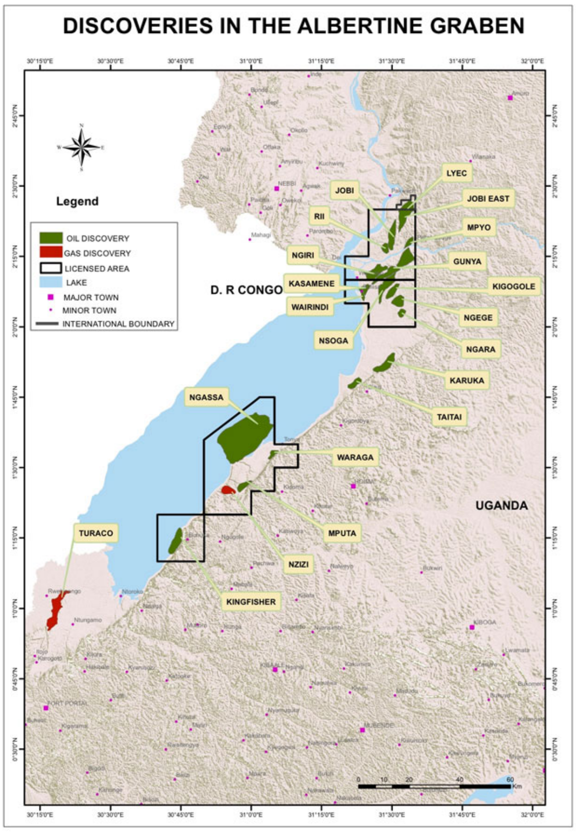


Figure 3.3: Map Western part of Uganda and oil discoveries in Hoima (The Independent, 2022)

3.4. Topography

Hoima consists of 2 main hills (Ibamba and Kyahaiguru) which are used for tree cultivation (Gauff Consultants, 2017). The hills are steep and flat-topped and are around 1400 m above sea level, as can be seen in Figure 3.4 and 3.5. Hoima City consists of a number of wetlands and streams and the valleys comprise regimes regimes of natural drainage channels that drain into the the natural streams: Wambabya, Rwenkondwa and Bigaajuka (Gauff Consultants, 2017). The wetlands cover 11.33 % of total area of Hoima City (Gauff Consultants, 2017, pp. 1.6–1.8).

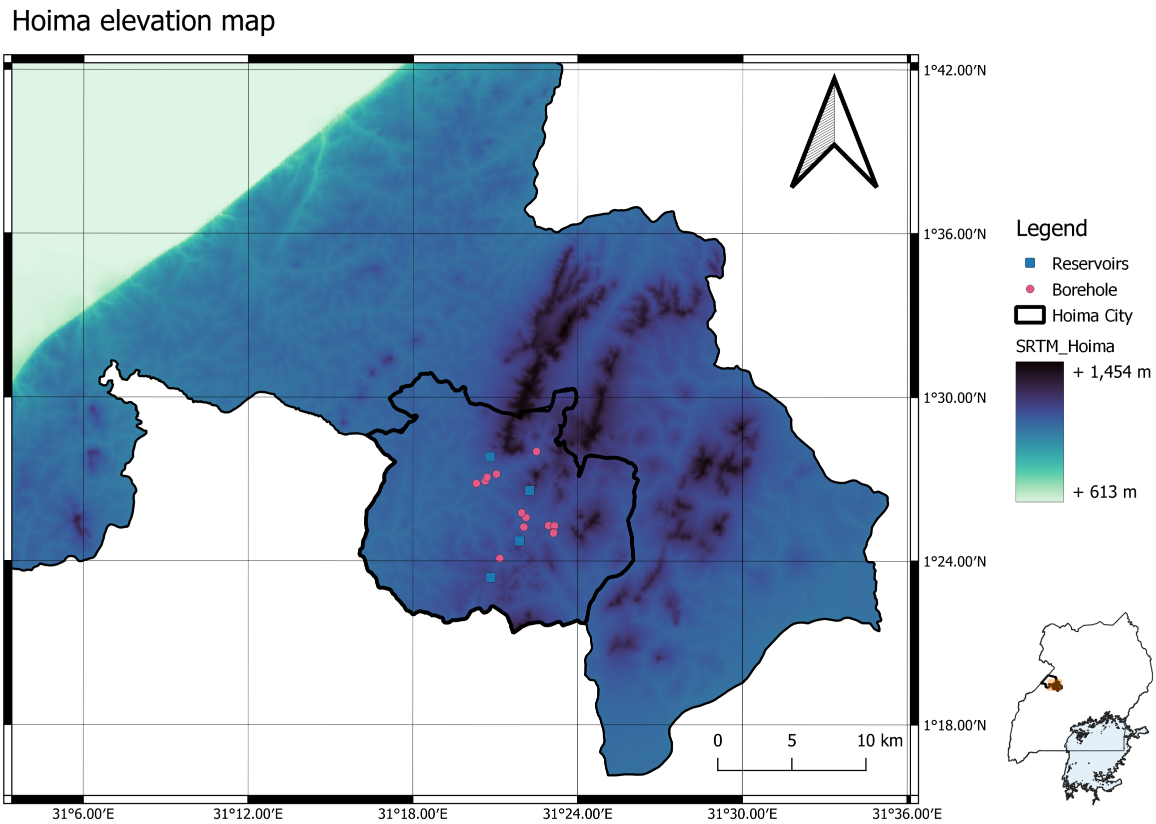


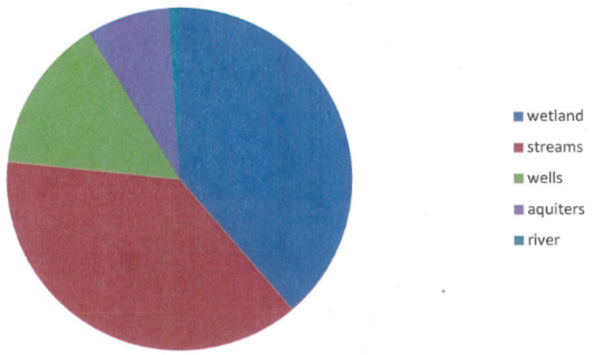
Figure 3.4: Elevation Hoima City (QGis, 2022)

Figure 3.5: Landscape Hoima City

3.5. Motivation for interests of location

Irumba Hillary (2018) investigated the impact of urbanisation on water resources for Hoima City by interviewing a variety of inhabitants. Figure 3.6 shows the division of water resources for Hoima City and the respondents revealed that the lowland areas are greatly occupied by wetland swamps which are the main water resource. However, respondents revealed that wetlands in Bujumbura and Kahoora division (see Figure 3.6) have dried off, because they have been replaced by settlements and crop farms (Hillary, 2018). Because of deforestation, agriculture and tourism, the pressure on water catchment areas increased and this means that 40% of the urban population suffered from water shortage (Hillary, 2018). Another effect of urbanisation is that surface water is subjected to significant water pollution due to discharge of domestic sewage, construction materials, agricultural waste and run off from commercial areas.

Irumba Hillary (2018) points out that the government of Uganda should inform the public about the impacts of urbanisation on water sources and the risks it exposes to humans. Also, facilitating waste storages and transport systems will reduce the level of domestic wastes into water catchment areas and will help poor individuals. It is important to improve the public health services and environmental conservation of Hoima City.



(a) Graph division of water resources in Hoima City (Hillary, 2018).

(b) Map villages in Hoima City (Barony of Burford, 2016).

Figure 3.6: Division of water resources and villages in Hoima City

4

Baseline study Hoima City

This baseline study focusses on Hoima City, and consists of four sub counties: Bujumbura division, Busiisi division, Kahoora division and Mparo division. The whole district is shown on a map in Appendix D in Figure D.1.

For this study the area has been visited (22nd of November, 2022 till the 25th of November, 2022). This was done together with the Senior Engineer, Groundwater & Boreholes Development - National Water & Sewerage Corporation (NWSC) and Eng. Dammie Hillary Atuhairwe. During the baseline visit, the NWSC Area Manager of Hoima as well as the District Officer of Hoima were consulted to gather information on the current water supply and information needed to determine the current and future water demand of the district.

4.1. Current situation

The baseline study of the current situation covers the current water demand and the current water supply system, including data on available siting, drilling and test pumping reports. An estimation of the water demand is based on the population, commercial entities, institutions and industries in the area. The water supply system takes into account (amongst others) the number of connections, a block map, the water sources and the transmission- and distribution networks.

4.1.1. Current demand

The first action in the design process is estimating a community's water demand. It begins with the definition of prospective supply regions and then moves on to a socioeconomic baseline study. The purpose of this study is to count the number of potential users. Counting all prospective customers is generally impossible; however, statistical approaches and sampling, as well as information acquired from the Uganda Bureau of Statistics (UBOS), district, and municipal governments, may be utilized to enhance estimates (Ministry of Water and Environment, 2014).

Current population

The basic data for the domestic population are based on the population projections by sub county and sex of (Uganda Bureau of Statistics, 2019). The 2022 population data for the current Hoima City water supply system is shown in Table 4.1.

Table 4.1: Population projection Hoima City 2022 (Uganda Bureau of Statistics, 2019)

		Male	Female	Total
Hoima City		63,100	67,900	**131,000**
	Bujumbura Division	14,100	15,000	**29,100**
	Busiisi Division	12,600	12,600	**25,200**
	Kahoora Divison	21,400	25,000	**46,400**
	Mparo Divison	15,000	15,300	**30,300**

Connections

The number of connections for different classifications is obtained from the area manager of National Water and Sewerage Corporation of Hoima. The classifications are the following: commercial, domestic, institutional, local authority, ministry, parastatal and public stand post. An overview is given in Table 4.2. It indicates how many of the connections are in use and how many are not in use or are closed.

Table 4.2: Number of connections (customer count)

Classifications	Count	In Use	Not In Use	Closed
Commercial	1,409	1,033	370	6
Domestic	5,107	4,178	916	13
Institutional	172	145	27	0
Local Authority	2	1	1	0
Ministry	14	14	0	0
Parastatal	4	4	0	0
Public Stand Post	194	177	17	0
Total	**6,902**	**5,552**	**1,331**	**19**

Current water demand estimation

The total water demand of an area can be determined by making an estimation of the different consumers. The common categories of consumption are domestic (which can be categorised into high, medium and low income categories); commercial, institutional and industrial categories. The water consumption can be estimated for each category. The estimations for these different categories can be made using the water supply manual (Ministry of Water and Environment, 2014).

The demand per consumer category is presented in Table C.1 in Appendix C. For Hoima City, a domestic demand of 50 l/ca/d is taken into account for urban areas. For rural areas, this number is 20 l/ca/d. The commercial demand, institutional demand, micro industrial demand and macro industrial demand can be found using tables C.2, C.3, C.4 and C.5 respectively. The guidelines for determining the non revenue water (NRW) are also formulated in Appendix C.

Using the tables and guidelines of the water supply manual (Ministry of Water and Environment, 2014) and the available data on Hoima, an estimation of the water demand for Hoima City has been made. The summarized result is shown in Table 4.3. The details are presented in the Appendix D.2.

Table 4.3: Estimation monthly water demand Hoima City 2022

	Water demand [m^3/month]
Domestic demand	**175,802**
Commercial demand	**11,700**
Institutional demand	**64,147**
Industrial demand	**3,750**
Total Demand	**255,399**

For the determination of the domestic water demand, a division of the total population of Hoima City is made with an estimation of 20% living in rural areas and 80% living in urban areas. The commercial and industrial water demand includes supply to hotels, lodges, bars/restaurants, shops, markets, petrol stations, washing bays and public sanitation. Institutional water demand consists of demand for schools, hospitals, health centres, offices and other institutions such as churches and mosques.

From these monthly demands, the average daily demands are determined by dividing the values by 30.5 days. The average daily water demands for Hoima City are shown in Table 4.4. The total average daily water demand is equal to 8,374 m^3/d. The average daily total water demand values per category are presented in Table 4.4.

Table 4.4: Average daily water demand Hoima City 2022

	Water demand [m^3/d]
Domestic	5,764
Commercial	384
Institutional	2,103
Industrial	123
Total demand [m^3/d]	**8,374**

4.1.2. Current treated water supply

During the fieldwork trip to Hoima, an inventory of the current water supply has been performed. An overview of this inventory is shown in the map of Figure 4.1.

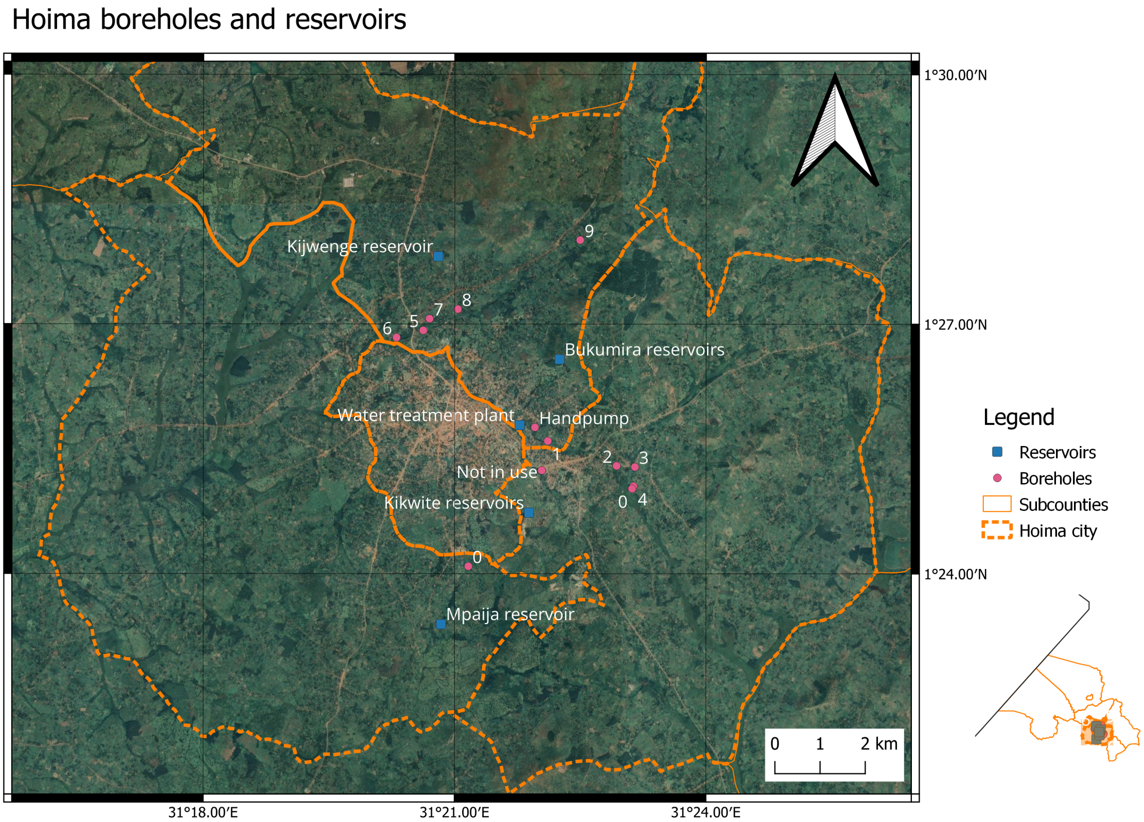


Figure 4.1: Boreholes, water treatment plant and reservoirs in Hoima District *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC; VEI and WE Consult*, made in QGis, 2022)

Water source supply

The current treated water supply in Hoima City consists of only groundwater sources. In Hoima City, 12 boreholes have been found in total, of which currently 6 are in use. An overview of the boreholes in Hoima City which are currently in use is shown Table 4.5. In Appendix D more information on the boreholes is given, including pictures of Borehole 5, 6 and 9 For the capacity, 18 hours of pumping per day is assumed to be most sustainable. In other words, the capacity in [m^3/d] is based on 18 hours of pumping. The total capacity of the 6 boreholes combined is 5,193 m^3/d.

Table 4.5: Current boreholes Hoima City (NWSC)

Borehole	**Coordinates**		**Capacity [m^3/h]**	**Capacity [m^3/d]**	**Actual production [m^3/d]**
	N°	**E°**			
Borehole 2	1.421589	31.38223	48	864	112
Borehole 3	1.421256	31.385833	37.5	675	550
Borehole 4	1.417484	31.385573	120	2,160	997
Borehole 5	1.448692	31.343793	40	720	901
Borehole 6	1.447325	31.338528	25	450	504
Borehole 8	1.452962	31.350544	18	324	232
Total				**5,193**	**3,301**

It is interesting to also look at the daily yield of each borehole, which is shown for the months August, September and October 2022 in Figure 4.2. This gives an indication of the continuity of each water source and the actual production. Based on the data of these three months, the total daily average actual production of the boreholes is calculated. This value is around 3,300 m^3/d, which is significantly less than the capacity of the boreholes. The difference between the actual production and the capacity can be due to power issues and the breakdown of pumps. Some boreholes are clogged and need to be regenerated to use them again. Other reasons can be that the data is not reliable, since the monitoring is done manually or maybe leakages and illegal usage.

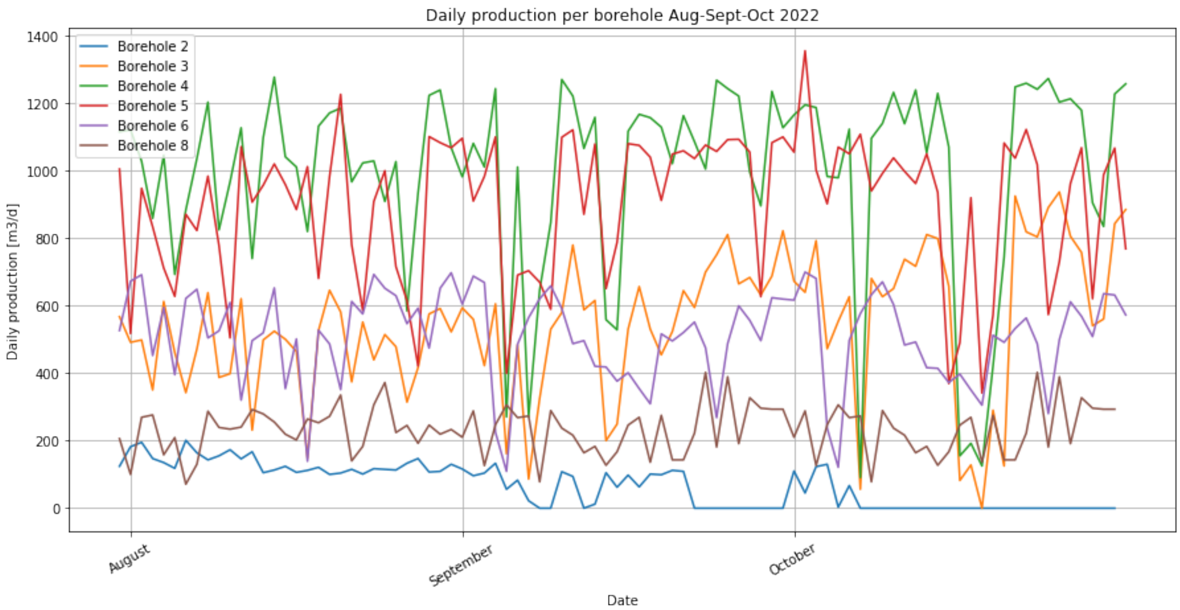


Figure 4.2: Daily yields boreholes Hoima City (production data retrieved from NWSC)

To summarize the borehole data, the following overview is provided.

- Total maximum current capacity: 5,193 [m^3/d]
- Total average current actual production: 3,301 [m^3/d]

The average current actual production that enters the water treatment plant in Hoima City is 3,300 m^3/d. At the water treatment plant, this extracted groundwater is treated and the iron bacteria are removed. When the water quality is satisfactory, the water is pumped to the reservoirs, at a rate between 1,600 and 2,800 m^3/d. There are multiple reservoirs, as can be seen in Table 4.6. The most important reservoirs are the two Kikwite reservoirs with each a capacity of 1,500 m^3. In Appendix D pictures of the reservoirs can be found.

Table 4.6: Reservoirs in Hoima City

Reservoir	Coordinates		No. of tanks	Total capacity [m^3]	In use?
	N°	E°			
Kikwite	1.412212	31.364808	2	3,000	Yes
Kijwenge	1.463518	31.346694	1	100	Yes
Bakumira	1.442918	31.370866	2	300	Yes
Mpaija	1.389842	31.347303	1	162	No
Booster station	1.401743	31.34814	-	-	Yes

From the reservoirs, the water is distributed to the current connections. The National Water & Sewerage Corporation (NWSC) area manager of Hoima (Tom Mbaziira) provided the block map of the city, which shows all the current connections.

Actual billed water supply
Another way to interpret the treated water supply, is to look at the amount of water that is actually supplied to the households. That is the amount of water that is billed, and the calculations are shown in Table 4.7. The billed water supply of 1,307 m^3/d can be seen as the actual distributed treated water supply. This is significantly less than the water that could be supplied from the boreholes to the water treatment plant and the amount of water that is pumped to the reservoirs from the water treatment plant. An explanation could be that the data is not correct, so it would be advised to research this further.

Table 4.7: Billed water supply Hoima City

	Billing [UGX/month]	Costs [UGX/m^3]	Supply [m^3/d]
Commercial	51,000,000	4,220	396
Domestic	80,000,000	3,516	746
Institutional	11,000,000	3,558	101
Local authorities/government	370,000	3,558	3
PSP	2,000,000	1,060	61
Total			**1,307**

A schematization of the current water supply system in Hoima City, including the water supply rates in the different stages of the system, is shown in the Appendix D.3.3, in Figure D.5.

4.1.3. Current gap between water demand and treated water supply

When all current water sources are used on full potential, there is still a gap between the current water demand and treated water supply ('demand-supply gap'). The current actual billed water supply in Hoima City is 1,307 m^3/d, whereas the current total water demand is 8,374 m^3/d. This results in a 'demand-supply gap' of 7,067 m^3/d. Since an increase of the population is expected for the upcoming years, the water supply system of Hoima City needs to be extended to meet the short-term and eventually the long-term water demand.

4.2. Project plan for future situation

The baseline study of the future situation covers the future water demand and the project plans for the future treated water supply system. An estimation of the future water demand is based on the current water demand and the expected population growth.

4.2.1. Future demand

Since water supplies are intended to last for numerous years, the future population must also be considered (Ministry of Water and Environment, 2014).

Future population projection
Based on the statistics found on the population in Hoima City (Uganda Bureau of Statistics, 2019) an average annual growth rate of 3.2% can be applied for the next 25 years. This situation is considered as the average scenario. However, because of the oil discovery, Hoima may become a very attractive city in the future since many new potential jobs will be created. Therefore, one could consider a high-demand scenario in which an annual growth rate of 5% is applied. The population in a certain year can be calculated according to Equation 4.1.

$$P_n = P(1 + r)^n \tag{4.1}$$

With:

- P_n = population after n years,
- P = present population and
- r = annual growth rate [%].

Using this method, an estimation of the population for the years 2023, 2028, 2033, 2038, 2043 and 2048 is made. The numbers for the average scenario are shown in Table 4.8, whereas the numbers for the high-demand scenario are shown in Table 4.9.

Table 4.8: Population projection Hoima City (average scenario)

	2023	2028	2033	2038	2043	2048
Bujumbura division	30,031	35,154	41,150	48,169	56,385	66,003
Busiisi division	26,006	30,442	35,635	41,713	48,829	57,157
Kahoora division	47,885	56,053	65,614	76,806	89,907	105,242
Mparo division	31,270	36,603	42,847	50,155	58,711	68,725
Total (Hoima City)	**135,192**	**158,252**	**185,246**	**216,844**	**253,831**	**297,128**

Table 4.9: Population projection Hoima City (high-demand scenario)

	2023	2028	2033	2038	2043	2048
Bujumbura division	30,555	38,997	49,771	63,522	81,072	103,470
Busiisi division	26,460	33,770	43,101	55,008	70,206	89,603
Kahoora division	48,720	62,180	79,360	101,285	129,269	164,983
Mparo division	31,815	40,605	51,823	66,141	84,415	107,737
Total (Hoima City)	**137,550**	**175,553**	**224,054**	**285,957**	**364,961**	**465,793**

Future water demand estimation
Based on the expected population growth, a rough estimation of the future water demand has been made. As said before, the expected annual population growth rate for the average scenario is 3.2%. The expectation is that the domestic water demand therefore increases with 3.2% annually. The commercial, institutional and industrial water demand are foreseen to increase by approximately the same rate. Growth rates of 3% are applied for these three categories. With these growth percentages, a future water demand estimation in Hoima City is made for the average scenario and shown in Table 4.10.

Table 4.10: Future water demand estimation Hoima City (average scenario)

	2023	2028	2033	2038	2043	2048
Domestic	5,948	6,963	8,151	9,541	11,169	13,074
Commercial	396	459	532	616	714	828
Institutional	2,166	2,511	2,911	3,375	3,912	4,535
Industrial	127	147	170	197	229	265
Total [m^3/d]	**8,637**	**10,080**	**11,764**	**13,729**	**16,024**	**18,702**

Likewise, the future water demands in Hoima city are determined for the high-demand scenario, with an annual population growth rate of 5%. Therefore, for this high-demand scenario, growth rates of 5% are applied for the domestic, commercial, institutional and industrial water demand. The results are shown in Table 4.11.

Table 4.11: Future water demand estimation Hoima City (high-demand scenario)

	2023	**2028**	**2033**	**2038**	**2043**	**2048**
Domestic	6,052	7,724	9,858	12,582	16,058	20,495
Commercial	403	515	657	838	1,070	1,365
Institutional	2,208	2,818	3,597	4,591	5,859	7,478
Industrial	129	165	210	268	343	437
Total [m^3/d]	**8,793**	**11,222**	**14,322**	**18,279**	**23,330**	**29,775**

4.2.2. Future treated water supply

Plans of the National Water & Sewerage Corporation for future supply

The National Water & Sewerage Corporation Area Manager of Hoima (Tom Mbaziira) has some future plans in mind for the water system of Hoima City. On the short term the pumps should be boosted or upgraded and boreholes should be added to the system, preferably borehole 9, with a yield of 60 m^3/h. Other recommendations for the short term are rainwater harvesting and discontinuing the disposal of iron from the water treatment plant into the swamp. The long-term future plans are tackling difficulties like unstable power supply, so a back-up generator should be used at each borehole, the iron problem should be fixed on the long term and a surface water source could be used potentially where smaller villages close by could benefit from as well. This means further research on the iron bacteria is recommended by the area manager as well as hiring a consultant for the feasibility. Another point of improvement for the supply system is reducing the leakage. The leakage in Hoima City is already reduced from 32 per cent to 22 per cent, but the goal is to get 17 per cent. The leakage is weekly checked and is caused by unequal connections.

Surface water supply options

There are different possibilities for Hoima City to increase the treated water supply. For surface water there are 3 plausible options:

- Kafu river: This is a stream at the boundary of the Hoima and Kyankwanzi district. Difficulties concerning this water source is drying up of the stream and that the water is for Kyankwanzi at first and only the remaining water can be used for Hoima, according to NWSC.
- Lake Albert: Lake Albert is located 100km from Hoima City, this is where the people from the area use the water from. The water can be treated at the port. Difficulties with this water source are the following: the water is salty, there are large height differences and floodings exist.
- Masindi Port: Masindi Port is located at the Victoria Nile at 85km from Hoima City. This is a long distance, but that also gives the opportunity to connect people in the rural area along the pipeline.

Groundwater water supply options

When it comes to ground water, multiple extension opportunities exist as well. There are already multiple boreholes available, and if necessary more boreholes could be drilled. This requires careful investigation of the geology to find more possible locations for aquifers.

For the long term it will be advised that the pumps will pump for 18 hours a day. Currently, some pumping stations operate less than 18 hours due to power supply problems. These power supply problems should be solved on the long term. It is also important that the pumps do not operate much more than the desired 18 hours, because this increases the chances to adversely affect the performance of the pump. Ground water options based on 18 hours of pumping per day are:

- Borehole 1: 504 [m^3/d]. This borehole is redrilled and the transmission network is already available, so this source could be used on the short term.

- Borehole 7: 540 [m^3/d]. This borehole is filled with rocks by people living close to the borehole, because of a sense of dissatisfaction. The borehole is not in use right now, because the mechanical breakdown, but this can be fixed on the short term.
- Borehole 9: 1,080 [m^3/d]. This borehole has already been drilled as well and the yield is promising for Hoima City. Only a new pump is needed.
- Borehole WE Consult 1: 630 [m^3/d]. This borehole has already been drilled in 2000 and seems to be in good state, but has never been connected to the transmission network. This good be a good source of ground water as well and building a pump station and pipe system to the water treatment plant could take only 2 years, which means it can be used as short-term supply.
- New borehole 2: There is already a new borehole drilled close to borehole 4. The future capacity is not known yet.
- Other boreholes. There is still potential for more ground water around Hoima City.

Combining the capacities of the remaining 6 boreholes, which are currently not in use, there is already an extra borehole potential available of around 2,970 [m^3/d]. To summarize the borehole data, the following overview is provided.

- Total current borehole capacity: 5,193 [m^3/d]
- Total extra borehole capacity that is already available: 2,970 [m^3/d]

Table 4.12: Future groundwater supply Hoima City

Borehole	**Coordinates**		**Capacity [m^3/h]**	**Future production [m^3/d]**
	N°	**E°**		
Borehole 1	1.42656	31.368616	28	504
Borehole 2	1.421589	31.38223	48	864
Borehole 3	1.421256	31.385833	37.5	675
Borehole 4	1.417484	31.385573	120	2,160
Borehole 5	1.448692	31.343793	40	720
Borehole 6	1.447325	31.338528	25	450
Borehole 7	1.450784	31.345072	30	540
Borehole 8	1.452962	31.350544	18	324
Borehole 9	1.466844	31.374953	60	1,080
New borehole 1	1.401442	31.352746	12	216
New borehole 2	1.417005	31.385281	-	-
Borehole WE Consult 1	1.420677	31.367323	35	630
Total				**8,163**

4.2.3. Future gap between demand and treated water supply

When all water sources are used on full potential, there is still a gap between the current water demand and treated water supply and the future water demand and treated water supply. To overcome the short-term (5 years) and long-term (25 years) gap between water demand and treated water supply, different alternatives of water resources should be invented and compared.

An estimate for the gap between demand and treated water supply ('demand-supply gap') for the average scenario is given below. For the long term, two situations are considered. One 'demand-supply gap' is based on no actual supply changes compared to the current situation. The other long-term 'demand-supply gap' is based on the actual treated water supply when all existing boreholes in Hoima City are taken into account. The same percentage of non-revenue water is taken into account:

- Non-revenue water:

$$NRW = 100\% - \frac{1,307}{3,301} \cdot 100\% = 60.4\% \tag{4.2}$$

Demand-supply gap for the average scenario's:

- The demand-supply gap between short-term average demand and current actual supply is:

$$G = D_{\text{short-term, average}} - S_{\text{current, actual}} = 10,080 - 1,307 = 8,773 \quad [m^3/d] \tag{4.3}$$

- The demand-supply gap between long-term average demand and current actual supply with the only the current boreholes is:

$$G = D_{\text{long-term, average}} - S_{\text{current, actual}} = 18,702 - 1,307 = 17,395 \quad [m^3/d] \tag{4.4}$$

- The demand-supply gap between long-term average demand and future actual supply is:

$$G = D_{\text{long-term, average}} - S_{\text{future, actual}} = 18,702 - 8,196 \cdot (100\% - 60.4\%) = 15,457 \quad [m^3/d] \tag{4.5}$$

- In case the non-revenue water percentage is lower, around 20%, the demand-supply gap between long-term average-demand and future actual supply is:

$$G = D_{\text{long-term, average}} - S_{\text{future, actual}} = 18,702 - 8,196 \cdot (100\% - 20\%) = 12,145 \quad [m^3/d] \tag{4.6}$$

With:

- D = Water demand [m^3/d]
- S = Water treated supply [m^3/d]
- G = Gap between water demand and water treated supply [m^3/d]

Likewise, for the high-demand scenario, the gap between water demand and treated water supply ('demand-supply gap') can be calculated. For the short term only the current actual supply is considered. For the long-term 'demand-supply gap' both the current actual supply and the future actual supply with all existing boreholes in Hoima City are taken into account. The non-revenue water percentage is 60.4 %. An estimate for the gap between the water demand and treated water supply for the high-demand scenario is the following:

- The demand-supply gap between short-term high-demand and current actual supply is 9,915 [m^3/d].
- The demand-supply gap between long-term high-demand and current actual supply is 28,468 [m^3/d].
- The demand-supply gap between long-term high-demand and future actual supply is 26,530 [m^3/d].
- In case the non-revenue water percentage is lower, around 20%, the demand-supply gap between long-term high-demand and future actual supply is 23,218 [m^3/d].

The amount of water that is used as the design value for the extension of the system is 17,400 m^3/d, which is the future gap between water demand and treated water supply. The NRW percentage for the design of the future supply system is further elaborated in Chapter 6 and 12.

5

Water source analysis Hoima City

5.1. Available water sources

To determine how the future water demand could be supplied, it is important to distinguish short-term and long-term solutions. On the short term, an extra treated water supply of around 8,773 [m^3/d] is required. On the long term there is a gap between the demand and treated water supply of around 17,395 [m^3/d].

5.1.1. Short term

Drilling extra boreholes, building a pump house and connecting the borehole to the water system with a pipeline to the water treatment plant, takes 1 to 2 years. Hoima has durable aquifers in general, and monitoring of the boreholes can make this alternative more reliable. This means that adding extra boreholes could be used as a short-term solution. Boreholes can be used as a long-term solution as well, but the continuity of a borehole cannot be completely guaranteed in case of water pockets.

Operational improvement

According to Chapter 4, there are large differences between the actual production and the amount of water that is actually supplied. This means that by operational improvement more water can be supplied in the near future. There is a capacity of groundwater of 5,193 [m^3/day] from the current boreholes of which 3,300 [m^3/day] is their actual production. The water treatment plant treats 1,600-2,800 [m^3/day] of this amount and 1,307 [m^3/day] is actually billed water from the connections. This would mean that in the most ideal case, almost half of the total short-term demand could already be supplied by the original boreholes when operational improvement has taken place. Some leakage is unavoidable, but the current water system can still be improved.

5.1.2. Long term

In Hoima there are four alternatives considered as options for the extension of the water supply network on the long term. The different alternatives will be evaluated later in a multi-criteria analysis. The options are:

- Lake Albert
- Masindi port (Lake Kyoga)
- Kafu river
- Groundwater

The different sources are presented in Figure 5.1.

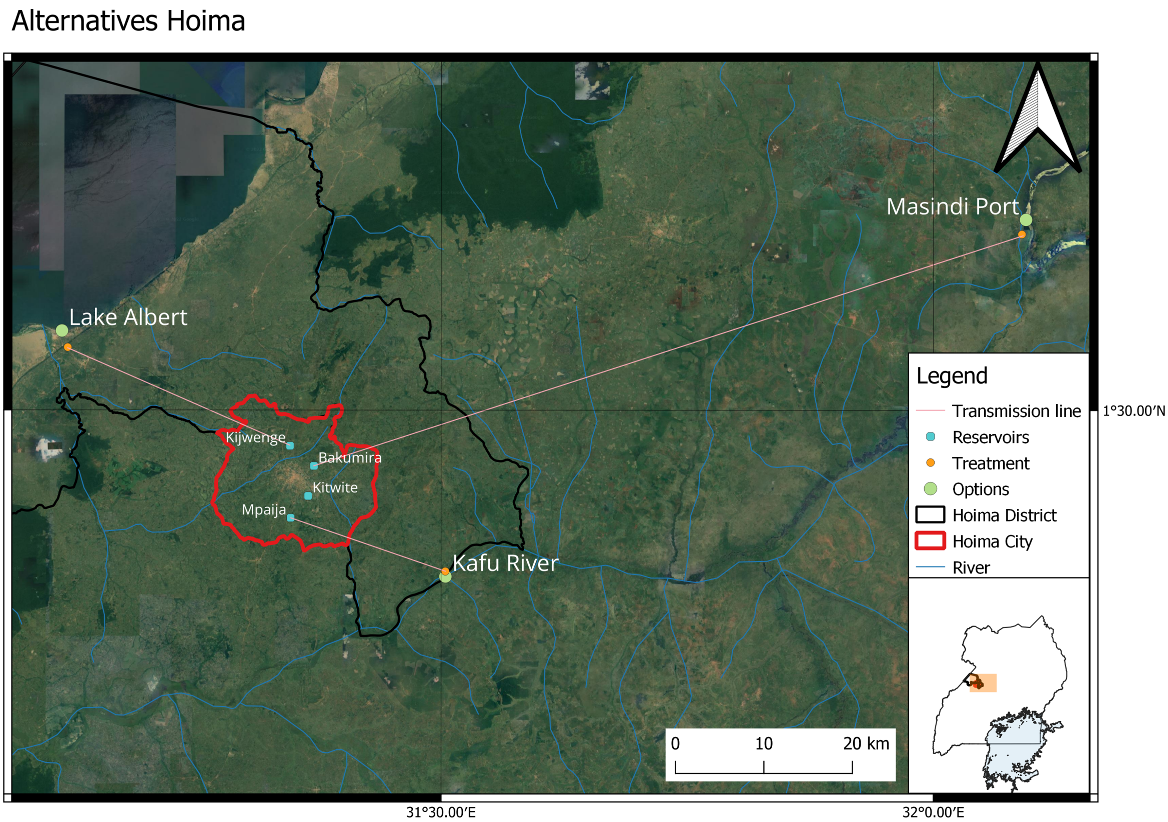


Figure 5.1: Alternatives Hoima *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI, made in QGis, 2022)*

Surface water
Generally, surface water is not directly suitable as drinking water, since the water contains high values of Electrical Conductivity and Turbidity. This means that the water needs to be treated extensively, which requires big investments. On top of that, surface water is not always located at the place where the demand is, implying long transmission lines. If a river is considered as a source, it is also required to consider the river regime in dry and wet season, because if the river is dry for part of the year this will cause difficulties for the supply. For the three alternatives a new treatment plant has to be constructed.

A possible water source for Hoima City is surface water. In the city of Hoima the amount of surface water is quite low, and on top of that, it is very polluted. The surface water is used for washing, sanitation and cleaning vehicles, which will negatively effect the water quality. Next to that, agricultural activities will increase the amount of nutrients in the water. The three potential surface water sources concern Lake Albert and an intake at Masindi Port and Kafu River, which will be discussed in the following paragraphs.

Intake from Lake Albert
Lake Albert is located between Uganda and the Democratic Republic of Congo. The lake is commonly used for commercial fishing and contributes for about 30% to the total fish production in Uganda (Wandera & Balirwa, 2010). This means this lake is of high importance for the people living here. The lake has a size of 5,300 km^2 and the distance from the lake to the nearest reservoir (Kijwenge) is about 17.5 kilometers.

Intake from Masindi Port
Masindi Port is located at Victoria Nile, the water comes from Lake Kyoga which is located between Lake Victoria and Lake Albert. A map of Lake Kyoga is shown in Figure D.6, see Appendix D. The port is located 85 km from the nearest reservoir in Hoima City (Bakumira). Lake Kyoga basin has a surface

of about 58,000 km^2 (JICA, 2011). The lake itself has a surface of approximately 1,720 km^2 and has a maximum depth of 6 meter and the water level varies 0.5-1.0 m from year to year between extreme events (JICA, 2011).

There is not much flow data available from Masindi port. According to Brown and Sutcliffe, 2011 there is reliable historic data available at Masindi port with a flow of around 1 km^3 per year. The flow rates are relatively fast at Masindi Port: 0.031 [m/s] according to R. Ongom and Lukubye, 2017, which causes a relatively low temperature of 25.12˚C. The flow at Masindi port is affected by the season.

The population and animals in the Kyoga basin is growing a lot and cause increased levels of pollution of the water. The pollution is caused by agriculture like livestock farming and crop growing. Many wetlands are lost between 1994 and 2008 due to the conversion to agriculture (R. Ongom & Lukubye, 2017). This agriculture has a high impact on the quality of the water, mainly because of the phosphorus and nitrogen enrichment. At Masindi port the phosphate concentration is 0.16 [mg/L] and the nitrite concentration is 0.28 [mg/L] (R. Ongom & Lukubye, 2017). The pH-value of the water at Masindi is relatively high, namely 7.15. It has a Dissolved Oxygen concentration of 12.06 [mg/L]. A graph of the water levels at Victoria Nile (and Kafu River) is shown in Figure D.7 in Appendix D. According to Ministery of Water and Environment, 2020 there are hypoxic conditions at Masindi port caused by floating vegetation, which can lead to death of fish.

Intake Kafu river
River Kafu could meet the demands of Hoima City based on the feasibility study done in 2017 (Gauff Consultants, 2017). The river is used by vast herds of livestock and provides water for households. The people use the water for fishing and agriculture. The river basin has a size of 15,983 km^2 (Amollo et al., 2020) and is shown in Figure D.8 in Appendix D. Since the catchment is heavily relying on rainfall, the catchment is very vulnerable to climate change (Wasswa, 2019).

According to the National Water & Sewerage Corporation the quality of the water is degrading due to aggressive migrants who burn charcoal and cultivate on unfavorable spots, which is affecting the water quality (Kazi Njema Reporter, 2021).

Groundwater
Hoima has a lot of potential for groundwater, as can be seen from the current yields, see Table 4.5. This potential comes from the boreholes which are already in use, the boreholes which are already drilled but not connected to the water system and eventually new boreholes which can be drilled. After a borehole is being drilled and constructed, a pump is being installed which will pump the water from the aquifer to the pipeline system.

To determine the best location(s) to bore new boreholes a groundwater assessment study has to be performed in the area around Hoima City. A map of the geology around Hoima City is shown in Figure D.9 in Appendix D. It is visible that The area around Hoima contains different types of geology. According to WE Consult geology with shales arkoses and quartzites mostly contains high yield aquifers. This geology occurs at the light orange striped area in the map, in which also Hoima City is located. The geology with undifferentiated gneisses (purple area in the map) contains a hard rift and granite, which makes it difficult to retrieve groundwater. Therefore it groundwater assessment studies should be performed in the light orange striped area, to determine the groundwater availability.

The advantages of using groundwater is that the distance to the source is generally smaller and the quality is generally better. Currently, the pumped groundwater is pumped to the treatment plant near Hoima City and is treated with three treatment steps: aeration, slow sand filter and a chlorination step, see Figure D.10.

The drawbacks of using groundwater is for example that the power supply is not constant, which means it is necessary to have a generator or another alternative to pump at the desired rate for about 18 hours a day.

5.2. Water quality

To compare the different water sources in terms of quality, the water properties pH (-), Electrical Conductivity ($\mu S/cm$), Color ($PtCol$), Turbidity (NTU), Total Suspended Solids (mg/l), Hardness (mg/l), Alkalinity (mg/l), Iron (mg/l) and Faecal Matter ($CFU/100mL$) are evaluated. The Hardness is measured in $CaCO_3$.

5.2.1. Data

Table 5.1 shows the quality of the samples taken at the boreholes and Lake Albert, which are tested in the Central Laboratory of the National Water & Sewerage Corporation (NWSC) in Bugoloobi (Kampala). The quality of the final treated water and the reservoirs is presented, which is based on the average water quality data of the water treatment plant of Hoima City. The Ugandan drinking water standards are based on UNBS, 2014 and are presented in Table 5.1 as well. The data that is found is compared with the National Standards for untreated potable water (by NWSC) and the drinking water standards. It gives an indication of the range for the parameters in order to evaluate the quality of the surface water or groundwater. The different sources that are considered for the extension of the water supply are evaluated looking at different properties.

Surface water

Lake Albert

In comparison to groundwater, the quality of Lake Albert is better. The water complies with the National Standards except for the value for color, which has a value of 9 True color unit (TCU), while the allowed value is 5 PtCo.

Masindi port

There is no water sample taken in Masindi port. In literature there are some studies about the water quality in lake Kyoga, which are used to estimate the water quality in Masindi Port. According to Ongom et al., 2017 the water quality in Lake Kyoga is highly influenced by anthropogenic activities and landing sites, causing high concentrations of nitrites and phosphates in Lake Kyoga. The quality data that is found in literature is incomplete, which makes it difficult to access how the quality is.

Kafu river

There is no water sample taken from the Kafu river, so values from literature are used to evaluate the quality of the water (Gauff Consultants, 2017). The quality of the water is very poor and has too high values for turbidity, colour, iron and E-coli as well.

Table 5.1: Water quality data Hoima
Water quality standards Uganda potable water and untreated potable water (UNBS, 2014), NWSC Hoima and fieldwork.

	pH [-]	EC [μS/cm]	Colour [PtCo]	Turb. [NTU]	TSS [mg/l]	Hdness [mg/l]	Alk [mg/l]	Iron [mg/l]	E. Coli [CFU/100ml]	F. Cl2 [mg/l]
Ugandan standards potable water	6.5-8.5	1500	15 TCU	5	0	300	20-200	0.3	0.0	1.0
Environmental standards	6.0-8.0		300	300	100					
Ugandan standards untreated potable water	5.5-9.5	2500	5 TCU	25	0	600	500	0.3	0	
Kikwite reservoir			9.6	2.6	0.6			0.17	0.0	0.56
Bakumira reservoir			8.4	2.1	0.1			0.11	0.0	0.56
Kijwenge reservoir			29.3	5.1	2.1			0.87	0.0	
Lake Albert	8.28	611	9 TCU	0.38	0	162.4	267.2	0.016		
Kafu average (16-6-2016 and 28-7-2016) (Gauff Consultants, 2017)	6.78	115	302	59.5	6	25.5	117.5	6.1	141,500	
Lake Kyoga (Kawongo) (Bwire et al., 2020)	7.27			136.03						
Lake Kyoga (Masindi Port) (Ongom et al., 2017)	7.15									
Kyoga Lakeside (2011) (JICA, 2011)	7.4	196		101		53		0.352		
Borehole 2	7.24	385	4 TCU	12.68	7	187.6	174	2.126		
Borehole 3	7.25	563	5 TCU	10.68	5	255.2	270.4	2.201		
Borehole 4	7.22	539	19 TCU	66.48	45	244.8	256.8	4.296		
Borehole 5	6.96	304	7 TCU	9.19	1	169.6	134.0	0.891		
Borehole 6	6.77	270	18 TCU	12.78	7	140	116.8	1.301		
Borehole 8	6.95	531	1 TCU	1.1	0	248.8	252.8	0.023		
Borehole 9	6.95	629	1 TCU	1.66	0	214.4	200.8	0.085		
Final Treated water	7.1-8.3	325.9	11.6	1.8	0.3	163	189.7	0.27	0.0	0.66

Groundwater
The quality of the borehole water is generally not complying with the National Standards. Especially for turbidity, color, TSS and iron, the values are most of the time above the accepted value. In Hoima a lot of boreholes have been affected by the iron bacteria. The water will be treated in the water treatment plant in Hoima City, but for groundwater the quality is quite poor.

In Table 5.2, the influent of the raw water to the WWTP (average of the months July, August, September and October) is compared to the results that have been found by the research conducted by the National Water & Sewerage Corporation laboratory. The average is taken of the concentrations found in the different boreholes . This value is compared to the influent of the water treatment plant. The values are in the same order of magnitude for most of the parameters. The color value differs a lot, the borehole color value is 7.86 TCU and the raw water is 83.3 PtCo. The iron concentration is 0.99 mg/l in the raw water, while the lab results of the samples is slightly higher, 1.56 mg/l.

Table 5.2: Water quality comparison Raw water Hoima City (Hoima City water quality measurements NWSC Hoima.)

	pH -	EC uS/cm	Col PtCo	Turb. NTU	TSS mg/l	Hdness mg/l	Alk mg/l	Iron mg/l	Feacal CFU/100mL	F. Cl2 mg/L
Raw water	7.0-8.3	318.9	83.3	10.5	7.9	193.7	198.0	0.99	0.71	
Average borehole quality (2, 3, 4, 5, 6, 8 & 9)	7.05	460.14	7.86	16.37	9.29	208.63	200.80	1.56		

5.2.2. Water treatment process
The treatment of the groundwater consists three steps, an aeration step, a rapid sand filtration and chlorination. The water treatment process of the water treatment plant in Hoima City is presented in Figure D.10 in Appendix D.

6

Water supply system design Hoima City

6.1. Short-term treated water supply options

On the short term, groundwater will be the only possible option. Higher treated water supply can be accomplished on the short term by improving the operational performance and when the currently drilled boreholes are added to the system. The Mpaija and Kikwite reservoirs can be added to the water system as well on the short term. The operational performance can be improved by cleaning the boreholes and measuring the ground water levels. The current transmission network is shown in green and the added parts to the transmission network on the short term are shown in blue, see Figure 6.1. The current distribution network could be expanded as well on the short term. In the best case, so if the operational performance can be improved to only 20% of non-revenue water and all drilled boreholes are added to the distribution network with 18 hours of pumping per day, around 6,000 extra connections could be created:

- Current number of connections in Hoima City (Table 4.2): 6,902.
- Production from all drilled boreholes with 18 hours of pumping per day (Table 4.12): 8,163 [m^3/d].
- Future amount of connections with future production with all 20% non-revenue water and 0.5 [m^3/d] per connection: $(8{,}163 \cdot 0.8) / 0.5 = 13{,}061$ connections.
- Potential short-term extension distribution network Hoima City : 13,061 - 6,902 = 6,159.

The possible extension of the current distribution network with 6,000 extra connections on the short term is shown in green in Figure 6.2.

6.2. Long-term treated water supply options

On the long term, so in 25 years, the future gap between the water demand and treated water supply should be overcome. This means both the transmission and distribution network should be expanded and extended greatly.

6.2.1. Transmission network

New water sources that can be added to the water system are surface water options or ground water options. For surface water Lake Albert, Masindi Port and Kafu river could be used. Their reservoirs can be built close to Kijwenge, Bakumira and Mpaija respectively, these are high-lying regions in Hoima City. These long-term surface water options are shown in orange in Figure 6.1. When it comes to groundwater, new boreholes can be drilled. According to Figure D.9 Hoima City is located on shales arkoses and quartzites which mostly contain high yield aquifers according to WE Consult. Borehole 4 and 9 have high yields, see Table 4.12, which could indicate good aquifers. The water quality in terms of iron concentration, color and turbidity is best at boreholes 8 and 9 (see Table 5.1. Based on this information, it is advised to search for boreholes in the orange-shaded areas of Figure 6.1.

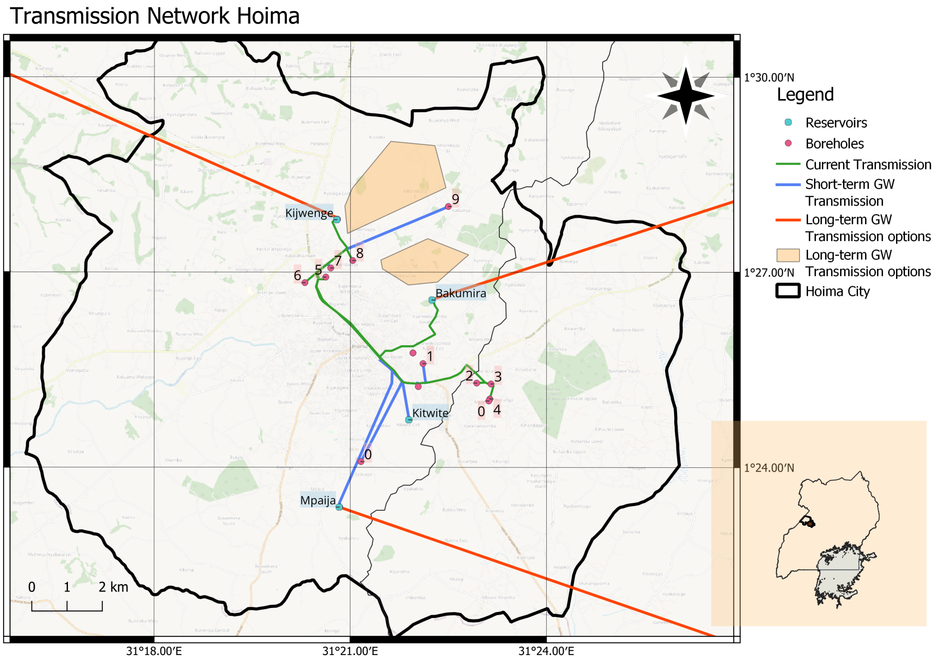


Figure 6.1: Current transmission network of Hoima City *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

6.2.2. Distribution network

The current distribution network of Hoima City is shown in red in Figure 6.2. The total length of the current distribution network is 450,580 [m], which corresponds to around 7,000 (6,902) connections. For the future demand (25 years), 35,000 (34,790) extra water connections are needed. This means the current distribution network should be extended by around five times the current network. A suggestion for this is given in blue in Figure 6.2. The total length of the distribution will also be extended by around 5 times the current length. This would give a total length of 2,700 km of distribution network in the future.

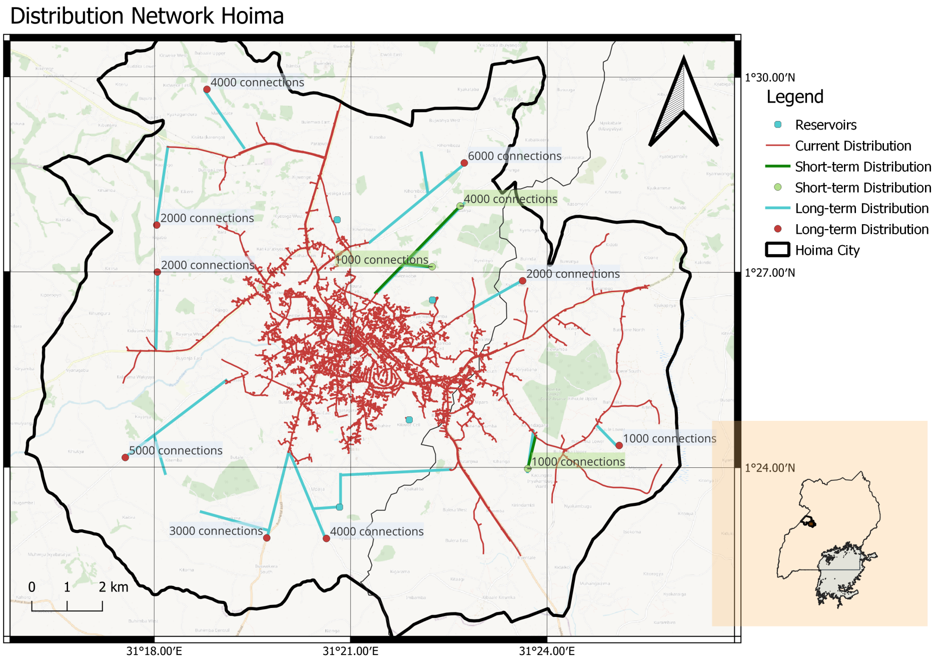


Figure 6.2: Current distribution network of Hoima City *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

Part II

Case study: Bugiri District

7

Background Bugiri District

In this chapter, some information is provided on the project area, the current water supply system and why this area is chosen as a case study. For example the location of the case study is described and the districts' Mission and Vision. Then some information on the climate, vegetation, geology and topography is given.

7.1. Description of project area

Bugiri is a district in the Eastern Region of Uganda and is located about 72 kilometers east of Jinja and 106 kilometers southwest of Mbale, which is the main city in the Eastern Region (Bugiri District, 2020). The project study area is the whole district of Bugiri, of which a map is shown in Figure 7.1.

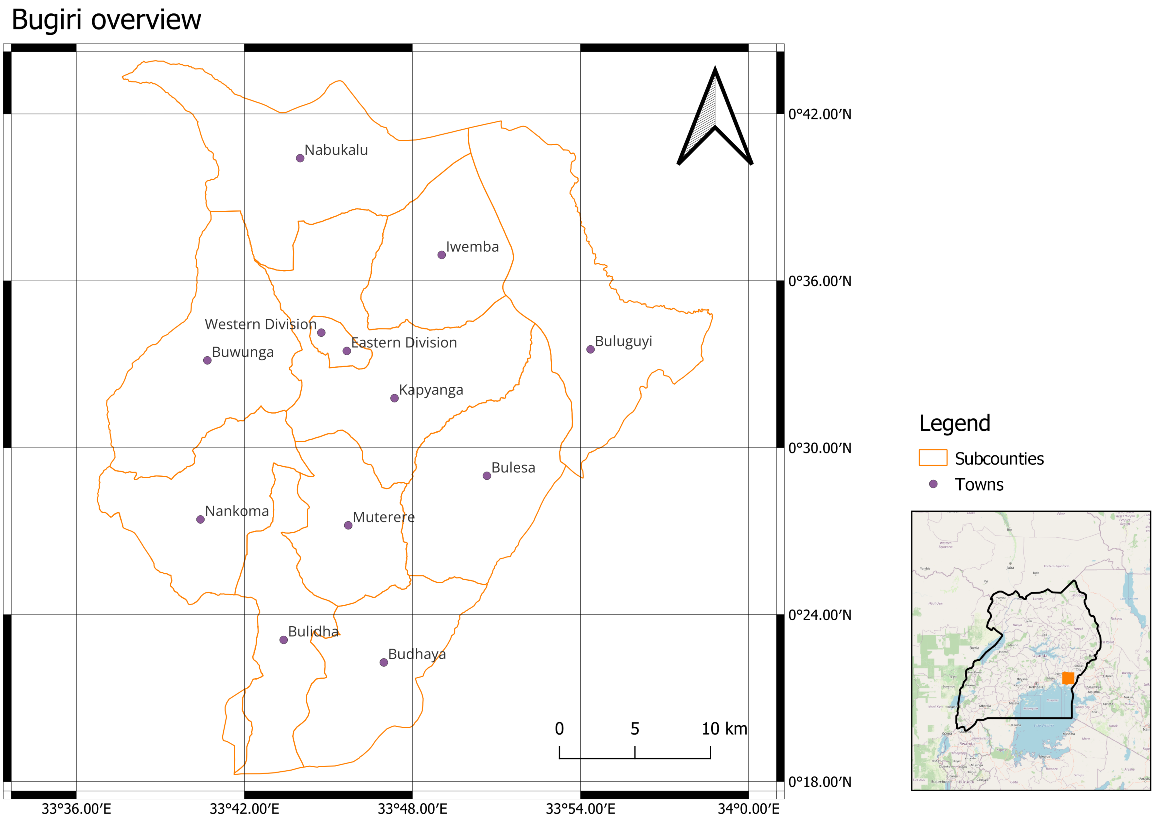


Figure 7.1: Bugiri District project area *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

7.2. Mission and vision

The Vision and Mission of Bugiri district is described in the District profile as follows:

DISTRICT VISION:
"A developed and harmonious population/community that has
all the essential amenities of life by 2040."
DISTRICT MISSION:
"To optimally utilize the available resources for quality service delivery
to improve on the quality of life of the population."
OVERALL GOAL:
"Prosperity for All through the provision of quality social services
and increase in household incomes."

(Bugiri District, 2020)

7.3. Current water supply system

At this moment, a big part of the treated water supply system is covered by other organisations besides the National Water & Sewerage Corporation (NWSC), such as umbrella organizations and NGOs. A lot of people are not connected to the piped water supply and get their water from springs or handpumps. However, the Ministry of Water and Environment plans to integrate the water services to make sure they can be managed together by the private sector (Gauff Consultants, 2017). Therefore the scope of this study focuses on the current piped water supply of NWSC only, to be able to determine the gap between demand and treated water supply to achieve the goal of having a piped water supply system run by NWSC only.

7.4. Motivation for interest of location

According to the National Water & Sewerage Corporation, there is a high groundwater potential in this area, but it is unknown if the aquifers will provide the necessary long-term treated water supply. It is noticed that the yield of some boreholes is decreasing in time. At the same time, the current water demand is higher than the current treated water supply and the deficit is increasing as the population grows, which means that a short-term, as well as a long-term solution is needed, to be able to fulfil the water demand of Bugiri District.

7.5. Climate and vegetation

The rainfall in this area is between 1,200 and 1,400 mm per year, of which most is falling in the periods between March and May and between August and October (Bugiri District, 2002).

In Figure 7.2 it can be seen that the area is covered with mostly crops, scrub and trees. Besides, there are many swamps covered with short grass and papyrus reed and marshes (Bugiri District, 2002). It can be seen that in the Southeastern part the vegetation is slightly denser compared to the northwestern part. Next to farming, fishing is a common activity practiced by the people living near Lake Victoria (Bugiri District, 2002).

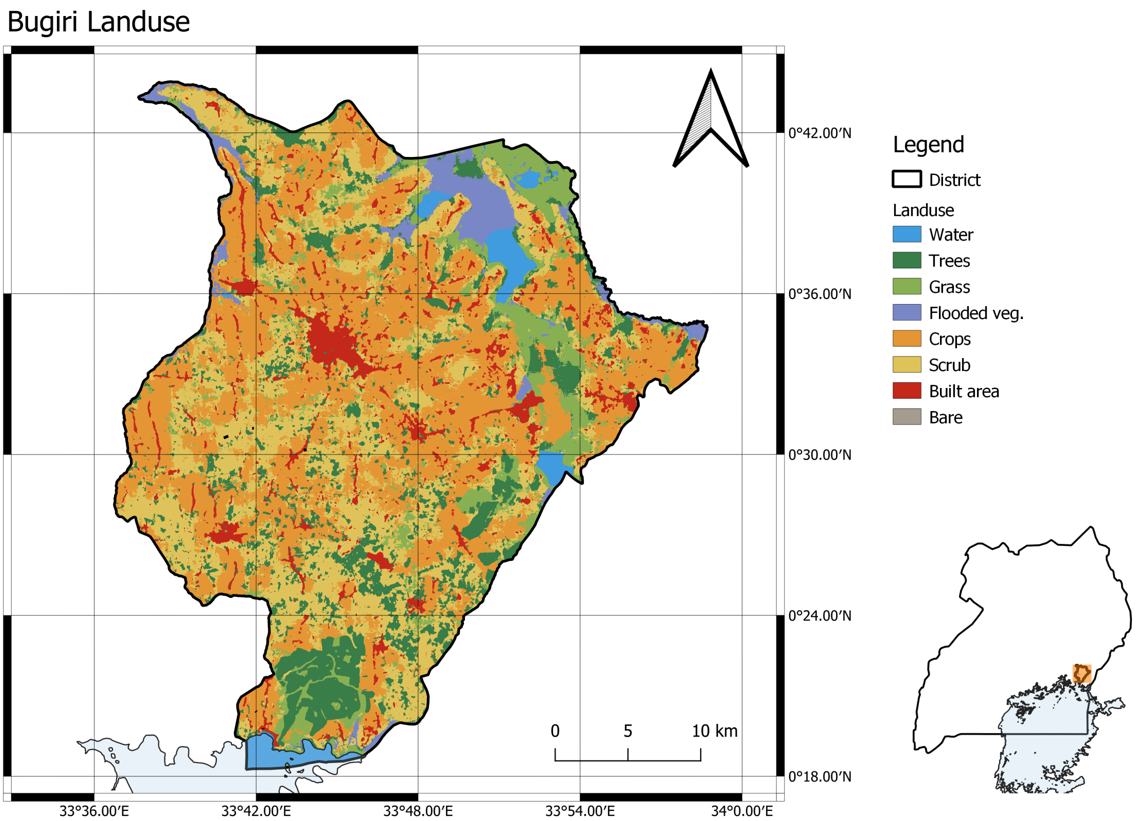


Figure 7.2: Land use Bugiri District *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

7.6. Geology

The geology of Uganda is quite complex. The land is mainly underlain by pre-Cambian rocks like granites, gneisses, migatities, meta-sediments, mudstones and argillites. According to Bugiri District, 2002, the geology of the western part of the Bugiri district consists of granitoid and highly granitized rocks and in the east and south the geology consists of metavolcanics, ironstones, quartizites and greywackes with areas of intrusive granites and undifferentiated granite gneisses and granulite facies rocks.

Groundwater occurs in the weathered rocks or overburden (regolith) and in the fractured bedrock, but the best aquifers are present in the contact between the overburden and fresh bedrock (NWSC, 2021b). So the boreholes are typically drilled into fractured bedrock, of which the main storage is being provided by the overlying saturated regolith (Bugiri District, 2002). The area where the overburden is thickest, is the best site for a borehole, because of the potential for a greater storage in the regolith, and where a fracture zone is present in the underlying bedrock (Bugiri District, 2002).

7.7. Topography

The northern part of the district has an altitude between 1,065 and 1,125 meters and the southern part is a bit higher with a bit more height differences between 1,160 and 1,291 meters (Bugiri District, 2002). In Figure 7.3 an overview of the elevation in Bugiri District is shown. It can be seen that the northern part of Bugiri is the lower area of the district, so the water drains in the northeast/northwest direction through the Kitutu and Malaba River. Only a small part of the area drains to Lake Victoria (south).

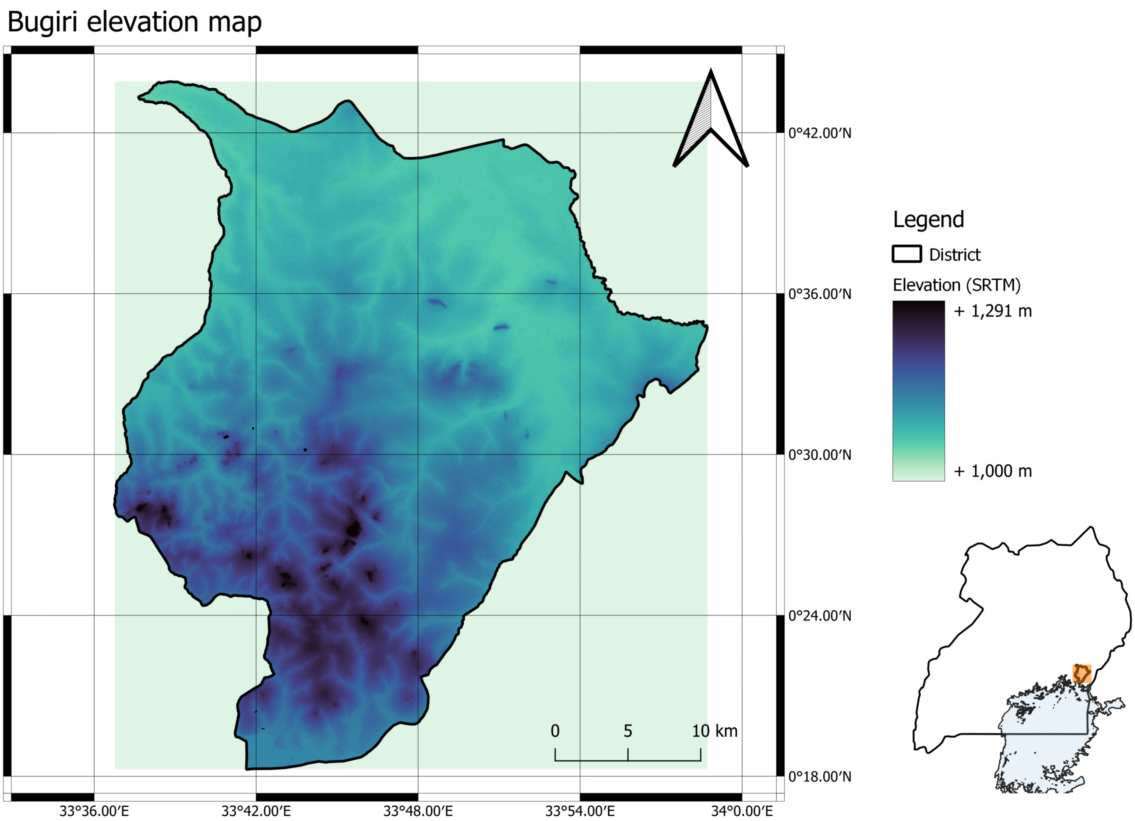


Figure 7.3: Elevation Bugiri District *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

8

Baseline study Bugiri District

The baseline study of Bugiri District focuses on the current water demand and the current water supply system. The information is gathered through field visits, discussions and interviews with relevant stakeholders and reviewing information from previous studies and current reports and documents from both the District and the National Water & Sewerage Corporation. The next part in the baseline study is estimating the future treated water supply and demand.

For this study the area has been visited (6th of December, 2022 till the 7th of December, 2022). This was done together with the Senior Engineer, Groundwater & Boreholes Development - National Water & Sewerage Corporation (NWSC), Eng. Dammie Hillary Atuhairwe and geohydrologist Jan Dirk Smid. During the baseline visit, the NWSC Area Manager Bugiri (Ms. Mable Abaho), the Bugiri District Planner (Mr. Kenneth Okello) as well as the Bugiri District Water Engineer (Mr. Robert Mwesigwa) were consulted. During the meetings information was gathered on the current water supply of NWSC. Also the information needed to determine the current and future water demand of the district was discussed with the engineers and the District Water Engineer. On top of that, insights in the different treated water supply options were found during the fieldtrip.

8.1. Current situation

In this section an estimation is made of the current demand and treated water supply. This is done by determining the population, commercial entities, institutions and industries in the area. The water supply system takes into account (amongst others) the number of connections, a block map of the current network, the water sources and the transmission- and distribution networks.

8.1.1. Current Demand

In this paragraph the current water demand is estimated. In order to do this, first, the current population is verified, after which the total amount of connections is given.

Current population

The total population is estimated as 517,000 people by the Area Manager of Bugiri. This value is verified using the population projection of Uganda Bureau of Statistics, 2019 presented in Table 8.1, which also contains the population projection per sub county. In this population projection the expected population in 2022 is equal to 517,400, which is more or less equal to the value given by the Area Manager. In Figure 8.1 the distribution of the people throughout the district in 2014 is shown. It can be seen that most people live in the sub counties Bulesa, Buwunga, Kapyanga and Nankoma.

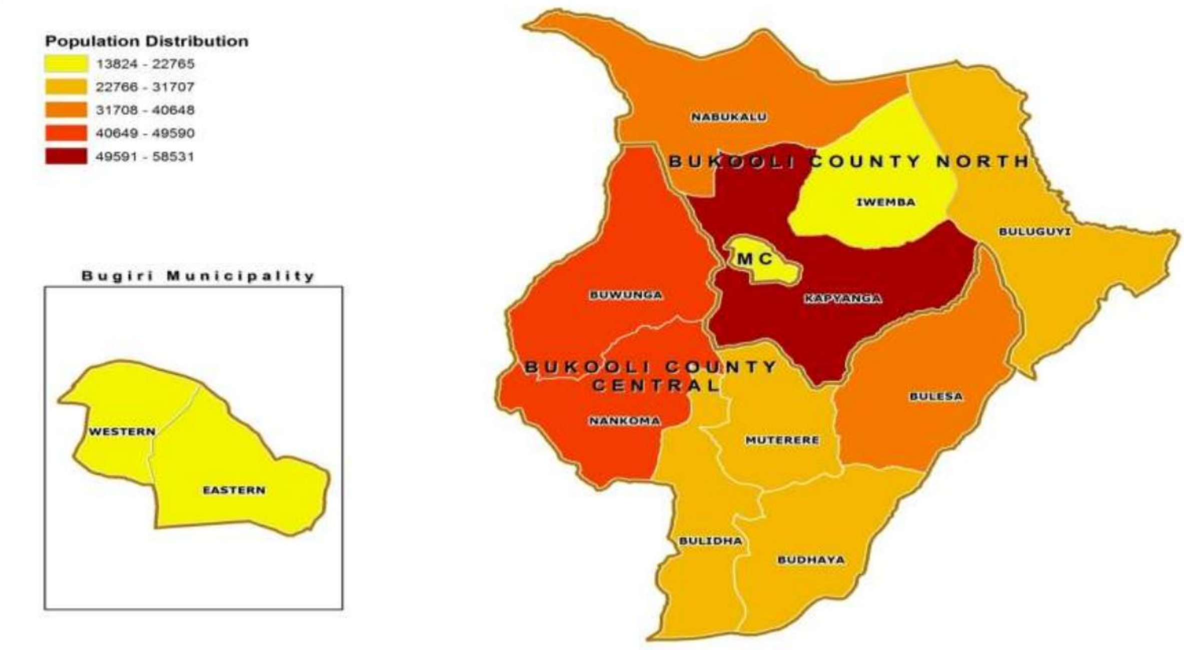


Figure 8.1: Distribution of Population by sub-county in Bugiri District, 2014 (Uganda Bureau of Statistics, 2017)

Table 8.1: Population projection Bugiri District, (Uganda Bureau of Statistics, 2019)

		Male	Female	Total
Total Bugiri District		254,400	263,000	**517,400**
	Bugiri Municipality (Eastern Division)	8,900	9,800	**18,700**
	Bugiri Municipality (Western Division)	9,500	10,700	**20,200**
	Budhaya	19,000	19,500	**38,500**
	Bulesa	26,400	27,200	**53,600**
	Bulidha	16,200	16,600	**32,800**
	Buluguyi	21,000	21,400	**42,400**
	Buwunga	31,000	32,200	**63,200**
	Iwemba	13,100	13,000	**26,100**
	Kapyanga	39,000	40,100	**79,100**
	Muterere	18,500	19,200	**37,700**
	Nabukalu	24,700	24,800	**49,500**
	Nankoma	27,100	28,500	**55,600**

Connections
According to the information obtained from the National Water & Sewerage Corporation (NWSC) Area Manager of Bugiri there are 1,755 connections in the whole district. The amount of connections is growing every month with an average of 12 new connections. Since the current treated water supply is constraining the growth, this number is still quite low. There are currently about 72-100 accounts with no treated water supply. This data was retrieved during fieldwork Bugiri.

Current water demand estimation
To make an estimation of the total water demand, several categories are considered. The information that was needed to make an estimation is gathered during the baseline visit in Bugiri. The rural population in the district is about 69% while the urban population accounts for 31% of the total District population. For rural a value of 20 L/p/d is used and for urban 50 L/p/d (Ministry of Water and Environment, 2014).

About the amount of restaurants and hotels no information was obtained, so an estimation of the total amount of restaurants is made by using Google Maps as a reference. The maps of the different towns including the bars and restaurants which are currently found on Google maps is shown in Appendix E.1.

In Bugiri District there are two big industries, the Bugiri sugar factory and the Kibimba rice industry. The demand for both these big industries is 20,000 m^3/month according to the area manager. Currently these industries have their own water supply, but in the future it is desired that they are served by NWSC.

Table 8.2: ("Google Maps", 2022)

	Restaurants	**Bars**
Bugiri (town)	12	4
Busowa	0	1
Nawambwa	0	2
Namayemba	1	2
Total	13	9

In Appendix C more information on the standard values that are used for the water demand estimation can be found. In Table E.1 in Appendix E, an overview of the demands in Bugiri District is shown. The sum for the different categories is 549,202 m^3/month.

From these monthly demands, the average daily demands are determined by dividing the values by 30.5 days. The average daily water demands for Bugiri District are shown in Table 8.3. The total average daily water demand is equal to 18,007 m^3/d.

Table 8.3: Average daily water demand Bugiri District 2022

	Water demand [m^3/d]
Domestic	15,148
Commercial	113
Institutional	1,431
Industrial	1,318
Total demand	**18,007**

8.1.2. Current treated water supply

During the fieldwork trip to Bugiri, an inventory of the current water supply of the National Water & Sewerage Corporation (NWSC) is established. As found in the background study, the goal is to have a piped water supply system that is run by only one organisation, NWSC. In order to find the gap between the current supply system and the demand, only the piped water supply of NWSC is considered as current system. An overview of the inventory of the current piped water supply of NWSC is shown in the map of Figure **??**.

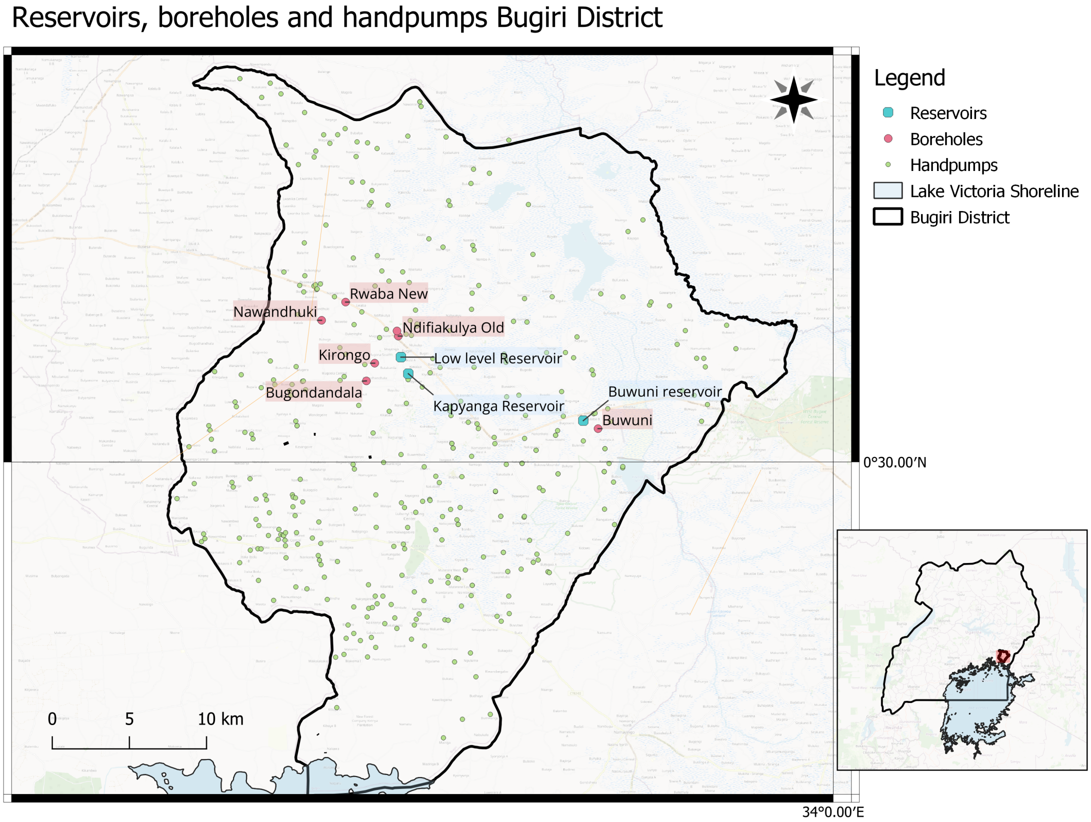


Figure 8.2: Boreholes and reservoirs Bugiri district *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI*, made in QGis, 2022)

Water source supply

Groundwater is used as a water source for the current piped water supply system of Bugiri District, which is pumped using five boreholes near Bugiri Town. Next to the current five boreholes, there are many hand pumps in the district. Currently there are 947 hand pumps, 112 shallow wells and 213 springs, which also supply the people in Bugiri District with water.

One of the boreholes, Kirongo, produces very turbid, orange colored water, which might be caused by a high concentration of iron. In Table 8.4 an overview of the boreholes of NWSC is given, including the coordinates and capacity per hour of the boreholes. The optimal hours of pumping is about 18 hours per day, this means there is a resting time of about 6 hours per day. However, due to bad power supply, most of the days, the pumps are pumping way less than 18 hours. For Bugiri District there are no values for the daily production available digitally. Although the values are written down every day by the borehole operators. For the estimation of the total treated water supply the monthly production values are used to compare the actual production with the capacity of the boreholes.

In Table 8.4 the monthly capacity is calculated considering 18 pumping hours per day. This daily volume is multiplied by 30.5 to calculate the potential water that in theory could be produced. This is compared with the given monthly values for the production. There is a big gap between the capacity of the boreholes and the actual production. Using the monthly production data and the capacity of every borehole, the average amount of pumping hours is 6.5. This is caused by the poor power supply and the malfunctioning of the pumps.

Table 8.4: Current boreholes Bugiri District

Borehole	Coordinates		Capacity [m^3/h]	Capacity [m^3/month] (18 h/d)	Actual production [m^3/month]	In use
	N°	E°				
Ndifakulya old BH	0.573915	33.746871	3	1,647	400	Yes
Ndifakulya new BH	0.576850	33.746020	15	8,235	1,800	Yes
Kirongo BH	0.547602	33.728203	6	3,294	2,401	Yes
Bugodandala BH	0.547602	33.728203	8	4,392	4,200	Yes
Buwuni BH	0.519437	33.863172	14	7,686	1,800	Yes
Total				**25,254**	**8,271**	

According to the NWSC Area Manager of Bugiri, the percentage of non-revenue water is 12% on average. This value will be used to calculate the actual amount of water that will be supplied to the customers. The data provided of the sold and produced water is presented in Table 8.5. The monthly average value for NRW is 12%, with corresponds with the 12% discussed during the field visit.

Table 8.5: Produced and sold water - months April-September 2022 Bugiri (data retrieved during fieldwork Bugiri)

	Produced [m^3]	Sold [m^3]	Difference [m^3]	NRW
Apr-22	7,944	7,095	849	10,69%
May-22	8,118	7,115	1,003	12,36%
June-22	9,212	8,087	1,125	12,21%
July-22	9,210	8,116	1,094	11,88%
Aug-22	7,901	7,014	887	11,23%
Sep-22	7,411	6,566	845	11,40%
Average		7,332		12%

An average of 7,332 m^3/month is sold (see Table 8.5), which means 240 m^3/day. This value is used to calculate the current treated water supply in Bugiri.

The groundwater is transmitted to three reservoirs after which it is distributed to the customers. To which reservoirs the different boreholes are connected is shown in Figure E.3 in Appendix E. The coordinates of the reservoirs together with the capacities can be found in Table 8.6. In Appendix E pictures of the reservoirs in Bugiri are shown.

Table 8.6: Current reservoirs Bugiri District (data retrieved during fieldwork Bugiri)

Reservoir	Coordinates		Capacity [m^3]
	N°	E°	
Buwuni reservoir	0.52429	33.8545400	180
Kapyanga reservoir	0.55182	33.7526100	100
Low level reservoir	0.56154	33.7482900	150

The reservoirs are presented in Appendix E.

The water is treated by chlorine dosing. This is done at the boreholes, but due to a mechanical failure, the dosing is done at the reservoirs instead. In Figure 8.3, it can be seen how an automatic dosing of chlorine looks like.

Figure 8.3: Automatic chlorine dosing at the Buwuni reservoir

The supply is divided in four main categories, shown in Table 8.7. More than half of the supply is for domestic use.

Table 8.7: Supply Bugiri District

	Division categories [%]
Domestic	52
Commercial	12
Institutes and Government	33
PSP	3

Non-Governmental Organisations (NGOs)

In Bugiri multiple boreholes and hand pumps are owned by Non-Governmental Organisations (NGOs), which contribute to the current water supply of the district. According to the GOAL Water Sanitation Hygiene coordinator, GOAL NGO has built piped water systems, 5 ‘deep’ boreholes, 500 handpumps and multiple tap points in Bugiri District. GOAL installed 4 pre-paid meters (still very affordable) on boreholes in Bugiri District and 1 new meter as a pilot, of which the test results are not known yet. The NGO has been working in Bugiri for 10 years and covered 80 percent of the whole district, which means the project is finished in Bugiri and that the same kind of project is continued in the surrounding districts.

According to the NWSC Area Manager, two boreholes of World Vision, an NGO focused on helping children overcome poverty and experience fullness of life (World Vision, n.d.), will be handed over to NWSC. These boreholes have a capacity of 2 m^3/h and 5 m^3/h.

The supply by the hand pumps is not added to the total supply since it is preferable that the district is covered with a piped water supply system by NWSC. The quality of the water pumped with the hand pumps is not closely monitored, which makes it a risk for the health of the people using the water. However, the boreholes of GOAL, World Vision and possibly other NGOs - should be researched further.

This will give more insight in the number of boreholes located in Bugiri and the corresponding yields, which can be handed over to NWSC in the future.

8.1.3. Current gap between demand and treated water supply

When all current water sources are used on full potential, there is still a gap between the current water demand and treated water supply ('demand-supply gap'). As shown before, the current billed water supply is equal to 7,332 m^3/month on average, which is equal to 240 m^3/d. As stated before, the current water demand is equal to 18,007 m^3/d. This results in a 'demand-supply gap' of 17,767 m^3/d. As stated before, this is the gap that should be covered by the National Water & Sewerage Corporation in the future.

8.2. Project plan for future situation

In order to find out how fast the demand is going to grow, it is useful to inform at the policy makers if there are any plans for the future.

8.2.1. Future demand

Since water supplies are intended to last for numerous years, the future population must also be considered (Ministry of Water and Environment, 2014).

Future population projection

According to the District Water Engineer of Bugiri District the population growth of Bugiri District is equal to 3%. The population in a certain year can be calculated according to Equation 8.1.

$$P_n = P(1 + r)^n \tag{8.1}$$

With:

- P_n = population after n years,
- P = present population and
- r = annual growth rate [%].

Using this method, an estimation of the population for the years 2023, 2028, 2033, 2038, 2043 and 2048 is made and shown in Table 8.8.

Table 8.8: Population Projection Bugiri District

	2023	**2028**	**2033**	**2038**	**2043**	**2048**
Bugiri District	532,510	617,325	715,649	829,633	961,772	1,114,958

Future water demand estimation

Based on the expected population growth, a rough estimation of the future water demand has been made. As said before, the expected annual population growth rate is 3%. The expectation is that the domestic water demand therefore increases with 3% annually. According to the District Water Engineer, the growth rate of the commercial and institutional water demand is equal to 3% as well. Besides, the industrial water demand is expected to grow with 4%. With these growth percentages, a future water demand estimation in Bugiri District is made and shown in Table 8.9.

Table 8.9: Future water demand estimation Bugiri District

	2023	**2028**	**2033**	**2038**	**2043**	**2048**
Domestic	15,602	18,088	20,968	24,308	28,180	32,668
Commercial	116	135	156	181	210	244
Institutional	1,474	1,709	1,981	2,296	2,662	3,086
Industrial	1,368	1,664	2,024	2,463	2,997	3,646
Total [m^3/d]	**18,560**	**21,595**	**25,130**	**29,249**	**34,049**	**39,644**

8.2.2. Future treated water supply

There are several possibilities for the extension of the water supply system. Some options use surface water as a source, in this case Lake Victoria. On top of that, there are also possibilities for extension using the groundwater in the district. The gap in the future will be estimated using the interpolated water demand and the estimation of the future treated water supply using the current plans of NWSC for extensions.

Surface water supply options

There are different possibilities for Bugiri District to increase the water supply, which will be further discussed in Chapter 9. For surface water there are 4 options considered in this case:

- Extension of treatment plant in Majanji
- Extension of treatment plant in Jinja (Masese)
- Intake from Lake Victoria at Wakawaka
- Intake from Lake Victoria at Bugadde

All these options will extract the water from Lake Victoria. The first two options focus on the extension of a treatment plant. In the case of the treatment plant in Majanji, there is space to extend the treatment plant. There are two options if this source is chosen: either construct a pipeline from Busia to Bugiri District, or directly transport the water from Majanji to Bugiri District. The construction of a new treatment plant is also possible in the district itself, for example at Wakawaka. Although this is a more costly alternative and it will probably take longer since a feasibility study first has to be performed. Another possibility for surface water is constructing an intake and treatment plant in Bugadde. A feasibility study has been done in 2018 by The Ministry of Water and Environment, which was not yet executed due to financial difficulties.

The options for extending the water supply system with surface water are further discussed in Chapter 11.

Groundwater water supply options

When it comes to ground water, there are some opportunities to extend the system. There are already multiple boreholes available, and if necessary more boreholes could be drilled. This requires careful investigation of the geology to find more possible locations for aquifers.

Two boreholes were recently drilled by the National Water & Sewerage Corporation, Rwaba and Nawandhuki, shown in Table 8.4 and Figure **??**. These boreholes are not yet installed with a pump and it has not been decided to which reservoir they will be connected.

As discussed before, in the future, boreholes of NGOs could be handed over to the National Water & Sewerage Corporation (NWSC) to use these in the piped water supply system of NWSC. Therefore, it is advised to include these boreholes in the future (short-term) supply network. Two boreholes of World Vision are already planned to be handed over to NWSC in the near future. These boreholes have a capacity of 2 m^3/h and 5 m^3/h.

For the long-term it will be advised that the pumps will pump for 18 hours a day. Currently, some pumping stations operate less than 18 hours due to power supply problems. These power supply problems should be solved on the long term. It is also important that the pumps do not operate much more than the desired 18 hours, because this increases the probability to adversely affect the performance of the pump.

The future production of all boreholes, when assuming they operate 18 hours per day, is shown in Table 8.10. If these boreholes are used in the future, the total future groundwater production would be equal to 75,762 m^3/month. As said before, the percentage of non-revenue water is equal to 12%, which results in a future long-term treated water supply of 66,671 m^3/month.

Table 8.10: Future groundwater supply Bugiri District

Borehole	**Coordinates**		**Capacity** [m^3/h]	**Future production [m^3/month]** (18 hours pumping)
	N°	**E°**		
Ndifakulya old BH	0.573915	33.746871	3	1,647
Ndifakulya new BH	0.576850	33.746020	15	8,235
Kirongo BH	0.547602	33.728203	6	3,294
Bugodandala BH	0.547602	33.728203	8	4,392
Buwuni BH	0.519437	33.863172	14	7,686
Nawandhuki BH	0.583142	33.702119	70	38,430
Rwaba BH	0.593820	33.716096	15	8,235
World Vision BH 1			2	1,098
World Vision BH 2			5	2,745
Total				**75,762**

8.2.3. Future gap between demand and treated water supply

When all water sources are used on full potential, there is still a gap between the current water demand and treated water supply and the future water demand and treated water supply. To overcome the short-term (5 years) and long-term (25 years) gap between the water demand and treated water supply, different alternatives of water resources should be invented and compared.

An estimate for the gap between the water demand and treated water supply ('demand-supply gap') is given below. For the long term, two situations are considered. One 'demand-supply gap' is based on no actual supply changes compared to the current situation. The other long-term 'demand-supply gap' is based on the actual supply when all existing boreholes in Bugiri District are taken into account.

As calculated before, the future short-term water demand in 2028 is equal to 21,595 m^3/d and the future long-term daily water demand in 2048 is equal to 39,644 m^3/d. The current billed water supply is equal to 7,332 m^3/month, which is equal to 240 m^3/d.

The future supply is calculated in the previous section and has a value of 75,762 m^3/month, which is equal to 2,484 m^3/d. The same percentage of non-revenue water is taken into account, namely 12%. According to the same equations as used for Hoima City, the following demand-supply gaps are calculated.

- The demand-supply gap between short-term demand and current actual supply is 21,355 [m^3/d].
- The demand-supply gap between long-term demand and current actual supply with the only the current boreholes is 39,404 [m^3/d].
- The demand-supply gap between long-term demand and future actual supply is 37,458 [m^3/d].

The amount of water that is used as the design value for the extension of the system is 39,404 m^3/d, which is the future gap between water demand and treated water supply. That means it is assumed that the current actual supply is not extended. The NRW percentage for the design of the future supply system is further elaborated in Chapter 10 and 13.

9

Water source analysis Bugiri District

9.1. Available water sources

To determine how the future water demand could be supplied, it is important to distinguish short-term and long-term solutions. On the short term, an extra treated water supply of around 21,355 [m^3/d] is desired. On the long term there is a gap between demand and treated water supply of around 39,404 [m^3/d] required.

9.1.1. Short term

For the short term, the first step to increase the treated water supply is to improve the power supply network, so that the pumps can operate for 18 hours a day. Next to that, the treated water supply can be extended by connecting the new drilled boreholes and the boreholes which are owned by the NGO Goal operating in this area.

9.1.2. Long term

For the long term there are five alternatives considered as options for the extension of the piped water supply network in Bugiri District. The first four alternatives use water from Lake Victoria and imply an installation or extension of a water treatment plant. These alternatives will be compared in the multi-criteria analysis.

- Extension of treatment plant in Masese (Jinja)
- Intake from Lake Victoria at Bugadde
- Intake from Lake Victoria at Wakawaka
- Extension of treatment plant in Majanji
- Groundwater

The different sources are presented in Figure 9.1.

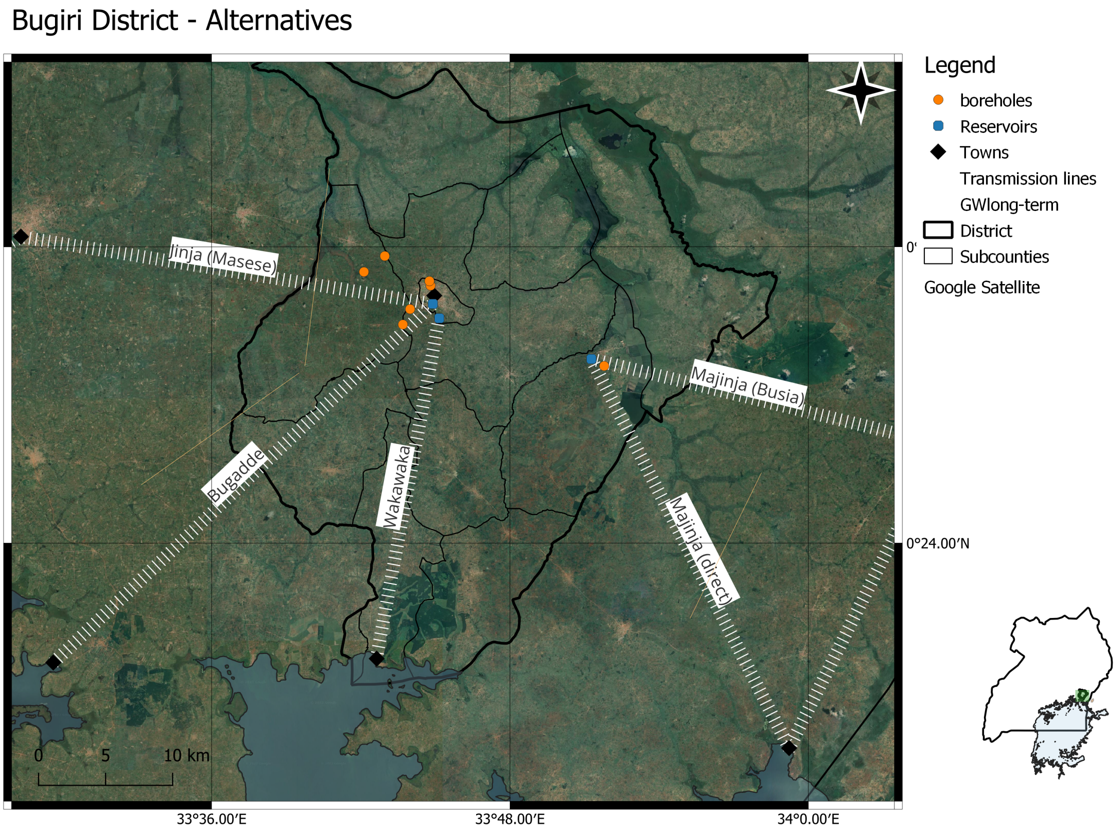


Figure 9.1: Water source alternatives Bugiri District

Surface water
Surface water is widely available because of Lake Victoria, which means that for the long term, the water availability will remain high.

However, this water needs to be treated extensively, as the water in the lake is polluted, which requires big investments. Besides using surface water from Lake Victoria requires long transmission lines to reach the area of Bugiri District. The alternatives considering surface water are focused on either extending an existing treatment plant or constructing a new one, all with Lake Victoria as water source.

If surface water is considered as an option, the intake should not be at the shore, but a bit further in the lake, since the water along the shore could be of bad quality due to human interference. It is recommended to do a feasibility study to find the most suitable location for the intake.

Extension of treatment plant in Masese (Jinja)
The water treatment plant of Jinja is called 'Masese Water Works', located in the Walukuba Division (Ministry of Water and Environment, 2021). The water is extracted from Lake Victoria in the Napoleon gulf (Ministry of Water and Environment, 2021). The treatment plant will be extended with a new clarifier according to the plan presented in 2021, which means that the treatment plant will be able to operate at full the full capacity of 30,000 m^3/d and will be able to produce water for Jinja, Iganga and Kaliro (Ministry of Water and Environment, 2021), of which the exact locations can be seen in Figure 9.1. Extending this system to serve Bugiri District would mean that the treatment plant in Jinja has to be expanded further. Currently a transmission line is being constructed from Jinja to Iganga to Kaliro. This line will not be sufficient to supply Bugiri district as well, which means that a new line needs to be constructed from Jinja to Bugiri district. The distance from the treatment plant to the closest reservoir (Low Level reservoir) in Bugiri district is 65.7 km ("Google Maps", 2022).

Intake from Lake Victoria at Bugadde
A feasibility study for The Ministry of Water and Environment in 2018 considered multiple options for

the extension of the water supply and sanitation systems in the Greater Bugadde area in Kityerera and Busakira sub-counties of Mayuge District (Ministry of Water and Environment, 2018). The option to supply this area by a new water treatment plant with water intake from Lake Victoria appeared to be the most feasible (Ministry of Water and Environment, 2018). As this plan was was financially not feasible at that moment, it has not been carried out yet and currently there are no plans to implement this system on the short term.

This feasibility study already concluded a new water treatment plant at Bugadde as an option. Therefore, building this plant for the water supply of the Greate Bugadde area and extending this system to Bugiri District could be an interesting option. It will save time and money since the study has been done already. Bugadde is around 40 kilometres away from the Low level reservoir in Bugiri Town ("Google Maps", 2022).

Intake from Lake Victoria at Wakawaka
The third option regarding surface water is the option to use the water from Lake Victoria at Wakawaka as a source. This water needs to be treated, and since there is no treatment plant yet, a new treatment plant has to be build. Besides a treatment plant, a new transmission line has to be constructed from Wakawaka to the Kapyanga reservoir, which will have a length of 26 kilometers ("Google Maps", 2022).

Extension of treatment plant in Busia
To supply Busia with treated water, there is a project being executed 'Busia Water Supply and Sanitation Project', which is funded by a loan from the World Bank (World Bank, 2018). The water intake will be in Lake Victoria in a small town named Majanji (World Bank, 2018). The treatment plant that is designed for this project will process about 13,000 m^3 of water per day and will supply Majanji and Busia (World Bank, 2018). The aim is to finish the construction in December 2023.

The treatment plant in Busia could be extended to Bugiri to extend the current water supply system of Bugiri using surface water as a source. According to the Ministry of Water & Environment, the treatment plant at Majanji is not big enough right now to treat an extra amount of water needed for Bugiri District, so this treatment plant has to be expanded and a sedimentation tank has to be added.

There are two options regarding the transmission network, one via Busia and one direct. The first option follows the already existing transmission network, which currently goes from Majanji to Busia. It is assumed that the current line to Busia is not big enough to transmit the extra amount of water for Bugiri, which means an extra pipe has to be added. The total distance from Majanji will be 52.5 kilometer to the Buwuni reservoir. The second option would be adding a new line from the treatment plant in Majanji directly to Bugiri, which will be a shorter distance of 33 kilometres. The distances are measured with ("Google Maps", 2022).

9.1.3. Groundwater

The option to extend the piped water supply network using groundwater is a widely used alternative in Bugiri District. After a borehole is being drilled and constructed, a pump is being installed, which will pump the water from the aquifer. The district has many boreholes, which are mainly hand pumps. The groundwater is indispensable in the short term, but since the yields are low and are dropping after a few years, further ground studies and tests have to be carried out to make sure that good aquifers are used for the long term.

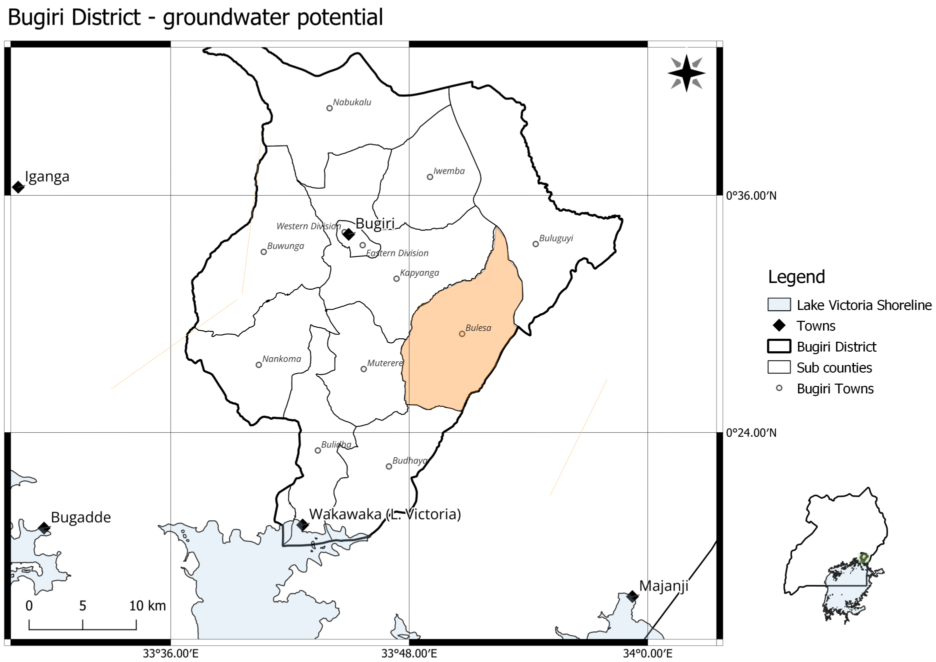


Figure 9.2: Bugiri District - groundwater potential *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC; VEI and WE Consult*, made in QGis, 2022)

To determine the best location(s) for boreholes a groundwater assessment study has to be performed in the area of Bugiri. According to WE Consult there is an aquifer in Bulesa, a subcounty in Bugiri, that can be researched to determine its yield and the groundwater availability in this area. The location of Bulesa is shown in Figure 9.2.

Besides Bulesa, there might be groundwater availability elsewhere in the area. A map of the geology in the Lake Kyoga area is shown in Figure E.4 in Appendix E. However, the geology with undifferentiated gneisses (purple area in the map) contains a hard rift and granite, which makes it difficult to retrieve groundwater. Besides, it has to be taken into account that groundwater appears to be salty close to lake Victoria, which is located south of Bugiri.

The advantage of using groundwater is that the distance to the source is generally smaller and the quality is generally better compared to surface water. Currently, in Bugiri District the pumped groundwater is only treated with a chlorine dosing at the pump station or in the reservoir.

If groundwater will be used for the future treated water supply, more studies have to be done to access the availability of the water. Currently there are a lot of complications regarding groundwater since the yields are decreasing after a few weeks of being drilled. The groundwater will not be considered as an alternative for the long term since currently there is not enough information available.

9.2. Water quality

To compare the different water sources in terms of quality, the water properties pH (-), Electrical Conductivity (EC) ($\mu S/cm$), Color ($PtCol$), Turbidity (NTU), Total Suspended Solids (TSS) (mg/l), Hardness (mg/l), Alkalinity (mg/l), Iron (mg/l), Faecal Matter ($CFU/100mL$) are evaluated. The Hardness is measured in $CaCO_3$.

9.2.1. Data

In Table 9.1 the water quality of the reservoirs, the boreholes and the lake water is shown, which was retrieved by the Area Manager of the National Water & Sewerage Corporation (NWSC) in Bugiri during the baseline visit. The water quality in Lake Victoria has been researched in 2018 for the construction of the water treatment plant in Bugadde (Alliance Consultants Ltd. and Infra-Consult Ltd., 2018). The average of the water quality at 200 and 300 meter from the shore and three different depths is taken.

The Ugandan drinking water standards are based on (UNBS, 2014) and are presented in Table 9.1 as well. The data that is found is compared with the National Standards for untreated potable water (by NWSC) and the drinking water standards. It gives an indication of the range for the parameters in order to evaluate the quality of the surface water or groundwater. The different sources that are considered for the extension of the treated water supply are evaluated looking at different properties.

Table 9.1: Bugiri water quality data
Water quality standards Uganda potable water and untreated potable water (UNBS, 2014), Lake Victoria data: from MWE, Alliance Consultants Ltd. and Infra-Consult Ltd., 2018 and NWSC Bugiri, monthly water quality report NWSC Bugiri average November and December 2022.

	pH [-]	**EC** [μS/cm]	**Colour** [PtCo]	**Turb.** [NTU]	**TSS** [mg/l]	**Hdness** [mg/l]	**Alk** [mg/l]	**Iron** [mg/l]	**E. Coli** [CFU/100ml]	**F. Cl2** [mg/l]
Ugandan standards potable water	6.5-8.5	1500	15 TCU	5	0	300	20-200	0.3	0.0	1.0
Environmental standards	6.0-8.0		300	300	100					
Ugandan standards untreated potable water	5.5-9.5	2500	5 TCU	25	0	600	500	0.3	0	
Lake Victoria (Bukoba, Mayuge District average)	7.2	87.7	66.0	3.4	6.7	34.7	52.0		3.0	
Lake Victoria Wakawaka Raw water	7.78	139.4	83.7	7.16		40	61	0.079		
Lake Victoria (Majinji) 6-1-2021	8.02	89.33				26.60	45.83			
Musongola reservoir	6.63	444	11	5,5	-	108	274	0.34	-	0,54
Kapyanga reservoir	6.67	505	6	5.5	-	100	282	0.27	-	0,53
Buwuni reservoir	6.63	671	-	0.5	-	298	376	0.02	-	0,51
Borehole Ndifakulya old	6.63	305	7	1.4	-	118	260	0.17	-	-
Borehole Ndifakulya new	6.70	316	19	5.0	-	106	278	0.89	-	-
Borehole Kirongo	6.62	433	149	16.5	-	100	316	1.41	-	-
Borehole Bugodandala	6.72	511	11	4.5	-	110	266	0.43	-	-
Borehole Buwuni	6.63	668	-	0.6	-	298	384	0.02	-	-

9.2.2. Surface water

All the four different options consider Lake Victoria as a source. It has to be taken into account that the water quality depends on the location of the intake, the depth and how far the intake is from the shore.

The surface water quality is monitored by the National Water & Sewerage Corporation. The sample for Lake Victoria is taken at Wakawaka on the 28th of November and shows a way too high value for color. Next to that, the turbidity is 7.16, this is too high as well in comparison with the Ugandan drinking water standards. Unfortunately the Faecal [CFU/100mL] is not measured. According to this sample, the water quality is not extremely bad, which means there are possibilities to treat this water and use it as a source for drinking water.

The water quality at Butoka is the average of six different samples taken at several depths and distances from the shore. The water quality is similar to the water sample taken at WakaWaka. TSS is measured at Butuka and has a value of 6.7 exceeding the drinking water standards of Uganda. The feacal matter is 3.0 CFU/100ml according to this report.

From the surface water quality monitoring stations monitored by Ministry of Water and Environment, 2014, the quality data of the station at Majanji on January, 6th 2021 is shared by Sr. Engineer Marcas Ahimbisibwe (Ministry of Water and Environment). The pH is slightly higher, but the other properties are quite similar for the other data on Lake Victoria.

9.2.3. Groundwater

As can be seen, both the color value and the iron concentration of Borehole Kirongo are relatively high. The water in this borehole contains a lot of iron, which is a big issue regarding the safety of the drinking water. This iron problem of Borehole Kirongo is also visible in the photo which is made during the baseline visit in Figure 9.3.

Figure 9.3: Poor water quality borehole Kirongo

9.2.4. Water treatment process

The current water treatment process exists of only chlorine dosing. In the surface water is used, a new treatment plant has to be built or an existing treatment needs to be extended. The recommended steps suggested for the construction of the treatment plant in Bugadde (Alliance Consultants Ltd. and Infra-Consult Ltd., 2018):

- Inlet Chamber
- Rapid Mixing
- Coagulation
- Flocculation
- Sedimentation
- Filtration and backwash with airscour and water
- Disinfection and contact tank

Since the water source for the treatment plant in Bugadde is the same, it is assumed that the same treatment steps have to be taken if a treatment plant is built at another location on the lake.

10

Water supply system design Bugiri District

10.1. Short-term treated water supply options

On the short term, groundwater will be the only possible option. Treated water supply can be gained on the short term when the currently drilled boreholes are added to the system. The current transmission network is shown in green and the added parts to the transmission network on the short term are shown in blue, see Figure 10.1. The current distribution network could be extended and expanded as well on the short term. In the optimal case, so if the operational performance can be improved to only 20% of non-revenue water and all drilled boreholes are added to the distribution network with 18 hours of pumping per day, around 2,200 extra connections could be created:

- Current number of connections in Bugiri District, see Table 8.7: 1,755.
- Production from all drilled boreholes with 18 hours of pumping per day, see Table 8.10: 75,762 [m^3/month].
- Future amount of connections with future production with all 20% non-revenue water and 0.5 [m^3/d] per connection: 75,762 · 0.8 / 30,5 / 0.5 = 3,974 connections.
- Potential extension distribution network Bugiri District on the short term: 3,974 - 1,755 = 2,219.

The possible extension of the current distribution network with around 2,000 extra connections on the short term is shown in green in Figure 10.2.

10.2. Long-term treated water supply options

On the long term, so in 25 years, the future gap between demand and treated water supply gap should be overcome. This means both the transmission and distribution network should be expanded and extended greatly.

10.2.1. Transmission network

New water sources that can be added to the water system are different surface water options. The water treatment plant in Jinja could be expanded which can supply water to the Low level reservoir in Bugiri. Other options are extracting water from Lake Victoria at either Wakawaka or at Bugadde and transport it to Kapyanga reservoir or Low level reservoir respectively. The last surface water option is expanding the water treatment plant in Busia and supply water from there to Buwuni reservoir. New reservoirs can be built close to the existing reservoirs, there is space available and Kapyanga and Buwuni reservoirs are at high-lying regions in Bugiri District. Bugiri District is not famous for high yield aquifers, so groundwater is not considered as the long-term solution. However, based on the experience of Sr. Hydrogeologist R. Sloots of WE Consult, the Buwuni borehole capacity data from Table 8.4 and the Buwuni borehole quality data from Table 9.1, the Bulesa region of Bugiri has good potential. These long-term surface water options are shown in orange in Figure 10.1.

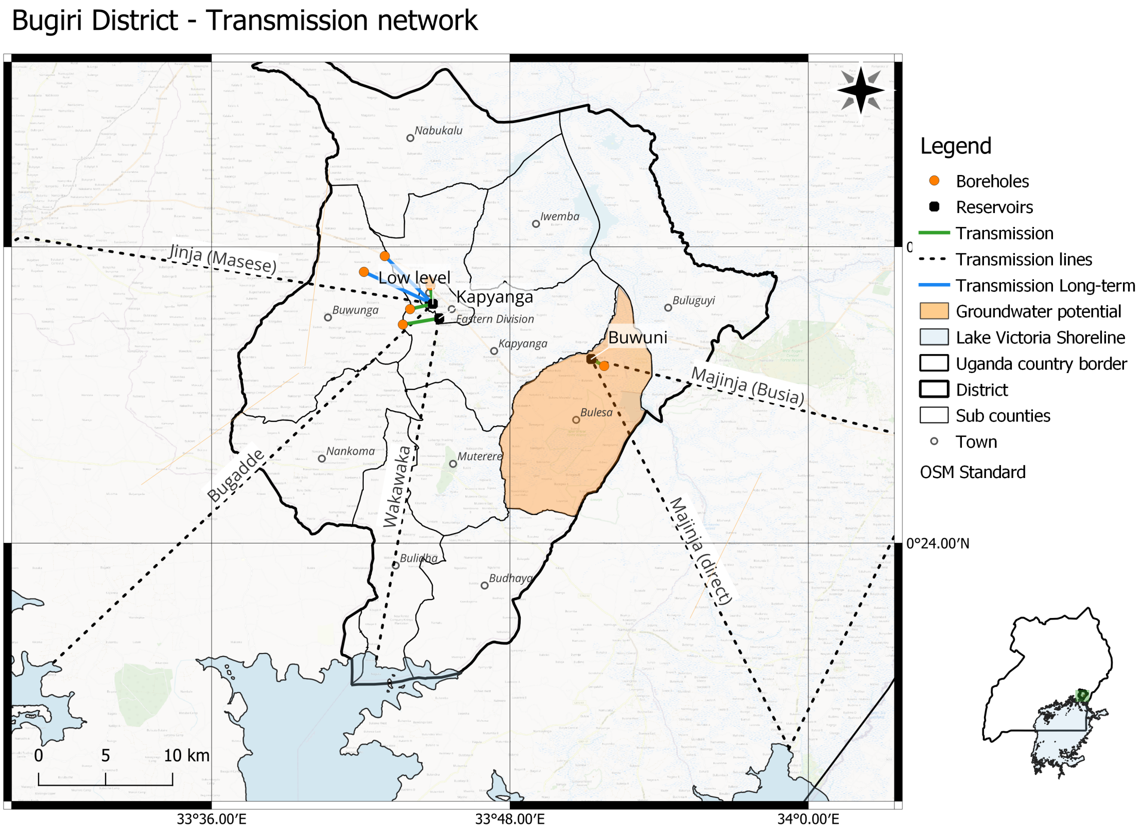


Figure 10.1: Current transmission network of Bugiri District

10.2.2. Distribution network

The current distribution network of Bugiri District is shown in red in Figure 10.2. The total length of the current distribution network is 51,267 [m], which corresponds to around 1,800 (1,755) connections. For the future demand (25 years), around 75,000 - 1,800 = 73,200 extra water connections are needed. This means the current distribution network should be extended by around forty times the current network. This would give a total length of at least 2,050 [km] of extended distribution network in the future, however because the distribution network is extended and expanded to the rural areas, this total length will be bigger. A suggestion for this is given in blue in Figure 10.2.

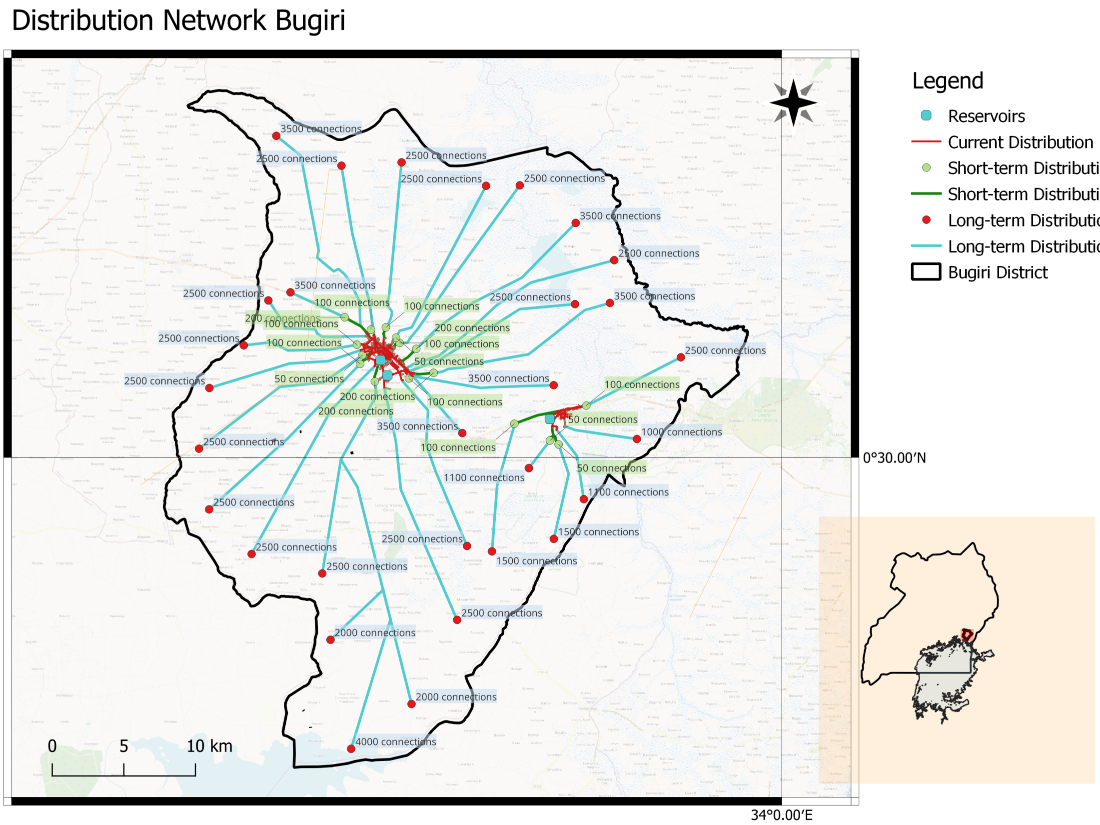


Figure 10.2: Current distribution network of Bugiri District *(Fieldwork 2022; OCHA, 2020; World Bank Water Data, 2010; "Google Earth", 2022; NWSC and VEI, made in QGis, 2022)*

Part III

Multi-criteria analysis tool

11

Multi-criteria analysis

A multi-criteria analysis (MCA) tool is constructed to compare different design alternatives for the treated water supply system in Uganda. A multi-criteria analysis provides insights in the decision-making process by giving weights to the main criteria that are used. Much time and effort could be wasted considering non-feasible options, while if one follows a step-wise approach this can be avoided. If the tool is used, the alternatives can be compared quickly and a choice can be made depending on the preference of the decision makers. The tool is set up using the experience during the visits of the project areas and using information from VEI, NWSC and MWE. It is focused on the evaluation of the long-term water sources in order to meet the future water demand.

The MCA-tool consists of three main analyses: a financial analysis, a performance analysis and a risk analysis. The financial analysis focuses on financial viability of the proposed project, i.e., if the proposed project is financially and economically attractive from the entity's viewpoint. Next to that, the performance analysis covers the following design criteria: sustainability, durability, society and feasibility. Finally, in the risk analysis, potential issues that could negatively impact the project plan are identified and analysed.

A user manual is written with an explanation on how to use the MCA-tool. This manual can be found in Appendix F.

11.1. Financial analysis

To roughly make an estimation of the costs of an alternative, the investment and the operational costs are calculated. The costs are estimated using several reports and billings of different contractors. Any grants can be filled out as well. It has to be noted that this is only to get insight in the order of magnitude of a particular alternative, and it cannot be guaranteed that the costs will exactly come down to the value presented.

11.1.1. Inputs

The required inputs are listed in the MCA user manual under the Financial Analysis, see Appendix F. Some inputs are explained in more detail below.

Non-revenue water (NRW)
The amount of water that will be lost between the extraction of the water and the costumer. This percentage can be estimated for every alternative and depends on the operational performance, the length of the pipeline and the complexity of the system in terms of unequal connections. A bearable amount which is assumed is 20% non-revenue water for an Ugandan drinking water system.

Coverage gap
This means the percentage of the future demand-treated water supply gap that will be covered by a certain alternative.

Number of connections
To calculate the amount of connections that will need to be installed to supply a certain amount of water, a value of 0.5 m^3/d per connection is used, which is a standard value used in Uganda according to Vitens Evides International (VEI). With the number of connections, the costs per connection can be

calculated. The reason that the number of connections is used to calculate the water demand instead of capita per household, is because there are also other important sectors beside domestic which are part of the water system. For example industrial and commercial use. On average VEI uses this value per connection.

$$\text{Estimated supply [m}^3\text{/d]} = \frac{\text{Demand-supply gap [m}^3\text{/d]}}{\text{Estimated coverage [\%]}} \tag{11.1}$$

$$\text{Number of connections} = \frac{\text{Estimated supply [m}^3\text{/d]}}{0.5} \tag{11.2}$$

Total volume of treated water
The total volume of treated water is automatically calculated when the future demand-supply gap, the non-revenue water percentage and the coverage of the gap are known.

$$\text{Total volume of treated water [m}^3\text{/year]} = \frac{DS_{gap,future} \cdot Cov \cdot 365}{1 - NR} \tag{11.3}$$

$DS_{gap,future}$ = Future demand-supply gap [m^3/d]
Cov = Coverage of gap [%]
NR = Non-revenue water [%]

11.1.2. Investment costs: Costs preparation

Before the construction of the project starts, an assessment study needs to take place. In case this has not been done yet for the area, this forms costs which are part of the investment costs. An assessment study for groundwater is around 70,000,000 [UGX] and for surface water is around 126,000,000 [UGX] (Gauff Consultants, 2017).

11.1.3. Investment costs: Network costs

The network costs consists of the generator costs in case that is needed and the costs of the groundwater or surface water network, or a combination of both. Each part of the water network has a certain length and a specific type of pipeline. For surface water the network is described as follows: from the water source to the water treatment plant, then the water is pumped to the reservoir, after that the water flows to the distribution net and eventually from the distribution net to the customer. For groundwater the water system is comparable, but the water is brought from the source to the pump station where the water treatment could take place as well. By measuring the distance in Google Earth or QGIS the length of each part can be known. Define the height difference between the source and the reservoir using for Google Earth Pro. The investment of both the amount and size of the booster and transport pumps are taken into account in this section as well.

The pipeline types that can be chosen depend on the location in the system, which has been discussed with the contractor 'Vidas Engineering Services'. An overview of the costs of the different pipeline types and sizes is shown in Table G.1 in Appendix G.

11.1.4. Investment costs: Facilities

Purchase of land
To estimate the area of land that needs to be bought to build the reservoirs and in some cases the borehole stations or water treatment plant, the formula below is programmed. The average area that is necessary for a borehole station or reservoir of 200 [m^3] is 100*100 [ft^2] according to (VEI Dutch Water Operator, 2022). This area corresponds to a price of 100*100 [ft^2] and is 30,000,000 [UGX] (VEI Dutch Water Operator, 2022). The area for the water treatment plant is based on the total volume of treated water per day ($V_{treated}$) with an average height of the treatment plant of 2 [m].

$$\text{Estimation land needed [ft*ft]} = BH \cdot 10,000 + \frac{V_{treated} \cdot 0.4 \cdot 10,000}{365 \cdot 200}(+\frac{V_{treated} \cdot 10.76}{365 \cdot 2}) \tag{11.4}$$

BH = Number of boreholes needed
$V_{treated}$ = Volume of treated water [m^3/year]

Construction reservoirs
The volume of the reservoir is calculated using 25% of the daily demand, taking into account a peak factor of 1.5 for a maximum day.

Reservoir
The following formula is used to calculate the volume of the reservoir:

$$\text{Reservoir capacity [m}^3\text{]} = Q_{day} \cdot PF \cdot 0.25 \tag{11.5}$$

Q_{day} = daily water demand [m^3]
PF = Peak Factor of 1.5

Other water source related facilities
Other facility costs are the costs of the grid power extension which is around 50 [UGX/m] (VEI Dutch Water Operator, 2022). The source of this power is hydro power and a power grid is required for a water treatment plant, only a borehole station could use solar power instead. The costs to construct a water treatment plant is based on feasibility studies of Hoima and Bugadde and are calculated converted to UGX per m^3. In case only an extension of a water treatment plant is necessary, only the costs of a sedimentation tank, rapid sand filter, clear water tank and a pump are taken into account. The construction costs per borehole consist of the following elements, all based on the cost estimate of (VEI Dutch Water Operator, 2022): Drilling and testing of borehole, construction of borehole, monitoring equipment and a chlorine dosing unit.

11.1.5. Operational costs

Labour costs
According to Vidas Engineering Services there are always at least 1 chief technician and 3 plumbers necessary when a water network is created. In case of a water treatment plant, there are also 2 security guards, 2 plant attendants, 1 chief technician, 2 plumbers and 2 pump attendants needed. At each borehole station, 1 pump attendant and 1 security guard are necessary. The salaries of these jobs are based on the feasibility study of Hoima (Gauff Consultants, 2017).

Energy costs
The amount of energy that is used can be roughly calculated using the Equation 11.6 and 11.7. After that the energy is multiplied by the price per kWh, which is estimated to be 583 UGX.

$$P = \frac{Q \cdot H \cdot \rho \cdot g}{\mu} \tag{11.6}$$

$$E = \frac{P \cdot t}{1,000} \tag{11.7}$$

Q: Transported water [m^3/s]
H: Height difference water intake and reservoir [m]
ρ : Density [kg/m^3]
g: 9.81 [m/s^2]
μ: Efficiency [$-$]
P: Power [W]
t: Time [h]
E: Energy [kWh]

To estimate the length of the extension of the power supply network, the website of Energy GIS working group, 2022 can be used. A map of Uganda of the current power supply network is presented in Appendix F

Water treatment costs
For the treatment of the water, chlorine and aluminium sulfate will be dosed. These costs are based on the volume of treated water and correspond with the feasibility study of Hoima (Gauff Consultants, 2017) and are verified by Vidas Engineering Services.

Pumps
For the pumps, two types of pumps can be chosen: booster pumps and transport pumps. The costs are roughly estimated and can have a small, medium and big size.

Maintenance
The maintenance costs consist of depreciation expenses of the civil works, of the reservoir (usually higher than other civil works), of the electrical components and of the mechanical components. The rates are respectively 1%, 2%, 5% and 5% based on the feasibility study of Hoima (Gauff Consultants, 2017) and are verified by Vidas Engineering Services.

11.1.6. Funding

In Uganda, water projects are usually initiated by the Government of Uganda, Ministry of Water and Environment. To finance the project, an investor should be found, which is usually a bank like the African Development Bank Group or the World Bank. These institutions can either give a grant or a loan and it is usually a combination of both. For the financial analysis it is recommended to fill out **the amount of grant** that is received for the specific alternative in case this is known. It is important to know the values and goals of the institution in order to receive funding, this is explained in the Stakeholder Analysis. There are also e.g. grants from the Energy Africa Compact program which requires the use of solar power at boreholes.

11.1.7. Calculations

The following costs and indicators are calculated:

- Total investment costs
- Total operational costs [UGX/year]
- Total costs during lifespan
- Total costs per connection per 40 years
  - This is an interesting indicator according to VEI
- Total grant
- Revenue per year
  - This is based on 3,500 UGX per m^3 and 0.5 m^3 per connection according to VEI (this is an average for all connections: domestic, commercial etc.). The total grant is divided over the lifespan of the project in years.
- Profit ratio
  - The profit ratio is calculated as the difference between the revenues and the operational costs divided by the revenues.
  - Water projects are usually initiated by the Ministry of Water and Environment, this means the investment costs are usually paid by funding or via the Government of Uganda. The National Water & Sewerage Corporation (NWSC) takes care of the operation of the system, so NWSC would like to balance out the operational costs with its water revenues from the connections.
- Total loan
  - This is the difference between the total costs (investment and operational costs over lifespan) minus the grants.
- Payback time

- Payback time is the total investment costs divided by the difference in revenues from the water connections and operational costs.
- The payback time is a debatable topic between the Ministry of Water and Environment (MWE) and the National Water & Sewerage Corporation (NWSC). Usually there is no such thing as 'paying back the investment', because the investment is done by the MWE, and NWSC only deals with the operation of the network.

11.2. Performance analysis

Different design alternatives can easily be compared based on a performance analysis. This performance analysis rates the alternatives on a scale of 1 to 10, considering four main categories: sustainability, durability, society and feasibility. Rating the criteria goes according to the user manual in Appendix F, which contain the descriptions of every score for each criterion. The four main categories and their criteria are explained in this paragraph.

11.2.1. Sustainability

Sustainability refers to the quality of causing little or no damage to the environment (Cambridge University Press, 2022). The sub criteria that support this category are environmental damage, pollution, waste production, materials, energy usage and operational efficiency.

Environmental damage can be due to soil erosion and the impact of the system on flora and fauna. This criterion is therefore separated into two sub-criteria, which are soil erosion and impact on flora and fauna. Inappropriate construction practices and soil protection measures may induce or accelerate soil erosion with possible pollution and siltation of downstream water sources (Ministry of Water and Environment, 2014). Next to that, removal of top soil may lead to loss of soil fertility (Ministry of Water and Environment, 2014). Also, the (negative) impact on flora and fauna can be considered a kind of environmental damage. This could be for example the loss of wetland plants and associated fauna, or cleared vegetation which may compromise aesthetic value of the sites (Ministry of Water and Environment, 2014). These impacts can for example be caused by constructing a pipe in the ground, drilling a borehole or constructing a new water treatment plant.

Several types of pollution are taken into account in this case: air pollution, soil contamination, water pollution and noise pollution. Air pollution means emissions of air pollutants. Soil contamination and water pollution occur by pollutants entering the soil and the water source. This can for example be caused by processing the waste of treatment incorrectly. Noise pollution occurs when noise, produced by the system, causes negative impacts to humans or animals. Determining the pollution goes for during construction as well as during the lifespan.

The waste production criterion considers the amount of waste produced during construction as well as during the lifespan of the system. Waste can for example be produced by clearing the area to build a new water treatment plant or reservoir or by treating very polluted water.

The sustainability of the materials used by construction of the system influences the overall sustainability. The impact of the materials on sustainability can be influenced by the amount of material used (large quantities have a higher sustainable impact than small quantities) as well as the kind of material that is used. Besides, the transport distance of the materials also has to be taken into account. Using local materials has a lower negative impact on sustainability than using materials that have to travel a long distance. The environmental impact of the materials can for example be determined by an Environmental Cost Indicator (ECI).

The energy usage is divided into energy usage during construction and during lifespan. During construction the existing power grid will be used, so for this criterion only the amount of energy influences the sustainability. During the lifespan of the system, the type of energy as well as the amount of energy that is used for the system influences the sustainability. To determine the score of this criterion, first the type of energy during the lifespan has to be determined. A distinction is made between renewable energy usage, non-renewable energy usage and a combination of renewable and non-renewable energy usage. After selecting the type of energy use, a score can be assigned, which covers the amount of energy use. One should be aware that the scores differ per type of energy, so the right type of energy has to be selected before assigning a score.

The operational efficiency considers the amount of water losses in the (piping) systems during its lifetime.

11.2.2. Durability

Durability of a system refers to the quality of being able to last a long time without becoming damaged (Cambridge University Press, 2022). The sub criteria that support this category are the following: expected lifespan water source, expected lifespan system, options for extension and maintenance accessibility.

The expected lifespan of the water source considers the expected time until the water source is depleted. This influences the durability of the whole system, as no water can be produced by the system when the water source is depleted.

The expected lifespan of the system considers the time until the system has to be replaced by a new system. According to the Ministry of Water and Environment, most water supply systems in Uganda are designed for a lifespan of 20 years. However, the bigger the life span, the lower the relative investments costs. Therefore the system is rated for this criterion with a score of 6 when the lifespan is equal to 20 years and the rating is higher for bigger lifespans. The system scores a 10 for a lifespan of 25 years and longer. Table F.1 in Appendix F contains the economic life of different parts of a system. This could be used to determine the estimated lifetime of a system.

The possibility of extending the system increases the durability of the system. The system could be needing an extension when the water demand is increasing with a higher rate than expected or when another area nearby has to be served.

The maintenance accessibility rates the system regarding the access to technology for maintaining the system. A high possibility to maintain the system increases the durability.

11.2.3. Society

This category covers the impact the system has on the society. The sub criteria that support this category are the following: stakeholder participation, health, job opportunities quality of living environment, illegal usage, ability to serve outside scope.

Stakeholder participation is very important in the decision-making process. Not every stakeholder has the same interest in the project. Therefore, when comparing the alternatives, the probability for cooperation of different stakeholders should be considered. Using a water source that is relatively far away from the project area, could result in a low stakeholder participation, due to the interests of multiple districts for example. Besides this, using a water source that is already known to be effective and is already familiar by people, will most likely result in a higher stakeholder participation.

The health criterion considers the health impact on the people by drinking the water. Direct use of untreated or poorly water may result in severe health issues. The way of treating the water therefore influences the water quality. Besides, more people using the water increases the risk of diseases. Besides this, other health issues can occur as well. For example, pools of stagnant water may form in pits, holes and excavated ditches and create suitable habitats for disease vectors such as malaria. Another main issue can be the potential of HIV spread as well as poor hygiene in workers camps.

By creating or extending a water supply system, new job opportunities are created. These jobs can be either on site or in the case area. Therefore, this criterion can be divided into two sub-criteria. The first sub-criterion covers the job opportunities created by the implementation of the new system. Examples of new jobs are work on site, for example at boreholes or at the water treatment plant, or the construction of the pipes. The second sub-criterion covers the job opportunities created in the project area. If the project area is highly supplied by water, this might result in economic growth and area development. The place might become more attractive to live and work.

Quality of the living environment can also be seen as the impact of the realization of the water supply system on the environment where people are living. For example, building a treatment plant where houses are located, would have a negative impact on the living environment. The quality is determined by a number of things. For example, disruption of social order, which is about the influx of people in the area which may affect the local economy, cause alteration of culture and introduce behavioral changes.

Illegal usage can be scored as the probability that illegal usage will occur, such as tapping water from a borehole when not paying for it.

Focusing on the long term, a water supply system could be designed which has a higher capacity than the water demand it should be designed for. In this case, areas outside the project scope could also be supplied with water.

11.2.4. Feasibility

The last category of the performance covers the feasibility of the project and the feasibility to serve everyone in the project area with water. The sub criteria that support this category are the following: demand-supply gap, time frame, operational costs vs. revenue and total connection costs.

The feasibility to serve everyone in the project area with water is influenced by the size of the remaining gap between the demand and the supply. This criterion can be rated using the coverage percentage in the last tab of the tool. A high coverage, means a small gap, which subsequently means a high score and vice versa.

The time frame criterion considers the time until full capacity of the water supply system is used from now on. According to Ministry of Water and Environment, 2014 it is generally accepted that the optimum period of a project is between 5 and 10 years and should rarely exceed 20 years. Besides, systems designed for the long term, are designed to serve water in 25 years. Therefore, it is desired that the system reaches its full capacity a lot earlier than these 25 years. The time frame scores medium, when it takes 10 to 15 years until the system can be used on full capacity.

Operational costs vs. revenue considers the difference between the operational costs and the revenue per connection. The system is low rated when it is unprofitable and high rated when it is profitable. The ratio between the operational costs and the revenue can be found in the finance tab of the tool.

The last criterion of the feasibility is the connection investment costs. These are the investment costs per connection in the system. The connection investment costs are determined in the finance tab of the tool.

11.3. Risk analysis

The risks are evaluated by giving a probability that a certain unwanted event will happen and by trying to estimate the impact of the unwanted event. A risk can be calculated according to equation 11.8. In the MCA manual presented in Appendix F, some examples are elaborated in order to give a estimate for the probability and the impact of a certain event.

$$R = P \cdot I \tag{11.8}$$

With:

- R = risk [-]
- P = probability [-]
- I = impact [-]

It can be hard to estimate or score the probability and impact of a certain risk, especially without prior detailed research. Therefore, the probability and impact are classified in this tool. The probability and impact classes are ranked from 1 to 5. In this case, a very low probability or impact is scored with 1. A very high probability or impact is scored with 5. With the knowledge that a risk is calculated by the product of the probability and impact, the lowest possible risk can be scored with 1 and the highest possible risk can be scored with 25. The risks are then also classified. Scores between 1 and 5 are classified as a very low risk (risk class 1). Scores between 20 and 25 are classified as a very high risk (risk class 5), etc. If an alternative has a score in risk class 5, it should be rejected instantly.

When considering the risks of the alternatives of a water supply system, the impact can be expressed as damage in terms of money, human lives, environment or dissatisfaction. However, in this tool, no distinction has been made between these different types of impact, since it is still a rough estimate.

The risks are subdivided into six main categories. A certain importance can be given to the different categories. Therefore, a weight factor is assigned to each of the categories and the sum of these weight factors should add up to 100 in total. The six main categories are listed below.

- Economics
- Politics
- Society
- Organization
- Technology
- Environment

The different categories are explained and elaborated in the next paragraphs.

11.3.1. Economics

The first category that is considered is 'economics'. The economic risks are very important in making a decision for a certain alternative, and the higher the risk is on this aspect, the less probable that this will be recommended as an alternative.

Due to bad maintenance, vandalism, price fluctuations or a poor quality of the materials (causing for example pump failure or leakages in the pipes), the chance exists that costs of the project turn out higher than expected. The effect is that the project will turn out too expensive and the project might not be executed.

Due to contamination (diseases) of the water source, there is a probability that treatment costs will be higher than expected. The contamination can be caused by for example the discharge of a nearby factory, the disposal of faecal matter or agricultural activities. The impact of a contamination is for example higher in a small stream or borehole in the village, than in a big lake or sea.

11.3.2. Politics

Secondly, the political risks are considered. There are two risks considered, the change in plans and the risk of not getting a grant for the land. These two risks could have an effect on the progress and might even cause failure of the completion of the project.

Due to political issues it is possible that plans will change during the implementation phase, which will slow down the project and could lead to complications in the execution of proposed plans.

Another issue that can be a risk is that due to political or societal reasons, it is not possible to get permission to buy the required land for the treatment plant or borehole that needs to be constructed on a certain location. The effect of this risk is that this will slow down the project or might even stand in the way of the completion of the project. For example: if the land, on which for example a treatment plant has to be build, is family property or is owned by the army, it might be hard to buy the land (too costly or it takes too much time to get permission).

11.3.3. Society

The risks in the category 'Society' might be one of the most difficult risks to estimate. The behaviour of the people is something that cannot be exactly predicted and differs in every situation, which makes it an important factor to consider in a risk analysis. In the following paragraphs the four main risks in this category are discussed.

There might be a situation that people are not interested in being connected to the system, because they already have their own source or they do not see the importance of safe and clean drinking water. Or in some cases, people simply cannot afford it to pay for their water. Therefore, there is a possibility that people are unwilling to pay for their water (payment 'loyalty'). The result of this is a lower revenue and that means the pay-back time is longer than expected. The impact is higher in the case of a supply system with higher investment costs.

Due to a challenging construction phase to execute the project, there is a probability that the workers are exposed to unsafe working conditions. This can be the exposure of workers to occupational safety hazards from activities such as excavations, working with heavy equipment, working under noisy conditions, working in confined spaces, lifting of heavy objects, storage and handling and use of hazardous substances and wastes. For example, building a pipeline that needs to bridge a large height difference, might endanger the safety of the workers more. This risk can be minimized if there will be surveillance, but it is even better to pick a less risky alternative in terms of working conditions.

Thirdly, if the water demand is not met, this could lead to the risk of inter-generational inequity. The effect of this will be that there could develop mutual tensions among the people demanding for the water.

Lastly, because of a rapid economic development or a war in a neighbouring country, the probability for a sudden population surge is increased. This has as an effect that the water demand is much higher than was accounted for. This means the future supply estimation will be an underestimation and there will not be enough water for all the people.

11.3.4. Organization

Depending on which water source is used, there are several risks that should be taken into account from an organizational point of view.

First of all, if there is limited availability of the water source, there is a higher probability that the water supply is unreliable and discontinuous. There can be periods with little water availability or no water at all. The impact of this risk is high since it is very important to provide the customers with water every day of the year. For example, the risk is lower if the water is extracted from a big lake than when it is pumped from the groundwater or extracted from a river with a fluctuating water level.

There is a higher probability that people will illegally tap water from the system, if the water supply system is not well protected. This will have as an effect that the system will be damaged and there will be high water losses.

If there is no importance given on monitoring the water level of the source or when there is no money provided for people to fulfil these jobs, there is a risk of the insufficient monitoring the source. The effect could be that the supply in the future is not guaranteed. In some cases, (for example a lake with a quite constant water level,) monitoring is not very important, which means a low impact for this risk.

11.3.5. Technology

The risks in the category ’technology’ are important and can be minimized if extensive research is done. The technical risks are mainly at the point of extraction.

There is a probability that the system or construction will fail, due to bad maintenance, vandalism or poor material quality. As an effect, for example, pumps can break down and water cannot be provided to the consumers.

If groundwater is used as a source, there is a higher probability of the water containing iron bacteria, resulting in clogging of boreholes (decreased water supply) and a poor water quality.

Other supply risks could be more groundwater or surface water related. For example, in the case of using groundwater as a water source, there could be a risk of borehole complications. Borehole complications include finding (small) water pockets, empty boreholes, difficulties with drilling, decreasing yields, high salinity close to lake and more. The effect is that the water supply is lower than expected.

In the case of using surface water as a water source, there is a probability of surface water complications. These include clogged intake due to for example noxious water hyacinth, problems in transport of water, temperature fluctuations and more.

11.3.6. Environment

Building a water supply system also has environmental risks. There are five risks that are considered for evaluating the risks of the alternatives from an environmental point of view.

If a treatment plant or borehole is constructed at a location near a place where floodings occur, the probability of floodings is higher. The effect of this is damage to or destruction of the system.

All over the world the climate is changing, so there is a probability that climate change will affect the water supply. Climate change is something that is happening, so it's a fact. Though it depends on the alternative (and water source) whether it forms a risk. For example, climate change can cause a source to dry up or to influence the amount of rainfall. The effect will be less water that is available meaning a limited water supply.

If a treatment or reservoir is built on top of a hill, the risk of landslides is higher than in case the constructions are built in a flat area. This is because landslides occur when slopes become unstable. Depending on the location, the probability of landslides can be higher, having damage or complete destruction of the built constructions as an effect.

In case groundwater is used as a source, unfavourable geotechnical conditions can be a risk. The result could be a very low yield or no yield at all. If the supply of the source is much smaller than expected, the water demand cannot be fulfilled.

There is a probability that seasonality influences the water supply of the source that is used, since there might be (dry) periods in which the water level is lower. This could be a problem for example in rivers. As an effect, in these periods, the water supply could be lower.

11.4. Tool

In the end, the tool gives a combined result of the three different analyses, for each of the alternatives. Based on these results, a fair selection of the alternatives can be made. Some extra considerations can be added to make a final decision, such as the costs/connection per 40 years, the payback time and the estimated gap coverage. An example of the MCA results of a fictitious case are presented in Table 11.1.

Table 11.1: Example of MCA results (fictitious case)

Category	**Alternative 1**	**Alternative 2**	**Alternative 3**
Costs [UGX]	350.000.000.000,00	800.000.000.000,00	550.000.000.000,00
Costs/connection per 40 years [UGX]	20.000.000,00	15.000.000,00	18.000.000,00
Performance	6.6	7.0	7.2
Payback time [years]	10	30	20
Risk	RISK CLASS 2	RISK CLASS 3	RISK CLASS 3
Estimated gap coverage [%]	30	100	75

As can be seen in Table 11.1, alternative 1 is the least expensive alternative and has the lowest risk compared to alternatives 2 and 3, but it only covers 30% of the gap between demand and treated water supply ('demand-supply gap'). Although alternative 2 is most expensive, it does cover 100% of the 'demand-supply gap', it scores a 7 on performance and has a medium risk. Alternative 3 covers 75% of the 'demand-supply gap', but is less expensive than alternative 2 and scores the highest on performance. Also, the payback time is lower than for alternative 2. Depending on the considerations of the stakeholders, a selection of the alternatives can be made. Most likely, alternative 2 or 3 would have the preference.

12

MCA: Hoima City

The developed multi-criteria analysis (MCA) tool is applied to the treated water supply alternatives in Hoima City. Five alternatives are considered and evaluated. There are three surface water alternatives: Lake Albert, Masindi Port and Kafu river. The two remaining alternatives are groundwater alternatives, one with 40% demand coverage and one with 80% demand coverage. The alternatives are all designed for a long-term solution.

12.1. Financial analysis

The current distribution network has a length of 450,580 meters. This current network exists of 6,900 connections. The connections are mainly located around the city center of Hoima, and on average it can be stated that one connection needs (at least) an additional 65 meters. The lifetime of the project is 25 years since it is desired to fill the demand-supply gap within this period. To be conservative, the future water demand in combination with the current treated water supply is considered. Therefore, the 'extra' daily water demand is 17,400 m^3/d, which is the future gap between water demand and treated water supply. For Hoima a value of 34,800 extra future connections is estimated based on the baseline study, considering 100% demand coverage and an average water demand of 500 L per day per connection. However, these values can vary for different situations. An overview with the input for the different alternatives is shown in Table D.4 in appendix D.

12.1.1. Lake Albert

For this alternative, a new and separate system is built from the currently existing system. It is assumed that 100% of the gap between the treated water supply and demand can be filled in the future. Therefore, the estimated number of new connections is 34,800. The estimated non-revenue water is 25%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from Lake Albert and transported to the Kijwenge reservoir. This reservoir in Hoima City is closest to Lake Albert. The elevation of Lake Albert is +616 m, whereas the elevation of the Kijwenge reservoir is +1190 m. This means the water has to be transported over a height difference of 574 meters. The total distance from Lake Albert to the reservoir is 17.5 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 2,262 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 2 large booster pumps and 3 medium transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 691,000,000,000.

12.1.2. Masindi Port

For this alternative, a pipeline is constructed from Masindi Port to Hoima City. In other words, this alternative is an extension of the water supply system in Masindi Port. It is assumed that 70% of the demand gap between the treated water supply and demand can be filled in the future. Therefore, the estimated number of new connections is 24,360. Due to the long pipeline distance needed, the estimated non-revenue water is 30%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from the water treatment plant in Masindi Port and transported to the Bakumira reservoir. This reservoir in Hoima City is closest to Masindi Port. The elevation of Masindi Port is +1,036 m, whereas the elevation of the Bakumira reservoir is +1,295 m. This means the water has to be transported over a height difference of 259 meters. The total distance from Masindi Port to the reservoir is 84.2 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 1,131 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 2 large booster pumps and 6 large transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 426,000,000,000.

12.1.3. Kafu river

For this alternative, a new and separate system is built from the currently existing system. In the feasibility study (Gauff Consultants, 2017) it has been concluded that over 40,000 m^3/d can be extracted from Kafu river. Therefore, it can be assumed that 100% of the demand gap between the supply and demand can be filled in the future. The estimated number of new connections is thus 38,400. The estimated non-revenue water is 20%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from Kafu river and transported to the Mpaija reservoir. This reservoir in Hoima City is closest to Kafu river. The elevation of Kafu river is +1,060 m, whereas the elevation of the Mpaija reservoir is +1,227 m. This means the water has to be transported over a height difference of 167 meters. The total distance from Kafu river to the reservoir is 18.2 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 2,262 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 2 large booster pumps and 2 medium transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 466,000,000,000.

12.1.4. Groundwater 40%

In this alternative, the existing current water supply is extended. It is assumed that 40% of the gap can be filled with groundwater. Therefore, the estimated number of new connections is 13,920. For this alternative, 10 new boreholes have to be drilled or installed with an average yield of at least 30 m^3/h. To achieve a demand coverage of 40%, next to these 10 new boreholes, the operational performance of the current treated water supply needs to be improved and the non-revenue water should be minimized to a maximum of 20%.

The distance between the constructed new boreholes and the existing treatment plant is estimated to be on average 5 kilometers for each borehole. This means 50 kilometers of pipeline have to be constructed. The suggested pipeline type is uPVC-OD90 PN16. There are already connections between the treatment and the reservoirs, but since there is more water now that has to be transported, it is estimated that the distance between the treatment plant and the reservoir is 3.0 km. This number is multiplied by 3 (for three reservoirs) in order to get the total length of pipeline that is needed. The suggested pipeline type is uPVC-OD315 PN16. The total estimated height difference is 200 meters. The distance to the power grid is estimated to be approximately 1,000 meters for every borehole, so about 16 kilometers in total, since the power grid is closer to the boreholes than the treatment plant is. The distribution network needs to be extended with 905 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD90 PN6. Furthermore, it is assumed that 2 medium booster pumps and 2 medium transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 190,000,000,000.

12.1.5. Groundwater 80%

In this alternative, the existing current treated water supply is extended. It is assumed that 80% of the gap can be filled with groundwater. Therefore, the estimated number of new connections is 27,840. For this alternative, 25 new boreholes have to be drilled or installed with an average yield of at least 30 m^3/h. To achieve a demand coverage of 80%, next to these 25 new boreholes, the operational performance of the current treated water supply needs to be improved and the non-revenue water should be minimized to a maximum of 20%.

The distance between the constructed new boreholes and the existing treatment plant is estimated to be on average 5 kilometers for each borehole. This means 125 kilometers of pipeline have to be constructed. The suggested pipeline type is uPVC-OD90 PN16. There are already connections between the treatment and the reservoirs, but since there is more water now that has to be transported, it is estimated that the distance between the treatment plant and the reservoir is 3.0 km. This number is multiplied by 3 (for three reservoirs) in order to get the total length of pipeline that is needed. The suggested pipeline type is uPVC-OD315 PN16. The total estimated height difference is 200 meters. The distance to the power grid is estimated to be approximately 1,000 meters for every borehole, so about 36 kilometers in total, since the power grid is closer to the boreholes than the treatment plant is. The distribution network needs to be extended with 1,810 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD90 PN6. Furthermore, it is assumed that 2 medium booster pumps and 4 medium transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 369,000,000,000.

12.2. Performance analysis

The different design alternatives for Hoima City can easily be compared based on a performance analysis. This performance analysis rates the alternatives on a scale of 1 to 10, considering four main categories: sustainability, durability, society and feasibility. Rating the criteria has been done according to Tables F.1, F.2, F.3 and F.4 in Appendix F, which contains the descriptions for the score of each criterion.

For the five alternatives, the scores for all criteria of the performance analysis are presented in Table 12.1. Both sustainability and society have a weight factor of 20. Durability and feasibility are considered more important and thus both have a weight factor of 30. As can be seen from the results, Lake Albert and Groundwater (80%) have the highest performance scores. Masindi Port has the lowest performance score.

Table 12.1: Performance scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
20	**Sustainability**	5.7	5.2	5.8	7.6	7.6
30	**Durability**	7.2	6.8	5.8	5.4	5.4
20	**Society**	7.2	6	5.3	4.5	5.6
30	**Feasibility**	6.6	6.2	8.2	7.1	8
100	**TOTAL**	**6.7**	**6.1**	**6.4**	**6.2**	**6.7**

As can be seen in Table 12.1, the groundwater alternatives score best on sustainability. This is mainly because boreholes do not require as much land, materials and energy as the surface water alternatives. The water losses are also expected to be lower, since the transmission network is less extensive. Masindi Port has the lowest score, because this alternative requires a large extension (and therefore has a huge impact on flora and fauna), a lot of materials and energy. Also, the water losses are expected to be high. A more detailed overview of the sustainability scores is presented in Table D.5 in Appendix D. Here, for the five different alternatives, the scores for all sub-criteria of sustainability are presented. The weight factors are also indicated. The sub-criterion 'water losses' has the highest weight factor, followed by 'materials' and 'renewable energy usage'. The remaining sub-criteria are weighted equally important.

Considering the results on durability in Table 12.1, Lake Albert has the best score. Since the lake is so big, it is unlikely that the water source will be depleted. Therefore, the expected lifespan of the water source is high. If sustainable materials are used, the system can also last long. The groundwater alternatives score worst on durability. This is mainly because the lifespan of the source is uncertain. The source can be depleted within a very short amount of time, if the aquifer doesn't refill. There is a high risk of water pockets, but unfortunately they cannot be detected so easily in advance. A more detailed overview of the durability scores is presented in Table D.6 in Appendix D. Here, for the five different alternatives, the scores for all sub-criteria of durability are presented. The weight factors are also indicated. The sub-criterion 'expected lifespan water source' has the highest weight factor, followed by 'expected lifespan system'. The remaining sub-criteria are weighted equally important.

Next to sustainability and durability, Table 12.1 also shows the scores on society for each of the five alternatives. As can be seen in the table, Lake Albert scores best on society. Since this alternative is expected to cover 100% of the demand gap, it is expected that this alternative will have a positive impact on the health of the people, when they are provided with clean drinking water. Lake Albert is also partly in Hoima district, so it is expected that there is a good ability to serve outside the scope. Next to that, since the network will be so extended, many job opportunities will be created, related to the water supply system as well as in the area of Hoima City. The groundwater (40%) alternative has the lowest score on society. Since only 40% of the demand gap is filled, this will not really positively or negatively affect the overall health of people. Only little job opportunities are created and there is a high probability of illegal usage, since it is easy to tap water from the boreholes. There is no ability to serve outside the scope, because the water demand is not even halfway met. A more detailed overview of the society scores is presented in Table D.7 in Appendix D. Here, for the five different alternatives, the scores for all sub-criteria of society are presented. The weight factors are also indicated. The sub-criterion 'health' has the highest weight factor, followed by 'stakeholder participation' and 'quality of living environment'. The sub-criteria on job opportunities have the lowest weight factor.

The last criterion considered for the performance analysis is feasibility. As shown in Table 12.1, Kafu river scores best on feasibility, followed closely by the 80% groundwater alternative. The 'demand-supply gap' is fully closed in the alternative of Kafu river and the alternative is profitable. However, it is expected that it will take quite long to build this water supply system, since Kafu river is also close to another district which has priority over the water from this river. The groundwater alternative meets the 'demand-supply gap' for 80% and it is expected that this supply system can be built between 4 to 8 years. Next to that, the alternative is slightly profitable. The Masindi Port alternative scores lowest on feasibility. This is mainly due to the expected time frame. Also, the connection investment costs are higher compared to Kafu river and the groundwater alternatives. A more detailed overview of the feasibility scores is presented in Table D.8 in Appendix D. Here, for the five different alternatives, the scores for all sub-criteria of feasibility are presented. The weight factors are also indicated. The sub-criterion 'demand-supply gap', which is the gap between the water demand and treated water supply, has the highest weight factor, followed by 'time frame' and 'operational costs vs. revenue'. The sub-criterion on connection investment costs has the lowest weight factor.

12.3. Risk analysis

The risks for the five different alternatives are evaluated in the risk analysis. The main result is presented in Table 12.2, whereas a more detailed overview is shown in Table D.9 in Appendix D. All the risks are specified in detail in the manual in Appendix F. In the manual the causes and consequences of the risks are described. In this section, the main risks of the five alternatives are discussed.

For Lake Albert, the main risks are unsafe working conditions, sudden population surge, system failure, flooding and land slides. For Masindi port, the main risks are high treatment costs, change of plans, unsafe working conditions, sudden population surge, unreliable and discontinuous water supply, illegal water tapping, system failure and surface water complications, floodings and seasonality. For Kafu river, the main risks are high treatment costs, change of plans, no grant for land, sudden population surge, Unreliable and discontinuous water supply, illegal water tapping, insufficient monitoring, system failure, iron bacteria and surface water complications, floodings, climate change affecting the source and seasonality. Lastly, for groundwater, as well for the 40% as for the 80% alternative, the main risks are no grant for land, sudden population surge, unreliable and discontinuous water supply, illegal water tapping, insufficient monitoring, iron bacteria, borehole complications and unfavorable geotechnical conditions.

The alternative with the highest risks is Kafu river, and will be categorized to be RISK CLASS 4. Masindi port and the groundwater alternatives are in the medium risk class, RISK CLASS 3. Lake Albert is estimated to have the lowest risks and will be classified in RISK CLASS 2.

Table 12.2: Risk scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater (40%)	Groundwater (80%)
10	ECONOMICS	12	13.5	16	6	6.5
10	POLITICS	8.5	15	20	10	12
25	SOCIETY	11.25	12.75	9.25	12	10.75
20	ORGANIZATION	9.3	13.7	20	18.3	21.7
20	TECHNOLOGY	7.25	8.5	14	12.75	12.75
15	ENVIRONMENT	11.2	12.2	15.8	9.8	9.8
100	**TOTAL**	**9.9**	**12.3**	**15.1**	**12.3**	**12.9**

12.4. Results

Table 12.3 shows the total results of the multi-criteria analysis. The performance of both the Lake Albert alternative and the 80% groundwater alternative score relatively high compared to the other alternatives. However, the other alternatives have a performance score of 6 or higher, so these solutions are still optional. As the Kafu River alternative is classified in Risk Class 4, it has a high risk, which is mainly due to the unreliability of the water supply, the surface water complications and seasonality affecting the water supply, as discussed before. The Lake Albert alternative is classified with Risk Class 2, which means that the risk is low. The other alternatives have a medium risk. The estimated gap coverage is also an important aspect when comparing the different alternatives. Both the Lake Albert and the Kafu River alternatives have an estimated gap coverage of 100%, while the Masindi Port alternative only has a 70% coverage. Logically, the groundwater alternatives have a 40% and 80% coverage.

The costs are the approximated total costs of the project, so including both the investment costs and operational costs. The costs per connection also include both the investment and operational costs for 40 years divided by the number of connections. Comparing the results shows that the costs of the Lake Albert alternative are quite a bit higher than the other alternatives and that the total costs of the 40% groundwater alternative are relatively low. The costs per connection of the Lake Albert alternative are quite high, while those of the Kafu River alternative are relatively low. Looking at the profit ratio, which is the ratio between the profit and the revenue, the alternatives score quite similar, except for the Lake Albert alternative, which has a very low profit ratio.

Table 12.3: Results alternatives Hoima City

Category	Lake Albert	Masindi Port	Kafu River	Groundwater (40%)	Groundwater (80%)
Costs [UGX]	691,000,000,000	426,000,000,000	466,000,000,000	190,000,000,000	369,000,000,000
Costs/connection (40 years) [UGX]	29,000,000	25,000,000	19,000,000	22,000,000	22,000,000
Performance	6.7	6.1	6.4	6.2	6.7
Profit ratio	0.01	0.22	0.40	0.34	0.35
Risk	RISK CLASS 2	RISK CLASS 3	RISK CLASS 4	RISK CLASS 3	RISK CLASS 3
Estimated gap coverage [%]	100	70	100	40	80

12.5. Alternative selection

After using the multi-criteria analysis to assign scores to every alternative, a conclusion can be drawn from the scores to determine which alternative is or which alternatives are most suitable. Taking the discussion of all results in consideration, the most favorable options to extend the drinking water supply system in Hoima City for the long term are the Lake Albert alternative and the 80% groundwater alternative. The estimated gap coverage of the Lake Albert alternative is 100%, the performance of this alternative scores relatively high and it is also classified with a low risk. It has to be noted however, that the investment costs as well as the operational costs are high, which also results in a low profit ratio. If the financial aspects are very important, the groundwater alternative with 80% coverage is a good option, as this covers most of the gap, has a relatively high performance score and is much cheaper than the Lake Albert alternative. However, it has a medium risk, which is something to keep in mind by choosing this alternative.

The Kafu River alternative has a 100% estimated gap coverage, but has very high risks as discussed in the previous section and is therefore considered as an undesirable option. The Masindi Port has the lowest performance score, while only having an estimated gap coverage of 70% and a medium risk. Therefore this alternative is also not considered as a most favorable option. Finally, the groundwater alternative with 40% coverage is also not the most favorable long-term option. This is a cheap solution, but has a small coverage of the gap and scores relatively low on its performance.

13

MCA: Bugiri District

The developed multi-criteria analysis (MCA) tool is applied to the treated water supply alternatives in Bugiri District. Four alternatives are considered and evaluated. All of them are surface water alternatives: Jinja (Masese), Bugadde, Wakawaka and Majanji. The alternatives are all designed as a long-term solution.

13.1. Financial analysis

The current distribution network has a length of 50,017 meters. This current network exists of 1,755 connections. This means an average length of about 28.5 meter per connection. The connections are mainly located around Bugiri town. For the whole district, it is important that the length needed per extra connection for the extension of the distribution network will be a lot bigger, and it is assumed that (at least) an additional 100 meters should be considered. The lifetime of the project is 25 years since it is desired to fill the gap between the demand and treated water supply ('demand-supply gap') within this period. To be conservative, the future water demand in combination with the current treated water supply is considered. Therefore, the 'extra' daily water demand is 39,404 m^3/d, which is the future 'demand-supply gap'. For Bugiri a value of 78,808 extra future connections is estimated based on the baseline study, considering 100% demand coverage and an average water demand of 500 L per day per connection. However, these values can vary for different situations. An overview with the input for the different alternatives is shown in Table E.2 in Appendix E.

13.1.1. Jinja (Masese)

For this alternative, a pipeline is constructed from Jinja (Masese) to Bugiri. In other words, this alternative is an extension of the water supply system in Jinja. The current capacity of the treatment plant is 26,000 m^3/d which is already being extended to 32,000 m^3/d because of the extension project to Iganda and Kaliro. The future gap is much higher than the current capacity, so it is assumed that only 20% of the gap can be filled. Therefore, the estimated number of new connections is 15,762. The estimated non-revenue water is 20%. For this option only surface water is considered, which means no boreholes are constructed.

The water can be extracted from the water treatment plant in Jinja and transported to a low level reservoir in Bugiri. The water has to be transported over a height difference of 11 meters. The total distance from Jinja to the reservoir is 65.7 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 1,576 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 2 medium booster pumps and 3 large transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 225,000,000,000.

13.1.2. Bugadde

For this alternative, a new and separate system is built from the currently existing system. It is assumed that 100% of the demand gap between the treated water supply and demand can be filled in the future. Therefore, the estimated number of new connections is 78,808. The estimated non-revenue water is 20%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from Lake Victoria and transported to a low level reservoir in Bugiri. The water has to be transported over a height difference of 11 meters. The total distance from the newly constructed water treatment plant in Bugadde to the reservoir is 39.0 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 7,881 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 2 medium booster pumps and 2 large transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 976,000,000,000.

13.1.3. Wakawaka

For this alternative, a new and separate system is built from the currently existing system. It is assumed that 100% of the demand gap between the supply and demand can be filled in the future. Therefore, the estimated number of new connections is 78,808. The estimated non-revenue water is 20%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from Lake Victoria and transported to the Kapyanga reservoir in Bugiri. The water has to be transported over a height difference of 69 meters. The total distance from the newly constructed water treatment plant in Wakawaka to the reservoir is 26.0 km, for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 7,881 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 1 large booster pump and 2 medium transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 1,031,000,000,000.

13.1.4. Majanji

For this alternative, a pipeline is constructed from Majanji to Bugiri. In other words, this alternative is an extension of the water supply system in Majanji. It is assumed that 50% of the demand gap between the supply and demand can be filled in the future. This estimation is made by comparing the current design capacity of the treatment plant with the gap that needs to be covered. Therefore, the estimated number of new connections is 39,404. The estimated non-revenue water is 20%. Since this option considers only surface water, no boreholes are needed.

The water can be extracted from the water treatment plant in Majanji and transported to the Buwuni reservoir in Bugiri. The water has to be transported over a height difference of -12 meters. The total distance from Majanji to the reservoir is 33.0 km (or 52.5 via Busia), for which a pipeline of type DIP DN300 is suggested to be used. The distance of the water intake to the treatment is about 2 km, for which also a pipeline of type DIP DN300 is proposed to be used. The distribution network needs to be extended with 3,940 kilometers of pipeline. The suggested type of pipeline for the extension of the distribution network is uPVC OD75 PN6. Furthermore, it is assumed that 1 large booster pump and 2 large transport pumps are needed.

Combining these input values, the total loan can be calculated. For this alternative, the estimated total loan is UGX 642,000,000,000.

13.2. Performance analysis

The different design alternatives for Bugiri District can easily be compared based on a performance analysis. This performance analysis rates the alternatives on a scale of 1 to 10, considering four main categories: sustainability, durability, society and feasibility. Rating the criteria has been done according to Tables F.1, F.2, F.3 and F.4 in Appendix F, which contain the descriptions of the score for each criterion.

For the four alternatives, the scores for all criteria of the performance analysis are presented in Table 13.1. Both sustainability and society have a weight factor of 20. Durability and feasibility are considered more important and thus both have a weight factor of 30. As can be seen from the results, Wakawaka has the highest performance score, followed closely by Bugadde. Jinja (Masese) has the lowest performance score.

Table 13.1: Performance total scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Manjanji
20	**Sustainability**	6.4	5.2	5.9	6.6
30	**Durability**	5.5	7.6	7.2	6.8
20	**Society**	4.9	6.2	6.9	5.6
30	**Feasibility**	5.9	8.7	8.7	7.3
100	**TOTAL**	**5.7**	**7.2**	**7.3**	**6.7**

As can be seen in Table 13.1, Majanji scores best on sustainability. This is because not much soil erosion is expected, as there is no big height difference to bridge. Next to that, since this alternative is an extension of another network, the impact on flora and fauna is not so high, not many materials are needed and the energy use is less compared to other alternatives. The water losses are also expected to be lower, since the transmission network is less extensive. Bugadde has the worst score on sustainability, because this alternative requires a large transmission network (and therefore has a big impact on flora and fauna), a lot of materials and energy. Also, the water losses are expected to be quite high. A more detailed overview of the sustainability scores is presented in Table E.3 in Appendix E. Here, for the four different alternatives, the scores for all sub-criteria of sustainability are presented. The weight factors are also indicated. The sub-criterion 'water losses' has the highest weight factor, followed by 'materials' and 'renewable energy usage'. The remaining sub-criteria are weighted equally important.

Considering the results on durability in Table 13.1, Bugadde scores best. The water is extracted from Lake Victoria and since this lake is so big, it is unlikely that the water source will be depleted. Therefore, it scores high on the 'expected lifespan water source' criterion. If sustainable materials are used, the system can also last long. There are options for extension, so if the water demand turns out higher than expected, there is an opportunity to extend the system. The Jinja (Masese) alternative scores worst on durability. This option covers only for 20% of the demand-supply gap, so the option to extend is very low. Next to that, since it is an extension of another network, the maintainability and supply chain scores lower. It is more difficult to maintain a system that has a very long transmission network. A more detailed overview of the durability scores is presented in Table E.4 in Appendix E. Here, for the four different alternatives, the scores for all sub-criteria of durability are presented. The weight factors are also indicated. The sub-criterion 'expected lifespan water source' has the highest weight factor, followed by 'expected lifespan system'. The remaining sub-criteria are weighted equally important.

Next to sustainability and durability, Table 13.1 also shows the scores on society for each of the four alternatives. As can be seen in the table, Wakawaka scores best on society. Since this alternative is expected to cover 100% of the demand gap, it is expected that this alternative will have a positive impact on the health of the people, when they are provided with clean drinking water. Since a new treatment plant and a whole new system is built for the Wakawaka alternative, it should be designed with room for extension, so therefore there will be a good ability to serve outside the scope (also because the transmission pipeline passes other areas). Next to that, since the network will be big, many job opportunities will be created, related to the water supply system as well as in the area of Bugiri District. Jinja (Masese) has the lowest score on society. Since only 20% of the demand gap is filled, this will not really positively or negatively affect the overall health of people. Only little job opportunities are created in the area and there is a probability of illegal usage, since the network is an extension and it cannot easily be controlled. There is no ability to serve outside the scope, because the water demand is not even halfway met. A more detailed overview of the society scores is presented in Table E.5 in Appendix E. Here, for the four different alternatives, the scores for all sub-criteria of society are presented. The weight factors are also indicated. The sub-criterion 'health' has the highest weight factor, followed by 'stakeholder participation' and 'quality of living environment'. The sub-criteria on job opportunities have the lowest weight factor.

The last criterion considered for the performance analysis is feasibility. As shown in Table 13.1, Bugadde and Wakawaka score equally best on feasibility. The demand-supply gap is fully closed in these alternatives and they are profitable. The Jinja (Masese) alternative scores lowest on feasibility. This is mainly due to an extremely low demand coverage. Based on the other sub-criteria, the Jinja (Masese) option is quite comparable to the other alternatives. A more detailed overview of the feasibility scores is presented in Table E.6 in Appendix E. Here, for the four different alternatives, the scores for all sub-criteria of feasibility are presented. The weight factors are also indicated. The sub-criterion 'demand-supply gap' has the highest weight factor, followed by 'time frame' and 'operational costs vs. revenue'. The sub-criterion on connection investment costs has the lowest weight factor.

13.3. Risk analysis

The risks for the four different alternatives are evaluated in the risk analysis. The main result is presented in Table 13.2, whereas a more detailed overview is shown in Table E.7 in Appendix E. All the risks are specified in detail in the manual in Appendix F. In the manual the causes and consequences of the risks are described. In this section, the main risks of the alternatives are discussed.

For the extension of the treatment plant in Masese (Jinja), the main risks are sudden population surge and floodings. The most important risks for the intake from Lake Victoria at Bugadde are higher project costs than expected, change of plans, surface water complications, floodings. For the intake from Lake Victoria at Wakawaka, the main risks are higher project costs than expected, surface water complications and floodings. Lastly, for the extension of the treatment plant in Majanji, the main risks are change of plans and floodings.

The result of the risk analysis is that all the alternatives are considered to be RISK CLASS 2. This means the risk of implementing the alternative is quite low. For Jinja only an extension is considered and only 20% is estimated to be covered by this alternative, which results in low impact of several risks. All the alternatives consider the same water source, which makes the scores in the category environment for example, quite similar. The risk scores in the categories society and politics are slightly higher if the source is located outside of the district.

Table 13.2: Risk scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
10	**ECONOMICS**	9	11.5	11.5	9
10	**POLITICS**	8	13	6.5	8
25	**SOCIETY**	11.75	8.5	8.5	10.25
20	**ORGANIZATION**	7	7	6	7
20	**TECHNOLOGY**	4.25	7.75	7.75	5.5
15	**ENVIRONMENT**	9.2	9.2	8.6	9.2
100	**TOTAL**	**8.3**	**8.9**	**8**	**8.1**

13.4. Results

Table 13.3 shows the total results of the multi-criteria analysis. The performance of the Jinja (Masese) alternative scores quite low compared to the other alternatives and the Bugadde and Wakawaka alternatives are the only options with a performance score of above 7. However, the Jinja (Masese) alternative has a low risk (Risk Class 2), while the others have a medium risk. The estimated gap coverage is also an important aspect when comparing the different alternatives. Both the Bugadda and Wakawaka alternatives have an estimated gap coverage of 100%, while the Majanji alternative has 50% coverage and the Jinja (Masese) alternative even only has a 20% coverage. As discussed before, these gap coverages are not 100% due to the fact that the treatment plants are extended in these solutions and already supplying other areas with water.

The costs are the approximated total costs of the project, so including both the investment costs and operational costs. The costs per connection also include both the investment and operational costs for 40 years divided by the number of connections. Comparing the costs shows that the costs of the Bugadde and Wakawaka alternatives are relatively high compared to the other options. The costs of the Jinja (Masese) alternative are much lower than the rest. The costs per connection of of the Majanji alternative are slightly higher than the other alternatives, but the values are quite close to each other. Looking at the profit ratio, which is the ratio between the profit and the revenue, the alternatives score quite similar.

Table 13.3: Results alternatives Bugiri District

Category	**Jinja (Masese)**	**Bugadde**	**Wakawaka**	**Majanji**
Costs [UGX]	225,000,000,000	976,000,000,000	1,031,000,000,000	642,000,000,000
Costs/connection (40 years) [UGX]	19,000,000	17,000,000	18,000,000	21,000,000
Performance	5.7	7.2	7.3	6.7
Profit ratio	0.49	0.51	0.47	0.46
Risk	RISK CLASS 2	RISK CLASS 3	RISK CLASS 3	RISK CLASS 3
Estimated gap coverage [%]	20	100	100	50

13.5. Alternative selection

After using the multi-criteria analysis to assign scores to every alternative, a conclusion can be drawn from the scores to determine which alternative is or which alternatives are most suitable. Taking the discussion of all results in consideration, the most favorable options to extend the drinking water supply system in Bugiri for the long term are the Bugadde alternative and the Wakawaka alternative. These are both options in which a whole new system is designed, including a new intake from Lake Victoria as well as a new water treatment plant. Both these alternatives have a 100% estimated gap coverage and have a high performance. However, it has to be noted that these alternatives have a medium risk and that the costs are high compared to the other options.

The Jinja (Masese) alternative is the cheapest option, but has a gap coverage of only 20% and also has a relatively low performance, why it is not considered as a very suitable option. Also the Majanji alternative has a relatively low estimated gap coverage of 50% and a medium performance. Therefore this is not one of the favorable options. To achieve a high gap coverage and a higher performance of both these alternatives, a new intake system and treatment plant should be built, which means that it would be more logical to build this new system at Bugadde or Wakawaka.

Part IV

Conclusion and recommendations

14
Conclusion

The overall goal of this multidisciplinary project was to set up an accessible tool to evaluate different alternatives for extending the drinking water supply system of an area in Uganda. The research question of the project is:

How can a multi-criteria analysis be set up to become an accessible tool for the evaluation of different alternatives for an extension of the drinking water supply system in a Ugandan area?

To answer this main question, the sub-questions need to be answered. The first sub-question is: *Which area specific water sources can be used in order to become feasible alternatives to extend the current water supply system?*
The area should be researched on the availability of water sources in terms of quantity, accessibility and time period. Water sources are groundwater, surface waters, rain water, recycled water, ice etc. In the case of Uganda, the only largely available water sources are groundwater and surface water.

Focusing specifically on the project areas of this study, it can be concluded that multiple water sources are optional to use for the extension of the water supply system of these areas. The water source that can be used for a short-term (5 years) implementation in both Hoima and Bugiri is groundwater. Using surface water as a short-term solution is not feasible due to the amount of time needed to implement a new system with surface water intake, considering the combination of required studies, politics and construction time. The water sources that can be used for a long-term (25 years) solution for Hoima City are both groundwater and surface water. The area around Hoima City has a high groundwater potential and Lake Albert, Kafu River and Masindi Port are surface water options to use as a source for the drinking water supply system. Long-term (25 years) solutions of Bugiri District include only one surface water source, Lake Victoria. Groundwater is in this case not considered as a feasible option for a long-term alternative yet, as the yields of current boreholes are low and dropping after a few years. Therefore studies have to be performed to research if groundwater could be a long-term option as well.

The subsequent question is: *What research should be done on the alternatives in order to determine its minimizing effect on the future water gap between demand and treated water supply?*
There are many aspects of a water source that are of importance when designing alternatives. It needs to be determined what the coverage of a certain alternative will be. This means the future gap between the demand and treated water supply ('demand-supply gap') needs to be known, so the water demand after a specific time period and the current water supply need to be calculated. It could be that certain alternatives can only partly fulfill the future 'demand-supply gap' or that an extension of an existing system forms a possibility. Other aspects to investigate are future water plans in the area, non-revenue water, water quality, the distance and height difference between the water source and the transmission and distribution network.

When considering the case studies of this project, it can be concluded that for Hoima City the short-term (5 years) gap between the demand and treated water supply ('demand-supply gap') is 8,773 [m^3/d] and for the long term (25 years), the 'demand-supply gap' will be 17,395 [m^3/d] if the operational performance is not improved. If the operational performance improves to only 20% non-revenue water, the long-term 'demand-supply gap' will be 12,145 [m^3/d]. Based on the long-term 'demand-supply gap', the only possible options with 100% 'demand-supply gap' coverage for Hoima City are Lake Albert or boreholes combined with Kafu River or Masindi Port. The most important characteristics of Lake Albert are its continuous source of water and its high height difference with Hoima City. More boreholes can be easily added to the existing transmission system, but many boreholes will be necessary to cover the whole 'demand-supply gap'. For Kafu River the seasonality is uncertain as well as the political situation around this source. Masindi Port is also a continuous source, but its location is far from Hoima City. For Bugiri District the short-term (5 years) 'demand-supply gap' is 21,355 [m^3/d] and for the long term (25 years), the 'demand-supply gap' will be 39,404 [m^3/d] if the operational performance is not improved. Otherwise the long-term 'demand-supply gap' will be 37,458 [m^3/d]. Because the boreholes in Bugiri District have very low yields, especially compared to the high 'demand-supply gap', all alternatives are from surface water: an extension of the treatment plant in Masese (Jinja), an intake from Lake Victoria at Bugadde, an intake from Lake Victoria at Wakawaka or an extension of the treatment plant in Busia.

The third research question is: *What criteria should be considered to evaluate different design alternatives?*
All criteria considered in the evaluation are based on the information of VEI, NWSC and MWE and on the experience during the visits in Hoima and Bugiri, are classified in three main categories. First of all, the financial aspects cover the investment costs, the operational costs and the profit ratio. The performance aspects of a design alternative, focusing on the construction phase as well as its lifespan, are divided into sustainability criteria (focusing on the environmental impact), durability criteria, society criteria and feasibility criteria. Finally, the risk aspects are also divided into sub-categories, namely: economics, politics, society, organization, technology and environment. The risk analysis includes risks of both the construction as well as the lifespan. These sub-categories, focusing on the risks of a design alternative, all include multiple risks, that are determined by the risk's probability and impact.

The last sub-question is: *How can the criteria be weighted and scored to ensure a valuable result for the decision making?*
To evaluate design alternatives, the results of the finance, the performance and the risks are not combined into one final score, but observed separately. Therefore no weights are assigned to these main categories. The finance part consists of a calculation of the investment costs with the operational costs over the total lifespan added. However, all criteria of the performance analysis (sustainability, durability, society and feasibility) as well as every sub-criterion subject is weighted with a value between 1 and 100, which can be adjusted when performing the analysis. Within each weighted criterion subject, there are several scored sub-criteria. These criteria are scored with one of the following values: 2, 4, 6, 8 or 10. The same holds for the risk analysis: all criteria subjects and sub-criteria subjects have adjustable weights on a scale from 1 to 100. In this way, the importance and therefore the contribution of every criterion can be adjusted according to the objective and stakeholders of the case study. The scores of the risk analysis are calculated by multiplying the probability and the impact, which are both scored with a value of 1, 2, 3, 4 or 5. These risk scores are converted to risk classes. The way of weighting and scoring is based on the experience during the visits of the project areas and conversations with people from VEI, NWSC and MWE.

Finally, using the conclusions of the sub-questions, the main question of this research can be answered. To set up the multi-criteria analysis, financial aspects, performance aspects and the risks of the optional design alternatives are taken into account. These three main categories can be divided into multiple criteria that are important for the evaluation of different alternatives. The financial aspects include the different costs of an alternative regarding both the investment and the operation. The performance aspects describe how well the alternative performs during the construction as well as its lifespan while looking at the sustainability, durability, society and feasibility of the design. Lastly, the risk analysis focuses on different kind of important risks during both the construction of the system and its lifespan. Important risk categories considered are economics, politics, society, organization, technology and environment. The performance criteria as well as the risks can be weighted according to the objective and stakeholders to distinguish the contribution of all criteria. It can be concluded that the defined criteria should be unambiguous and independent and that the final multi-criteria analysis should be comprehensive and carefully weighted.

The accessibility of the tool is tested during a case study with multiple stakeholders, including NWSC area managers from Hoima and Bugiri and engineers from both NWSC and MWE. It can be concluded from the feedback retrieved during this session that the tool is accessible, but that it still has to be more 'Ugandanised', meaning that a team of Ugandan engineers have to take a critical look at all criteria to finalize the tool.

15

Discussion and Recommendations

In this chapter, some recommendations are given on different parts of the project. First of all, recommendations on the water supply in Uganda itself are discussed. General recommendations as well as recommendations focusing on Hoima City and Bugiri District are collected during the research. Recommendations for further research are provided as well.

Next to that, recommendations regarding the multi-criteria analysis (MCA) are discussed. The MCA is meant to get insights in the different criteria which are important to take into account for making a decision. There are some suggestions on how to extend the tool. Also some recommendations are given on how to evaluate different alternatives.

15.1. Treated water supply

This section contains general recommendations regarding the treated water supply, the working environment and the study approach in Uganda. After the general recommendations, location specific recommendations for Hoima City and Bugiri District are discussed.

15.1.1. General

Currently the treated water supply system is too small to serve drinking water to all people. Mostly, short-term solutions are used to increase the supply of clean drinking water, reasoning that people need water right now and not only in the far future. However, these short-term solutions are mostly based on the current water demand, while the population and therefore the water demand is increasing with a high rate. Because of this, the water supply system constantly needs improvements as the short-term projects cannot keep up with the high population growth. It is therefore recommended to also focus on long-term solutions, taking into account the future water demand in 25 years, aside from short-term plans. The investment costs are higher and the implementation time is longer for a long-term solution than a short-term solution, but a long-term solution could be more cost effective and serve more costumers in the end.

In order to have a constant treated water supply and to maintain this in the future, it is important to pump at a sustainable rate when retrieving groundwater. This rate can be determined by pumping tests. On top of that, the water level should be monitored to check whether the water level, after the resting time, recovers to the original rate. For the pumps it is best to operate at a steady low rate and have a resting time of at least four hours per day. In this way, the lifetime of groundwater system will be improved. Besides, it is recommended, especially in areas with clogging problems due to the iron bacteria, to rehabilitate the boreholes when needed. Rehabilitation means repairing a borehole which has failed or which productivity has declined (International Committee of the Red Cross, 2010). If the boreholes are maintained frequently, the complete collapse of the borehole or breakdown of the pump can be avoided, which prevents the need of redrilling a borehole.

As observed during the baseline visits in Hoima City and Bugiri District, most borehole and reservoir production data is collected and written down in a book. This is sensitive for errors and sometimes data is missing. Digital monitoring could improve the accuracy of the data and it could give insight in the production rates over time.

When considering the use of boreholes as a long-term solution it is recommended to perform further studies and tests to make sure aquifers are suitable for long-term use. Furthermore, considering the case of Bugiri District, it is recommended to also use the existing boreholes of NGOs or umbrella organisations for the future supply system when handed over to the National Water & Sewerage Corporation.

The stability of the power supply is also something that is recommended to be improved. Due to bad power supply at some boreholes, the amount of pumping hours is relatively low, which decreases the production. Right now, many boreholes need a generator in order to guarantee a supply. If the power grid is improved or solar energy is used, there could be a more stable power supply, which is beneficial for the efficiency of the pumps and increases the amount of water produced by a borehole. Another problem of the unstable power supply is the breakdown of electrical or mechanical equipment, which is something that should be avoided.

A high percentage of non-revenue water could be caused by multiple things, for example poor operational performance and maintenance, lack of leakage control, illegal usage of boreholes, unbilled water consumption and more (PPIAF/WBG, 2021). Improving the operational efficiency and maintenance as well as discouraging illegal usage and improvement of monitoring, minimizes the water losses between the extraction of water and the supply to the costumers and therefore decreases the amount of non-revenue water. This increases the amount of water that can actually be served to the customers and so the revenue by selling the water. Another explanation for the high percentage could be is that there is a mistake in the data received.

Uganda is divided into 135 districts (Ministry of Local Government, 2022) and every district has its own water supply system. Further studies could be performed to research if it is possible to implement a water supply system in multiple districts together or even designing a supply system for a whole region in the future. In this way the water supply of different areas could be combined, resulting in a more effective water supply system in the whole country.

15.1.2. Hoima City

The water from the boreholes is treated in a drinking water treatment plant in Hoima. To remove the iron, an aeration step is used which caused the iron particles to flocculate partly (shown in Figure 15.1). It is advised to bring the flocs to a special disposal place instead of dumping it in the nearby wetland, so that it does not end up in the groundwater again.

Figure 15.1: Aeration step drinking water treatment plant Hoima

15.1.3. Bugiri

As discussed before, the current piped water supply network in Bugiri covers only a small part of the district. The other parts of the districts, mainly the rural areas, are covered with a lot of handpumps. Bugiri is a large district with a high population and therefore it is recommended to first start with extending the drinking water supply network in the towns. Until the new system is installed, people in rural areas can still use the currently existing handpumps.

15.2. Multi-criteria analysis tool

The multi-criteria analysis tool is meant to be used in the very early stage of designing an extension of the drinking water supply system. The tool can be developed further to be used in other stages of the design, for example for a feasibility study. In this section multiple recommendations are given for further elaboration of the tool. Besides, some other recommendations are considered, including general advises as well as recommendations regarding the different parts of the MCA.

15.2.1. General

Scoring the criteria is mainly done in a subjective manner and cannot be completely objective. Therefore, it is recommended that the same person performs the total analysis to be able to fairly compare all alternatives. The analysis can be performed by multiple persons, after which the results can be compared and discussed.

It is important that the person who is performing the analysis, has a critical look on the results when evaluating them. For example, a high sustainability score due to the use of solar power results in higher power supply costs in the financial analysis, so is taken into account twice in the total analysis.

If the coverage of some alternatives is not equal to 100%, it can be considered to use a combination of different alternatives. For example, combining groundwater and surface water as sources for the water supply could lead to a higher coverage and also increases the reliability of the supply system, because two different sources are used.

15.2.2. Financial analysis

The costs of the different parts during the implementation of an alternative are estimated using several sources. The financial analysis gives an approximation of the costs and can be used to compare the different design alternatives. When further developing the tool to use it in other design stages, it is recommended to perform an elaborated study on the different costs in order to have a more refined estimation. Some ideas for the elaboration of the cost analysis are given below.

Currently the quality of the water is not evaluated in the costs for the treatment. It would be advised to extend the tool with a separate sheet in which the concentrations and values of the different water properties can be filled in. If these values are compared to the standard values for water quality, the water can be classified as very bad, bad, medium, good or very good quality. The worse the water quality of the considered alternative, the higher the treatment costs.

The costs of the pumps are calculated with an estimation of the prices for big, medium and small pumps. The amount of pumps needed is estimated by looking at the head and the distance to the reservoir. It would be advised to make a better estimation of the amount of pumps by precisely categorize pumps based on the capacity. The pump prices could be more accurate when exact pump prices of all available pumps are implemented in the financial analysis.

When the MCA is further developed for a later design stage, it would be interesting to be able to evaluate the costs in a schedule giving insights into when certain costs and replacements need to be made and when a project is break-even.

In an African country like Uganda, there is a possibility that people do not want to be connected to a treated water supply system, since they are not interested or cannot afford the water. Therefore, there is a risk of unpaid water. In this tool, unpaid water is taken into account in the risk analysis, but not as part of the financial analysis. If there is a lot of unpaid water, this means that the ratio between revenue and operational costs might not be as positive as how it is scored now. This could result in a lower profit ratio and in some cases it might even turn out in a negative profit ratio. Therefore, it is recommended to make an assessment of the amount of unpaid water, in order to get a more fair estimate of the profit ratio.

15.2.3. Risk analysis

The risk analysis consists of multiple risks that can occur during the implementation and operation phase. It is recommended to study which mitigation measures can be taken to eventually reduce the risk of certain alternatives.

The risks are based on the experience during the baseline visits and meetings with various people. The risks are covering the following categories: economics, politics, society, organization, technology and environment. Legal risks are not yet included in the risk analysis, due to a lack of time to study the legal aspects of the drinking water supply system. Besides legal risks, there could be other risks that might be important for the evaluation of a water supply extension. It is therefore recommended to perform further studies regarding potential legal issues and besides, to conduct multiple baseline studies to areas in Uganda other than Hoima and Bugiri. Visiting other Ugandan areas could give insight in risks that are not included in the current version of the MCA.

15.3. Feedback final presentation

A final presentation and workshop of the MCA-tool for all people involved from Uganda (people from The National Water and Sewerage Corporation, The Ministry of Water and Environment, Vitens Evides International etc.) was given. Some recommendations were given afterwards. It was recommended that a slot on flexibility of any option is included to address the issue of phased development as a way of cutting back on huge operation costs that come with a fully fledged system operating at low capacity. When the MCA-tool becomes more detailed, it is recommended to add the option for phased development. Next to that, it was recommended to make it possible to give a risk a score of 0, since if only surface water is considered, the ground water complications should be scored at 0, instead of the current value of 1. Also, it was advised to split up some sub-criteria of the risks and sustainability part, then it will be possible to make a difference in score for the construction and operation phase.

References

African Development Bank Group. (2022). *Mission & strategy*. Retrieved December 29, 2022, from https://www.afdb.org/en/about/mission-strategy

Alliance Consultants Ltd. and Infra-Consult Ltd. (2018). Consultancy services for feasibility study and detailed design of water supply and sanitation systems for the greater bugadde project area - lot 2.

Amollo, C., et al. (2020). *Comparing performance of different lumped conceptual hydrological models: A case study of river kafu catchment* (Doctoral dissertation). Kyambogo University [Unpublished work].

Barony of Burford. (2016). *The barony of burford, count of mparo, viscount of kahoora*. Retrieved December 6, 2022, from http://www.barony-of-burford.info/15.html

Brown, E., & Sutcliffe, J. (2011). The water balance of lake kyoga, uganda. *Hydrological Sciences Journal*, 342–353.

Bugiri District. (2002). *District groundwater report. part 1 & part 2*.

Bugiri District. (2020). *Bugiri district profile*.

Bwire, G., Sack, D. A., Kagirita, A., Obala, T., Debes, A. K., Ram, M., Komakech, H., George, C. M., & Orach, C. G. (2020). The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of uganda: An analysis of vital physicochemical parameters. *BMC Public Health*, *20*(1). https://doi.org/10.1186/s12889-020-09186-3

Cambridge University Press. (2022). *Cambridge dictionary*. Retrieved December 29, 2022, from https://dictionary.cambridge.org/dictionary/english/sustainability

Climate Data. (2022). *Hoima climate*. Retrieved December 7, 2022, from https://en.climate-data.org/africa/uganda/western-region/hoima-31058/

Directorate of Petroleum - Uganda. (2022). *Sedimentary basins*. Retrieved December 7, 2022, from https://www.petroleum.go.ug/index.php/resources/sedimentary-basin

Energy GIS working group. (2022). *Distribution lines uganda (maps in image format)*. Retrieved December 30, 2022, from https://energy-gis.ug/gis-maps

Gauff Consultants. (2017). Feasibility study and pre-design for the development of water and sanitation infrastructure for the hoima-masindi areas [A research report about the current and future water supply system network in Hoima], *1*, 1–307.

Google Earth. (2022). Retrieved December 13, 2022, from https://earth.google.com/web/

Google maps. (2022). Retrieved December 13, 2022, from https://www.google.com/maps/@0.3078018,32.6164299,15z

Hillary, I. (2018). Impacts of urbanisation on water resources: A case study of hoima municipality hoima district, uganda [A research report submitted to the College of Humanities and Social Science in partial fulfillment of requirements for the award of Bacherlor degree of Development Studies of Kampala International University].

Hoima District. (2022a). *District profile*. Retrieved December 6, 2022, from https://hoima.go.ug/district-profile-2/

Hoima District. (2022b). *Vision & mission*. Retrieved December 20, 2022, from https://hoima.go.ug/vision-mission/

International Committee of the Red Cross. (2010). *Technical review, borehole drilling and rehabilitation under field conditions*. ICRC. https://www.icrc.org/en/doc/assets/files/other/icrc_002_0998.pdf

JICA. (2011). *The development study on water resources development and management for lake kyoga basin*. Retrieved December 27, 2022, from https://openjicareport.jica.go.jp/pdf/12025219_01.pdf

Kazi Njema Reporter. (2021). River kafu degradation frustrates water supply plans in hoima oil city. *Environment & Climate*. https://kazi-njemanews.com/river-kafu-degradation-frustrates-water-supply-plans-in-hoima-oil-city/

Marks, S. J., Clair-Caliot, G., Taing, L., Bamwenda, J. T., Kanyesigye, C., Rwendeire, N. E., Kemerink-Seyoum, J. S., Kansiime, F., Batega, D. W., & Ferrero, G. (2020). Water supply and sanitation services in small towns in rural–urban transition zones: The case of bushenyi-ishaka municipality, uganda. *npj Clean Water*, *3*(1). https://doi.org/10.1038/s41545-020-0068-4

Ministery of Water and Environment. (2020). *Sector performance report*. Retrieved December 16, 2022, from https://mwe.go.ug/sites/default/files/library/WaterandEnvironmentSector%20PerformanceReport2020.pdf

Ministry of Local Government. (2022). *Ministry of local government*. Retrieved January 4, 2023, from https://molg.go.ug/

Ministry of Water and Environment. (2014). *Water supply design manual second edition by the republic of uganda - ministry of water and environment*. Retrieved December 6, 2022, from https://www.mwe.go.ug/sites/default/files/library/WaterSupplyDesignManualv.v1.1.pdf

Ministry of Water and Environment. (2018). *Feasibility study and detailed design of water supply and sanitation system for the greater bugadde*.

Ministry of Water and Environment. (2021). *Integrated water management and development project: Environmental and social impact assessment report* [IGANGA & KALIRO DISTRICTS].

Ministry of Water and Environment. (2022). *Wsdf*. Retrieved December 29, 2022, from https://www.mwe.go.ug/content/wsdf-east

NWSC. (2021a). *About us*. Retrieved October 19, 2022, from https://www.nwsc.co.ug/about-the-corporation/

NWSC. (2021b). *Hydrogeological/geophysical survey for two (6) production borehole sites in bugiri municipality and sorrounding areas, bugiri district*.

OCHA. (2020). *Uganda - subnational administrative boundaries*. Retrieved December 19, 2022, from https://data.humdata.org/dataset/cod-ab-uga?

Ongom, R., Andama, M., & Lukubye, B. (2017). Physico-chemical quality of lake kyoga at selected landing sites and anthropogenic activities. *Journal of Water Resource and Protection*, *09*(11), 1225–1243. https://doi.org/10.4236/jwarp.2017.911080

PPIAF/WBG. (2021). *Non-revenue water*. Retrieved January 4, 2023, from https://ppiaf.org/sectors/non-revenue-water

QGis. (2022). *Qgis 3.28*. Retrieved December 19, 2022, from https://www.qgis.org/en/site/forusers/download.html#

R. Ongom, M. A., & Lukubye, B. (2017). Physico-chemical quality of lake kyoga at selected landing sites and anthropogenic activities. *Journal of Water Resource and Protection*, *9*(11).

The Independent. (2022). *Historic: Final decision on 10bn dollar uganda oil project*. Retrieved December 7, 2022, from https://www.independent.co.ug/historic-final-decision-on-10bn-uganda-oil-project/

Uganda Bureau of Statistics. (2017). *The national population and housing census 2014 – area, specific profile series, kampala, uganda*.

Uganda Bureau of Statistics. (2019). *Population projections by sub county and sex (2015-2030)*. Retrieved December 16, 2022, from https://www.ubos.org/?pagename=explore-publications

UNBS. (2014). Potable water - specification.

VEI Dutch Water Operator. (2022). *From and for water operators*. Retrieved December 29, 2022, from https://www.vei.nl/about-us

Wandera, S. B., & Balirwa, J. S. (2010). Fish species diversity and relative abundance in Lake Albert—Uganda. *Aquatic Ecosystem Health & Management*, *13*(3), 284–293. https://doi.org/10.1080/14634988.2010.507120

Wasswa, P. (2019). *Assessment of march-may rainfall characteristics and effect on the stream flow of river kafu in masindi district catchment, uganda* (Doctoral dissertation). Makerere University.

WE Consult. (2017). *Consolidated hydrological year book for uganda 1978-2014*. Ministry of Water and Environment. https://www.mwe.go.ug/sites/default/files/library/Consolidated%5C%20Hydrological%5C%20YearBook%5C%201978-2014%5C%20for%5C%20Uganda.pdf

World Bank. (2018). *Integrated water management and development project: Environmental and social impact assessment report* [WATER SUPPLY AND SANITATION PROJECT IN MAJANJI, LUMINO, BUHEHE, MASAFU, MASABA, DABANI, BUTEBA, MASINYA and SIKUDA SUB-COUNTIES; BUSIA MUNICIPALITY, BUSIA DISTRICT.]. Ministry of Water; Environment.

World Bank Water Data. (2010). *Waterbodies in uganda*. Retrieved December 19, 2022, from https://wbwaterdata.org/dataset/waterbodies-in-uganda
World Vision. (n.d.). *World vision*. Retrieved December 16, 2020, from https://www.wvi.org/

A

Hydraulic Training

During the week of the 28th of November, a hydraulic design training was given by one of the colleagues of VEI, Leo, for engineers from both the Ministry of Water and Environment (MWE) and National Water & Environment (NWSC). We assisted Leo during the training by answering the questions of the engineers about the exercises they had to do. The program of the week is shown in Table A.1. The engineers are working on water supply systems in several locations in Uganda. Generally they have a lot of knowledge from a practical/operational point of view, but sometimes the theory behind designing the system is lacking. The goal of the training was to teach them the basics of hydraulics, but also how to use MS Excel in an effective way.

Table A.1: Schedule of the training 28th of November, 2022 / 2nd of December, 2022

	Content
Monday (9:30-11:00)	Meeting with Leo and discuss the content of the training.
Tuesday (8:30-17:00)	Basics of hydraulics (dimensioning of pipes, reservoirs, projections, parallel lines)
Wednesday (8:30-17:00)	Network modelling and design (extension network in Bujuuko, Kampala)
Thursday (8:30-17:00)	Pumpstation design + start case studies
Friday (8:30-14:00)	Case studies

On Tuesday the training considered the basic concepts of hydraulics. It was a nice recap for us as well and we could really help out the engineers. On Wednesday the training continued on some basics, but it was more specific on network modelling. After lunch, the engineers worked on the extension of a transmission- and distribution network, for a specific location in Kampala (Uganda) and Livingstone (Zambia). On Thursday, the topic of the training was on pump station design, which was discussed in the morning. This afternoon as well as Friday, the engineers started working on their case studies, that consist calculations of a hydraulic system for a location with a certain problem. The case on which they are working should be about a problem like pressure problems in a current system, a reservoir that is too big or too small or a falling/rising main with a pump which is not operating as desired.

It was interesting to work together with engineers from Uganda, since they have a lot of practical experience. They were very motivated and enthusiastic during the training, which was very nice to see. At the beginning we were a bit uncertain about our capability to explain engineers how to design a network and answer their questions, but we quickly found out that we could really contribute to the training and transfer our knowledge. It was nice to hear the enthusiasm of the engineers, how satisfied they were about the training and how they experienced it as very useful.

B

Contact persons

During the project, people with different backgrounds and from different locations were involved and provided information. A list of contact persons is shown in a table*. We have had meetings with all people from the list. The persons from The National Water and Sewerage Corporation (NWSC), The Ministry of Water and Environment (MWE), the sub-county council and the District Local Government provided us with information about Hoima City and Bugiri District. They also gave us a lot of insight in the organisational and political situation of Uganda and the future drinking water supply system plans. The persons from the WaterWorX program and from Witteveen+Bos gave us a lot of insight on how to create a useful MCA-tool. STUDI International is a company that has executed many drinking water projects in Africa and gave a lot of information about the different risk factors that are specific for Uganda. GOAL explained the projects which are executed by non-governmental organisations in Bugiri District. WE Consult is an expert in groundwater and boreholes in Uganda, which helped us with the current and future groundwater supply options for the different areas. Vidas Engineering Services is a contractor, which provided us with a lot of information about different costs for the financial analysis.

*The table with the contact persons is removed because of privacy reasons.

C

Design Manual

This appendix contains information retrieved from the Water Supply Design Manual Second Edition (Ministry of Water and Environment, 2014).

C.1. Water demand

C.1.1. Domestic demand

CONSUMER CATEGORY	Rural Area (l/ca/d)	Urban Area (l/ca/d)	Remarks
Low income using kiosks or public taps	20	20	Most squatter areas, to be taken as the minimum
Low income multiple household with Yard Tap	40	40	Low income housing with no inside installation.
Low income, single household with Yard Tap	50	50	Low income housing with no inside installation.
Medium Income Household		100	Medium income group housing, with sewer or septic tank.
High Income Household		200	High income group housing, with sewer or septic tank.

Figure C.1: Demand per customer category (Ministry of Water and Environment, 2014)

C.1.2. Commercial demand

Consumer	Unit	Rural	Urban	Remarks
Hotels/Lodges	l/bed/d	50	50 300 600	Low class Medium class High class
Bars/Restaurant	l/bar/d	500	700 1,000	Low class High class
Shops	l/shop/d	50	50 100	Small Town Large Town
Shops/dwelling place	l/shop/d	100	150 200	Small Town Large Town
Petrol Station/washing bays	l/Petrol Station/d	1,000	5,000 10,000	Small Town Large Town
Markets	l/ha/d	20,000		
Public Sanitation	l/person/d	20	50 70	Small Town Large Town

Figure C.2: Commercial water demand (Ministry of Water and Environment, 2014)

C.1.3. Institutional demand

CONSUMER	UNIT	RURAL l/d	URBAN l/d	REMARK
Schools Day Schools	l/std/d	10	10 20	With pit latrine With WC
Boarding Schools	l/std/d	50	100	With WC
Health care Dispensaries	l/visitor/d	10	50	Out patients only
Health Center 1	l/bed/d	20	50	No modern facilities
Health Center 2	l/bed/d	50	70	With maternity With pit latrine
Health Center 3	l/bed/d	70	100	With maternity With pit latrine
Health Center 4	l/bed/d	100	150	With maternity With WC
Hospital, District	l/bed/d		200	With surgery unit
Hospital, Regional Referal	l/bed/d		400	With surgery unit
Administrative Offices	l/worker/d	10	- 70	With pit latrine With WC

Figure C.3: Institutional water demand (Ministry of Water and Environment, 2014)

C.1.4. Industrial demand

Industry	Product of Raw Material Unit	Water Consumption in m³ per Unit of Raw Material
Food Industry		
Diary	Milk received (m^3)	2 - 5
Abattoir	Animals slaughtered (ton)	5 - 10
Brewery	Beer (m^3)	10 – 20
Sugar	Cane (ton)	10 - 20
Grain millers	Grain received (ton)	2 - 5
Others		
Pulp mill	Bleached pulp (ton)	100 – 800
Paper	High quality paper (ton)	300 – 500
Chipboard factory	Chipboard (ton)	50 – 200
Tannery	Raw skins (ton)	50 – 150
Cotton mill	Cotton thread (tufi)	50. – 150

Figure C.4: Micro industry water demand (Ministry of Water and Environment, 2014)

Industry Type	Water Demand m^3/ha/d
Medium Scale (water intensive)	40
Medium Scale (medium water intensive)	15
Small Scale (dry)	5

Figure C.5: Macro industry water demand (Ministry of Water and Environment, 2014)

C.1.5. Livestock

According to the Water Act of Uganda 1997 in Part I - Interpretations, ”livestock unit” means a mature animal with a live weight of 500 kilograms and for the purposes of this definition -

- one head of cattle shall be deemed to be 0.7;
- one horse shall be deemed to be 0.6;
- one donkey shall be deemed to be 0.4;
- one goat shall be deemed to be 0.15; and
- one sheep shall be deemed to be 0.15; of a lifestock unit;

To cater for pigs and poultry farming, the figures below can be used for design:

- one Pig shall be deemed to be 0.4; and
- one chicken shall be deemed to be 0.05 of a livestock unit;

Where demand is large, consideration must be made for bulk water transfers. (Ministry of Water and Environment, 2014)

C.1.6. Non revenue water (NRW)

Loss = 64.522 UFW - 2.249 (Ministry of Water and Environment, 2014)

C.2. Economic Life

	Component	Economic Life (Years)	Annual Maintenance Costs - % of Construction Costs
1	Dams	40	0.5
2	Intake works, including boreholes; mass concrete structures such as intakes, underground pits, culverts, etc.	40	1
3	Earthworks generally	40	1
4	Boreholes and wells	20	1
5	Pumps	10	5
6	Diesel engines	10	5
7	Electric motors, cables and switch gears	10	5
8	Piping all types	30	1
9	Treatment works: Treatment works in masonry or reinforced concrete	30	1
10	Storage tanks in masonry or reinforced concrete	30	1
11	Storage tanks: sectional steel including towers	20	2
12	Storage tanks corrugated galvanized steel (C.G.S.) on timber stands	10	2
13	Buildings C.G.S. on timber	20	1
14	Buildings, masonry	30	1
15	Water kiosks, latrines, licensed retailer points etc.	20	2
16	Gantries, steelwork etc.	20	2
17	Permanent tools and plant not mentioned elsewhere	10	2
18	Water meters	10	5
19	Chemical dosing gear	10	5
20	Instruments and testing apparatus	5	5
21	Access roads	30	1
22	Fences, G.S. wire or mesh on timber	10	1
23	Fences, G.S. wire or mesh on concrete posts	20	1

Figure C.6: Annual Maintenance Costs and Economic Life (Ministry of Water and Environment, 2014)

D

Hoima City

D.1. Case area

An overview of Hoima district including the boundaries that indicate the municipality is presented in Figure D.1, in which Hoima city, the defined project area, is presented as the green area.

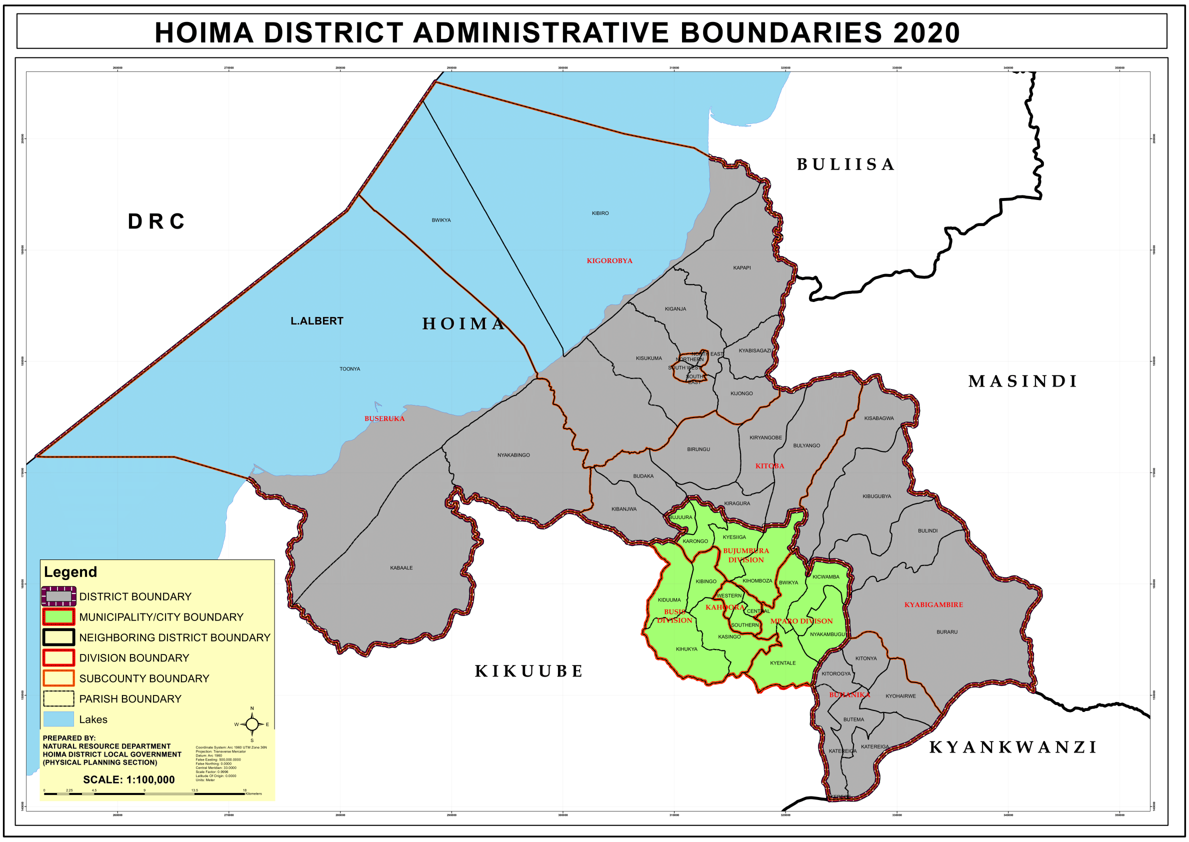


Figure D.1: Hoima District Map (received from area manager Hoima, Tom Mbaziira)

D.2. Water demand

An estimation of the water demand for Hoima City has been made. The following results are found for the water demand in 2022. The detailed monthly numbers per category are shown in Table D.1.

Table D.1: Estimation monthly water demand Hoima City 2022

		Water Demand [m^3/month]
DOMESTIC DEMAND		**175,802**
	Rural	15,982
	Urban	159,820
COMMERCIAL DEMAND		**11,700**
	Hotels/Lodges	4,000
	Bars/Restaurants	2,500
	Petrol Stations	6,000
	Washing Bays	1,200
	Public Sanitation	500
INSTITUTIONAL DEMAND		**64,147**
Education centres	Day Schools	22,375
	Boarding schools	33,562
Health Centers and Hospitals	H.Center 1	150
	H.Center 2	560
	H.Center 3	700
	H.Center 4	300
	District Hospital	2,000
	Administrative Offices	2,500
	Other Institutions	2,000
INDUSTRIAL DEMAND		**3,750**
	Small Scale	1,250
	Large Scale	2,500
Total Demand		**255,399**

D.3. Water supply

D.3.1. Boreholes

Table D.2: Current boreholes in Hoima City (comments)

Boreholes	Coordinates N°	E°	Comments
Borehole 1	1.42656	31.368616	Collapsed so redrilled, but not yet in use, it will be used february 2023. It was the first to be drilled.
Borehole 2	1.421589	31.38223	Redrilled
Borehole 3	1.421256	31.385833	Redrilled, 90m deep. Has bad power supply, is switched off and on.
Borehole 4	1.417484	31.385573	Redrilled because of higher yield wanted.
Borehole 5	1.448692	31.343793	Redrilled
Borehole 6	1.447325	31.338528	Redrilled
Borehole 7	1.450784	31.345072	Not in use, because people filled the borehole with rocks (->mechanical breakdown), because they don't think the National Water & Sewerage Corporation pays enough for the area, can be solved with a lot of power
Borehole 8	1.452962	31.350544	A new one is drilled already with a capacity of 40-50m3/hr will be used from june 2023 (current one is not built right, so yield was much lower than 40-50 ->19 m3/h)
Borehole 9	1.466844	31.374953	Not in installed and in use yet because they needed a new pump
New borehole 1	1.401442	31.352746	Not yet installed, planned to be used in January. Depth around 120 inches, diameter 8 inches
New borehole 2	1.417005	31.385281	Close to borehole 4 (coffee/sugar cane), New drilled borehole without a number yet. Not in use yet. Check with coordinates of Ron
Borehole WE Consult 1	1.420677	31.367323	Drilled in 2000, but not installed/used

(a) Borehole 2

(b) Borehole 3

(c) Borehole 4

Figure D.2: Bucunga boreholes

(a) Borehole 5

(b) Borehole 6

(c) Borehole 8

Figure D.3: Katasiha boreholes

D.3.2. Reservoirs

Table D.3: Current reservoirs in Hoima City (comments)

Reservoir	Coordinates N°	E°	Comments
Kikwite reservoirs	1.412212	31.364808	Enough capacity, but not enough water received
Kijwenge reservoir	1.463518	31.346694	
Bakumira reservoirs	1.442918	31.370866	
Mpaija reservoir	1.389842	31.347303	New reservoir, not in use yet.
Booster station	1.401743	31.34814	

(a) Kikwite reservoirs

(b) Bakumira reservoirs

(c) Mpaija reservoir

Figure D.4: Reservoirs Hoima

D.3.3. Schematization water supply

A schematization of the current water supply system in Hoima City is shown in Figure D.5.

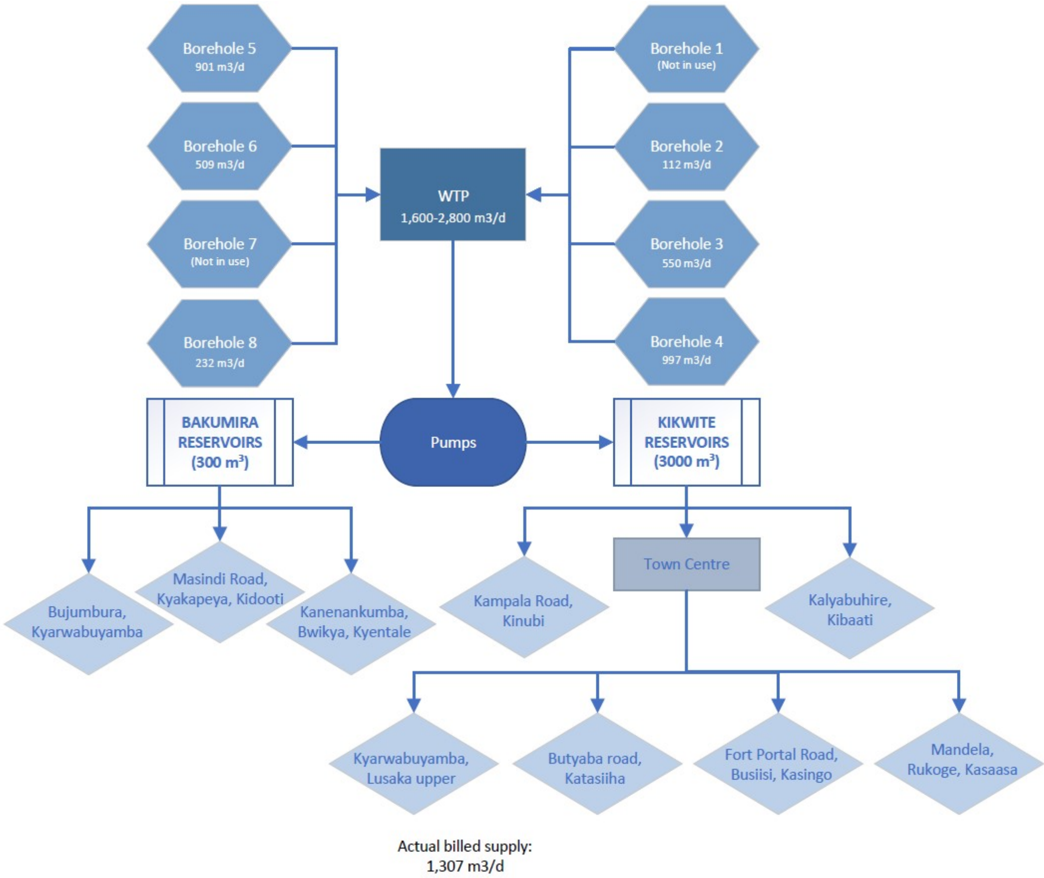


Figure D.5: Current water supply Hoima City (NWSC)

D.4. Water sources

D.4.1. Lake Kyoga and Masindi Port

The Figure below D.6 shows a map of Lake Kyoga, which is one of the options for the expansion of the water system of Hoima.

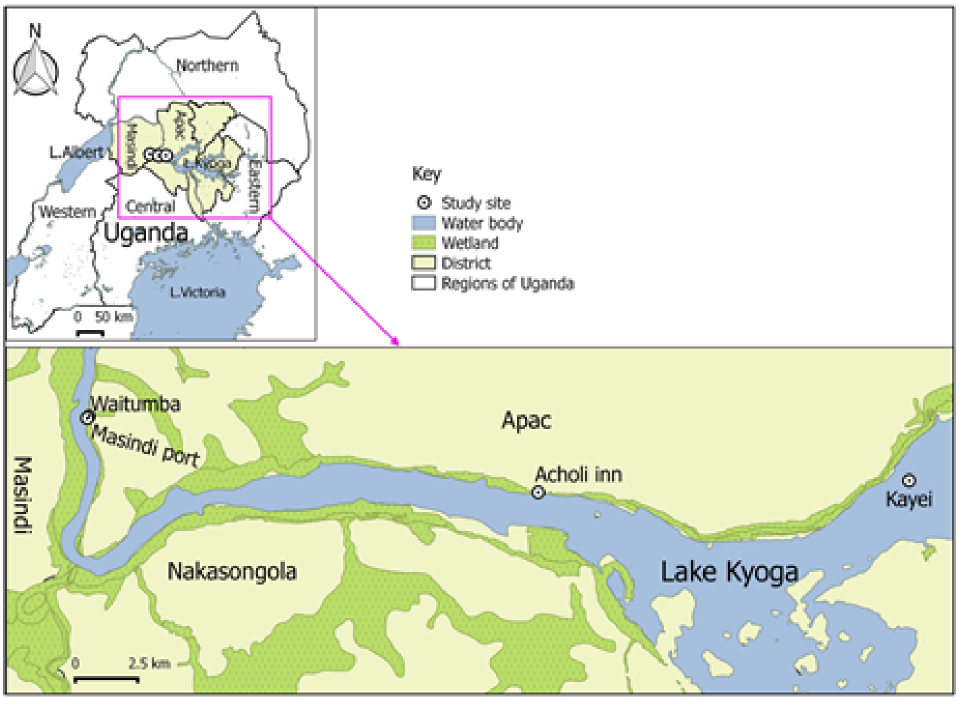


Figure D.6: Map of Uganda showing Lake Kyoga and the location of Masindi Port (R. Ongom & Lukubye, 2017).

The water levels at Masindi port are shown in Figure D.7.

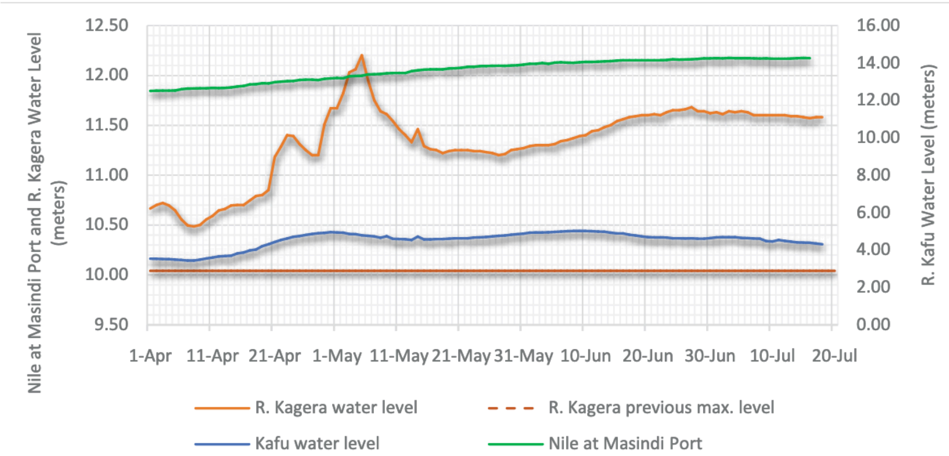


Figure D.7: Water levels at Masindi Port (R. Ongom & Lukubye, 2017)

D.4.2. Kafu River

The catchment area of Kafu River is shown in Figure D.8, which is one of the options for the future water system of Hoima City. This is explained in Chapter 5.

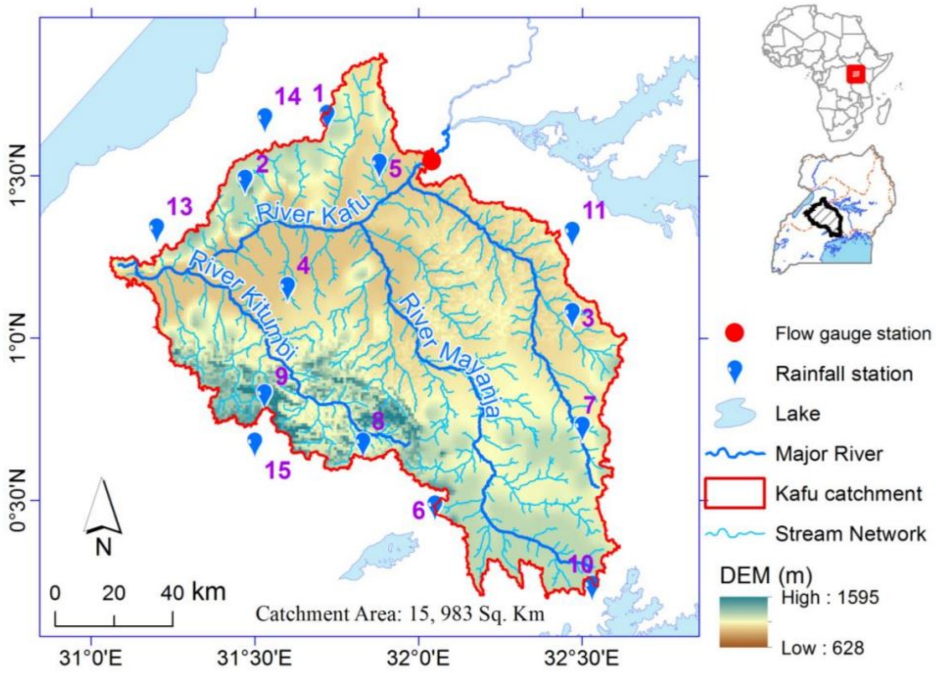


Figure D.8: Delineated map showing Kafu Catchment (Amollo et al., 2020).

D.4.3. Geology

Figure D.9 shows the geology around Hoima City which is used in Chapter 5.

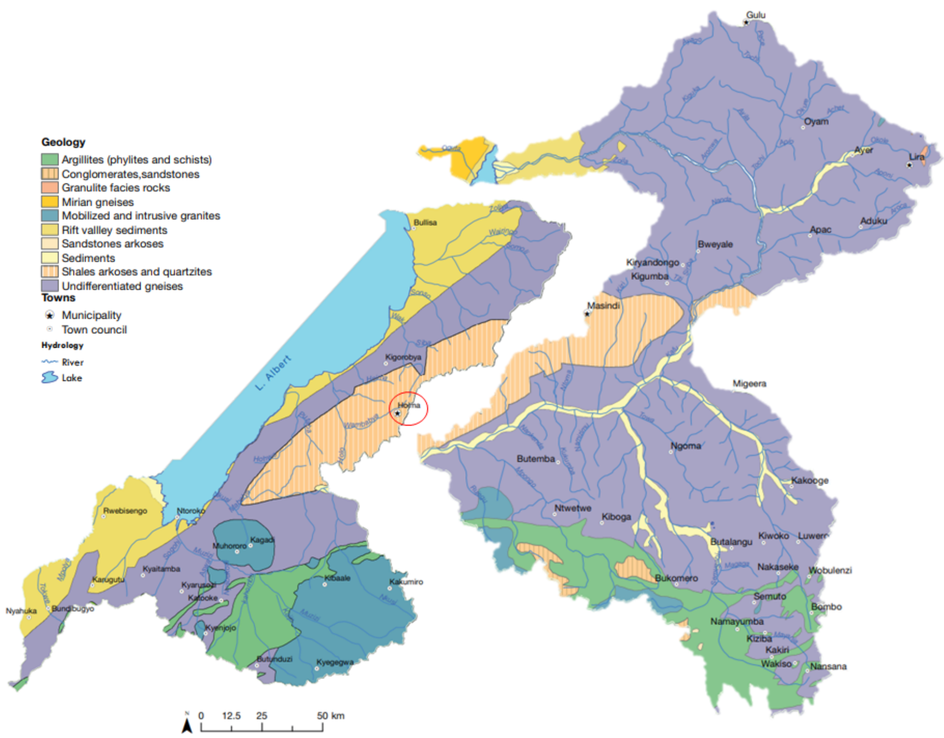


Figure D.9: Geology in Lake Albert area (left) and Victoria Nile area (right) (WE Consult, 2017)

D.4.4. Water treatment process

The water treatment process at the Waste Water Treatment Plant of Hoima City is shown in Figure D.10.

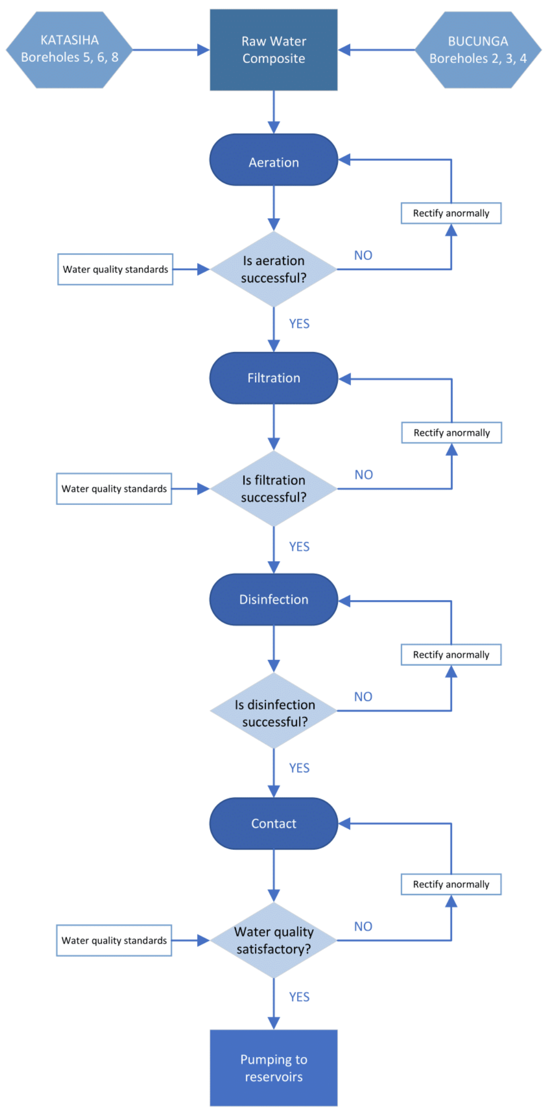


Figure D.10: Water treatment process (information retrieved during fieldwork Hoima)

D.5. MCA results

D.5.1. Financial analysis

Table D.4: Input financial analysis alternatives Hoima City

Alternative	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
Demand coverage gap [%]	100	70	100	40	80
Non revenue water [%]	25	30	20	20	20
New connections	34,800	24,360	34,800	13,920	27,840
Needed boreholes	0	0	0	16	32
Water source	Surface	Surface	Surface	Ground	Ground
Reservoir	Kijwenge	Bakumira	Mpaija	All	All
Height difference [m]	574	259	167	200	200
Intake - treatment [m]	2,000	2,000	1,000	80,000	160,000
Treatment - reservoir [m]	17,500	84,200	18,200	9000	9000
Distribution network [m]	2,262,000	1,131,000	2,262,000	904,800	1,809,600
Booster pumps	2	2	2	2	2
Transport pumps	3	6	2	2	4
Intake - power [m]	2,000	1,000	1,000	10,000	25,000
Remarks	New	Extension	New	Extension	Extension

D.5.2. Performance analysis

Table D.5: Sustainability scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
10	**Soil erosion**	4	4	4	8	8
10	**Impact on flora and fauna**	4	2	2	6	6
10	**Pollution**	6	6	6	6	6
10	**Waste production**	6	4	4	8	8
15	**Materials**	8	8	8	10	10
10	**Energy usage**	4	4	6	8	8
15	**Renewable energy usage**	6	8	8	6	6
20	**Water losses**	6	4	6	8	8
100	**TOTAL**	**5.7**	**5.2**	**5.8**	**7.6**	**7.6**

Table D.6: Durability scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
35	**Expected lifespan water source**	8	8	4	2	2
25	**Expected lifespan system**	8	8	8	6	6
20	**Options for extension**	4	6	6	8	8
20	**Maintability and supply chain**	8	4	6	8	8
100	**TOTAL**	**7.2**	**6.8**	**5.8**	**5.4**	**5.4**

Table D.7: Society scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
20	**Stakeholder participation**	6	4	4	8	8
25	**Health**	10	8	6	6	8
5	**Job opportunities (system)**	10	6	8	4	6
5	**Job opportunities (area)**	10	8	10	6	8
20	**Quality of living environment**	4	4	4	2	4
15	**Illegal usage**	6	6	6	2	2
10	**Ability to serve outside scope**	8	8	4	2	2
100	**TOTAL**	**7.2**	**6**	**5.3**	**4.5**	**5.6**

Table D.8: Feasibility scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater 40%	Groundwater 80%
35	**Demand-supply gap**	10	8	10	4	8
25	**Time frame**	4	2	4	10	8
25	**Operational costs vs. revenue**	6	8	10	8	8
15	**Connection investment costs**	4	6	8	8	8
100	**TOTAL**	**6.6**	**6.2**	**8.2**	**7.1**	**8**

D.5.3. Risk analysis

Table D.9: Risk scores

Weight factor	Criteria	Lake Albert	Masindi Port	Kafu river	Groundwater (40%)	Groundwater (80%)
10	**ECONOMICS**	12	13.5	16	6	6.5
	Higher project costs than expected	12	12	12	6	9
	High treatment costs	12	15	20	6	4
10	**POLITICS**	8.5	15	20	10	12
	Change of plans	12	20	20	4	4
	No grant for land	5	10	20	16	20
25	**SOCIETY**	11.25	12.75	9.25	12	10.75
	Payment ‘loyalty’	10	10	10	8	10
	Unsafe working conditions	16	16	8	8	8
	Inter-generational inequity	3	9	3	12	9
	Sudden population surge	16	16	16	20	16
20	**ORGANIZATION**	9.3	13.7	20	18.3	21.7
	Unreliable and discontinuous water supply	10	15	25	15	25
	Illegal water tapping	12	16	20	20	20
	Insufficient monitoring	6	10	15	20	20
20	**TECHNOLOGY**	7.25	8.5	14	12.75	12.75
	System failure	15	15	15	10	10
	Iron bacteria	3	3	15	15	15
	Borehole complications	1	1	1	25	25
	Surface water complications	10	15	25	1	1
15	**ENVIRONMENT**	11.2	12.2	15.8	9.8	9.8
	Floodings	20	20	20	5	5
	Climate change affects water supply	8	12	20	4	4
	Land slides	15	5	5	5	5
	Unfavourable geotechnical conditions	9	9	9	25	25
	Seasonality affects water supply	4	15	25	10	10
100	**TOTAL**	**9.9**	**12.3**	**15.1**	**12.3**	**12.9**

E

Bugiri District

E.1. Water demand

Table E.1: Overview monthly demands Bugiri District (data retrieved during fieldwork Bugiri)

		[m^3/month]
DOMESTIC DEMAND		**462,017**
	Rural	217,605
	Urban	244,412
COMMERCIAL DEMAND		**3,440**
	Hotels/Lodges	2,400
	Bars/Restaurants	1,100
	Petrol Stations	1,000
	Washing Bays	25
	Public Sanitation	15
INSTITUTIONAL DEMAND		**43,645**
Education centres	Day Schools	30,408
	Boarding schools	11,203
Health Centers and Hospitals	H.Center 1	100
	H.Center 2	375
	H.Center 3	310
	H.Center 4	155
	District Hospital	1,094
INDUSTRIAL DEMAND		**40,100**
	Small Scale	100
	Large Scale	40,000
Total Demand		**549,202**

Figure E.1: Restaurants and bars

E.2. Water supply

E.2.1. Reservoirs

(a) Kapyanga reservoir

(b) Reservoir Low level reservoir

(c) High level reservoir

Figure E.2: Reservoirs Bugiri

E.2.2. Current system

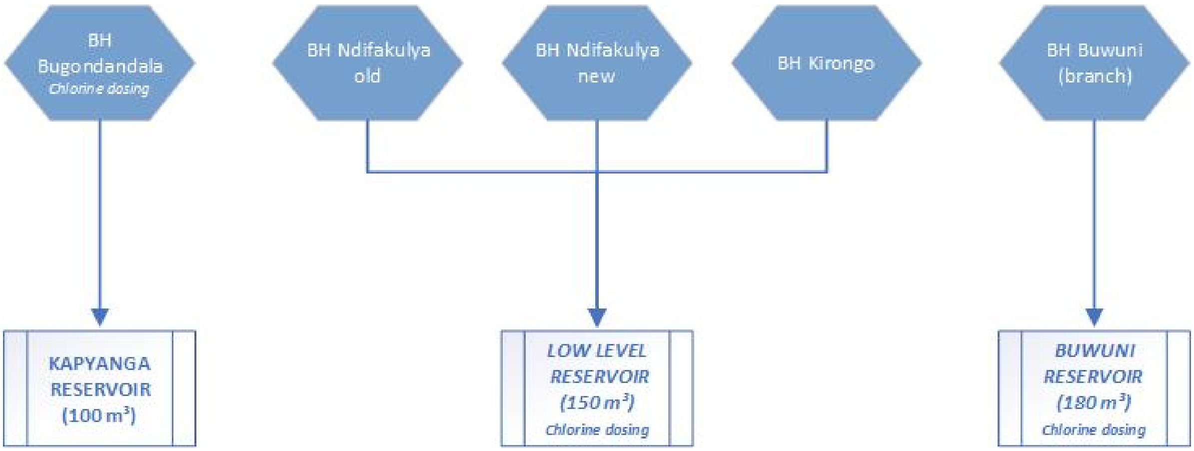


Figure E.3: Current water supply Bugiri District (information retrieved during fieldwork Bugiri)

E.3. Geology

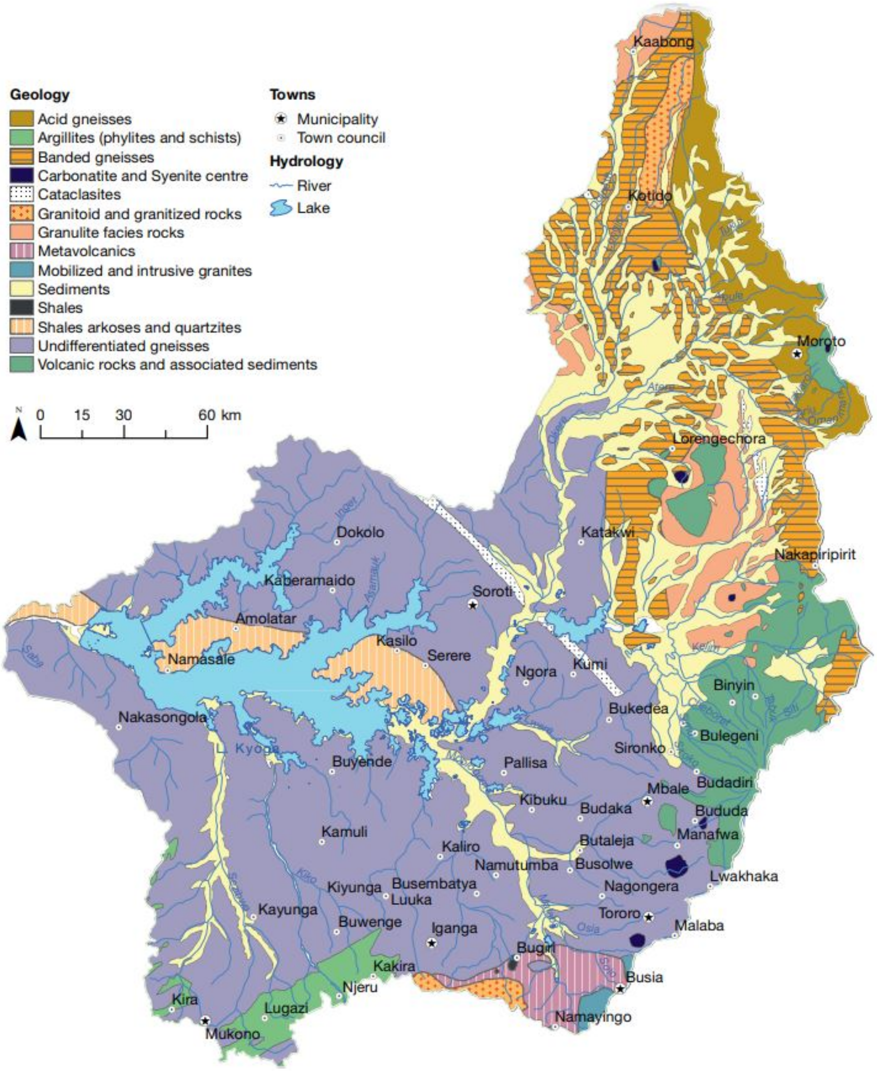


Figure E.4: Geology in Lake Kyoga area (WE Consult, 2017)

E.4. MCA results

E.4.1. Financial analysis

Table E.2: Input financial analysis alternatives Bugiri District

Alternative	Jinja (Masese)	Bugadde	Wakawaka	Majanji
Coverage gap [%]	20	100	100	50
Non revenue water [%]	20	20	20	20
New connections	15,762	78,808	78,808	39,404
Number of boreholes needed	0	0	0	0
Surface/groundwater	Surface	Surface	Surface	Surface
Reservoir	Low level	Low level	Kapyanga	Buwuni
Height difference [m]	11	11	69	-12
Intake - treatment [m]	2,000	2,000	2,000	2,000
Treatment - reservoir [m]	65,700	39,000	26,000	33,000 or 52,500 (via Busia)
Reservoir - Bugiri town [m]	600	600	1,700	12,700
Booster pumps	2	2	1	1
Transport pumps	3	2	2	2
Water intake - power supply [m]	1,000	5,000	1,000	1,000
Remarks	Extension	New	New	Extension

E.4.2. Performance analysis

Table E.3: Sustainability scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
10	**Soil erosion**	6	4	4	6
10	**Impact on flora and fauna**	8	4	4	8
10	**Pollution**	4	6	6	4
10	**Waste production**	6	6	6	6
15	**Materials**	8	6	6	10
10	**Energy usage during construction**	8	2	2	6
15	**Renewable energy usage**	8	6	8	6
20	**Water losses**	4	6	8	6
100	**TOTAL**	**6.4**	**5.2**	**5.9**	**6.6**

Table E.4: Durability scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
35	**Expected lifespan water source**	8	8	8	8
25	**Expected lifespan system**	6	8	8	8
20	**Options for extension**	2	8	6	6
20	**Maintainability and supply chain**	4	6	6	4
100	**TOTAL**	**5.5**	**7.6**	**7.2**	**6.8**

Table E.5: Society scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
20	**Stakeholder participation**	4	6	8	6
25	**Health**	6	8	8	6
5	**Job opportunities (system)**	8	8	8	8
5	**Job opportunities (area)**	4	8	8	6
20	**Quality of living environment**	6	4	4	6
15	**Illegal usage**	4	4	6	4
10	**Ability to serve outside scope**	2	8	8	4
100	**TOTAL**	**4.9**	**6.2**	**6.9**	**5.6**

Table E.6: Feasibility scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
35	**Demand-supply gap**	2	10	10	6
25	**Time frame**	6	6	6	6
25	**Operational costs vs. revenue**	10	10	10	10
15	**Connection investment costs**	8	8	8	8
100	**TOTAL**	**5.9**	**8.7**	**8.7**	**7.3**

E.4.3. Risk analysis

Table E.7: Risk scores

Weight factor	Criteria	Jinja (Masese)	Bugadde	Wakawaka	Majanji
10	**ECONOMICS**	9	11.5	11.5	9
	Higher project costs than expected	12	15	15	12
	High treatment costs	6	8	8	6
10	**POLITICS**	8	13	6.5	8
	Change of plans	12	16	8	16
	No grant for land	4	10	5	4
25	**SOCIETY**	11.75	8.5	8.5	10.25
	Payment 'loyalty'	8	10	10	8
	Unsafe working conditions	12	12	12	12
	Intergenerational inequity	12	3	3	9
	Sudden population surge	15	9	9	12
20	**ORGANIZATION**	7	7	6	7
	Unreliable and discontinuous water supply	5	5	5	5
	Illegal water tapping	12	12	9	12
	Insufficient monitoring	4	4	4	4
20	**TECHNOLOGY**	4.25	7.75	7.75	5.5
	System failure	4	12	12	6
	Iron bacteria	3	3	3	3
	Borehole complications	1	1	1	1
	Surface water complications	9	15	15	12
15	**ENVIRONMENT**	9.2	9.2	8.6	9.2
	Floodings	15	15	15	15
	Climate change affects water supply	6	6	6	6
	Land slides	10	10	10	10
	Unfavourable geotechnical conditions	9	9	6	9
	Seasonality affects water supply	6	6	6	6
100	**TOTAL**	**8.3**	**8.9**	**8**	**8.1**

F

User manual MCA-tool: Drinking Water Supply Uganda

This Appendix contains the user manual of the multi-criteria analysis tool. It is subdivided into four parts: a summary of the steps that need to be taken to perform the analysis, an introduction, a section on how to use the tool and finally how to evaluate the analysis.

F.1. Summary

This multi-criteria analysis (MCA) tool is constructed to compare different design alternatives for water supply in Uganda. The steps to be performed are the following.

F.1.1. General

1. Define the objective of the study.
2. Collect useful information about project area, including geology, climate, vegetation, topography, current and future water demand, current water supply, challenges, future plans.
3. Determine the different design alternatives.
4. Collect for every alternative the following information: amount of water available, water quality, rough design of transmission and distribution system.
5. Select the exact design criteria.
6. Assign weights to the categories of the performance analysis. The total of weights should be equal to 100.

F.1.2. Financial analysis

1. Find the needed values for the input.
2. Estimate the gap that will be covered.

F.1.3. Performance analysis

1. Define the criteria in every category based on the scope and context
2. Adjusting the weights (between 1 and 100) of all criteria is optional. It is also possible to use the weights provided in the tool. If adjusting the weights, check if they add up to 100.
3. Describe the expected performance of all criteria for each alternative using the information collected per criterion according to the user manual.
4. Give scores for every criterion according to the score tables provided in the sheets.

F.1.4. Risk analysis

1. Define the risks in every category based on the scope and context.
2. Adjusting the weights (between 1 and 100) of all risk categories is optional. It is also possible to use the weights provided in the tool. If adjusting the weights, check if they add up to 100.
3. Describe the expected probability and impact of all risks for each alternative.

4. Give scores, based on the objective. Score both the probability and impact with a value between 1 and 5. A very low probability or impact is scored with 1. A very high probability or impact is scored with 5.

F.1.5. Evaluation

In the ‘RESULTS’-sheet of the tool the results can be found. A summary of the results (costs, costs/connection, performance, payback time, risk and estimated gap coverage) is given in the ‘TOTAL SCORE’-table.

A choice between the alternatives can be made based on the results of the MCA-tool. Discussing the analysis with different stakeholders improves the results and makes sure that every interest is considered.

F.2. Introduction

This multi-criteria analysis (MCA) tool is constructed to compare different design alternatives for water supply in Uganda. A multi-criteria analysis provides insights in the decision-making process by giving weights to the main criteria that are used. Much time and effort are wasted considering non-feasible options, while if one follows a step-wise approach this can be avoided. If the tool is used, the alternatives can be compared quickly and a choice can be made depending on the preference of the decision makers. This tool is focused on the evaluation of the long-term water sources in order to meet the future water demand.

F.2.1. Why using an MCA?

It can be difficult to compare alternatives, since an option can be preferred because a source is very reliable and another option is better looking at the costs. That is why it is interesting to evaluate the different alternatives using a multi-criteria analysis. An MCA provides insights in the decision-making process and will quantify a criterion like ‘stakeholder participation’, even though these objective criteria cannot be evaluated in terms of costs or numbers. In an MCA, criteria are combined and averaged using scores and weights. The MCA supports the discussion between the different stakeholders and is transparent for everyone involved.

F.2.2. How this tool is structured

The MCA-tool consists of three main analyses: a financial analysis, a performance analysis and a risk analysis. The financial analysis focuses on financial viability of the proposed project, i.e., if the proposed project is financially and economically attractive from the entity’s viewpoint. Next to that, the performance analysis covers the following design criteria: sustainability, durability, society, feasibility. Finally, in the risk analysis, potential issues that could negatively impact the project plan are identified and analysed.

F.3. Using the tool

F.3.1. General

This MCA-tool considers the gap between the future water demand and current supply as the problem that needs to be solved. In order to find the right solution for the problem, the objective of the study has to be clearly defined. The objective results in which design criteria are considered and the weights that will be assigned to the criteria.

After defining the objective, useful information has to be collected about the project area. This includes the geology, the climate and vegetation and the topography. Besides, the current and future water demand have to be studied, as well as the current water supply. Lastly, it is important to know the different challenges regarding the water supply of the area and to have an overview of the future plans of the National Water & Sewerage Corporation, the Ministry of Water and Environment and the District Office.

After collecting useful data, the different alternatives for a solution can be determined. The next step is, to find out how much water the source can provide, the water quality and the rough design of the transmission and distribution system. If this information is available, the alternatives can be analysed using the tool. The information needed to use the tool is described in the next paragraphs. The MCA-tool consists of three main analyses:

- A financial analysis;
- A performance analysis, considering sustainability, durability, society and feasibility;
- A risk analysis.

The financial analysis focuses on financial viability of the proposed project, i.e., if the proposed project is financially and economically attractive or not from the entity's viewpoint. Next to that, the performance analysis covers the following categories: sustainability, durability, society, feasibility. Finally, in the risk analysis, potential issues that could negatively impact the project plan are identified and analysed.

Before filling in the data and the scores, the exact design criteria should be selected and a weight should be applied to every criterion of the performance analysis. The weights of all four categories (sustainability, durability, society and feasibility) can be assigned in the 'RESULTS'-sheet and the weights of all criteria in every category can be assigned in the sheets of the categories. The sum of the weights should always be equal to 100.

F.3.2. Financial analysis

To roughly make an estimation of the costs of an alternative, the investment and the operational costs are calculated. The costs are estimated using several reports and billings of different contractors. In the 'Finance'-sheets an estimation of the cost of a certain alternative is calculated. Every design alternative uses its own sheet (i.e., use 'Finance (Alt. 1)' for the first alternative, use 'Finance (Alt. 2)' for the second alternative, etc.). If all the alternatives are evaluated, the alternatives can be compared from a financial point of view, for example looking at the costs per connection or the profit ratio.

It has to be noted that this is only to get insight in the order of magnitude of a particular alternative, and it cannot be guaranteed that the costs will exactly come down to the value presented.

Inputs

To perform the financial analysis, the following inputs are needed.

- Demand supply gap [m3/day]: resulting from baseline study
- Non-revenue water [%]: resulting from baseline study (calculated by using amount of sold and produced water)
- Lifetime project [years]
- Coverage gap [%]: depending on the water availability and the gap, the percentage can be calculated.
- Network: The network costs consist of the generator costs in case that is needed and the costs of the groundwater or surface water network, or a combination of both. Each part of the water network has a certain length and a specific type of pipeline.
  - Number of generators [-]
  - Number of boreholes needed: estimate the number of boreholes needed to fill (the percentage of) the gap.
  - Type of treatment: new, extension or none
  - Assessment study surface/groundwater: decide if the alternative considers surface water, groundwater or both.
  - Height difference [m]: the height difference between the water intake and reservoir can be estimated using Google Earth Pro or a Digital Elevation Map of the region.
  - Intake – treatment:
    - Distance [m] can be measured in Google Maps or QGis.
    - Diameter [mm] depending on amount of water that needs to be transported.
    - Type of pipeline

        - GW: [uPVC PN16 series; HDPE PN10 series]
        - SW: [DIP series]
  - Treatment - reservoir [m]:
    - Distance [m] can be measured in Google Maps or QGis.
    - Diameter [mm] depending on amount of water that needs to be transported.
    - Type of pipeline
      - GW: [uPVC PN16 series; HDPE PN10 series]
      - SW: [DIP series]
  - Reservoir – distribution network [m]:
    - Distance [m] can be measured in Google Maps or QGis.
    - Diameter [mm] depending on amount of water that needs to be transported.
    - Type of pipeline
      - GW: [uPVC PN6 series; uPVC PN10 series]
      - SW: [uPVC PN6 series; uPVC PN10 series]
  - Distribution network - Customer:
    - Distance [m]
    - Diameter [mm] depending on amount of water that needs to be transported.
    - Type of pipeline
      - GW: [uPVC PN6 series; uPVC PN10 series]
      - SW: [uPVC PN6 series; uPVC PN10 series]
  - Booster pumps: the number of pumps and type [small; medium; large]
  - Transport pumps: the number of pumps and type [small; medium; large]
  - Water intake - power supply: distance grid [m] can be estimated using the map 'distribution lines' https://energy-gis.ug/gis-maps or solar power.
- Funding: Grants (optional)

The length needed for one extra connection is estimated to be 100 meters, but depends on the location and existing network. New connections: it is estimated that for every connection 0.500 m3/day is used on average.

Output
Investment costs
These are the total costs to create the water system. It consists of the studies that need to be performed, the generators, pumps, pipelines, land that needs to be bought, reservoirs and the construction of the treatment plant/borehole.

Operational costs
The operational costs are the cost of the operation of the system. This includes maintenance, labour, energy costs and the costs of the chemicals.

Payback time
The payback time is the amount of years that it will take to earn back the investment. The income earned by selling the water should be higher than the operational costs, which means that it is possible to earn back the investment costs that have been made at the beginning of the project. The longer the payback time, the longer it takes before the project is profitable.

Costs per connection per 40 years
The cost per connections is calculated by the total operational costs for 40 years added to the investment costs, divided by the amount of connections. The costs per connection decrease if more connections are installed and the operational and investment costs are minimized.

Profit Ratio

The profit is calculated as the difference between the water connection revenues and the operational costs divided by the revenues. The profit ratio indicates the profitability of the operation. A positive value for the ratio means a profit is made and the closer the ratio comes to 1, the lower the operational costs are compared to the water revenues.

F.3.3. Performance analysis

Different design alternatives can easily be compared based on a performance analysis. This performance analysis rates the alternatives with a score between 1 and 10, considering four main categories: sustainability, durability, society and feasibility. Each category can be considered in their own sheet in the tool. Rating the criteria goes according to Table 1 to 4, which contain the descriptions of every score for each criterion. The four main categories and their criteria are explained in this paragraph. The following steps have to be conducted to analyse the performance:

1. Define the criteria in every category based on the scope and context.
2. Adjusting the weights (between 1 and 100) of all criteria is optional. It is also possible to use the weights provided in the tool. If adjusting the weights, check if they add up to 100.
3. Describe the expected performance of all criteria for each alternative.
4. Give scores for every criterion, based on the objective and according to Tables F.1, F.2, F.3 and F.4.

Sustainability

Sustainability refers to the quality of causing little or no damage to the environment. The sub-criteria that support this category are the following: environmental damage, pollution, waste production, materials, energy usage and operational efficiency. Table F.1 gives an overview of the scores which can be assigned to every criterion.

Table F.1: Sustainability criteria

Criteria	2	4	6	8	10
Environmental damage: soil erosion	Extreme damage	High damage	Medium damage	Little damage	No damage
Environmental damage: impact on flora and fauna	Extreme damage	High damage	Medium damage	Little damage	No damage
Pollution	Extreme pollution	High pollution	Medium pollution	Little pollution	No pollution
Waste production	Extreme waste production	High waste production	Medium waste production	Little waste production	No waste production
Materials	Non-sustainable	Slightly non-sustainable	Neutral	Slightly sustainable	Sustainable
Energy usage during construction	Very high energy use	High energy use	Medium energy use	Low energy use	Very low energy use
DROP DOWN (Energy usage during lifespan)	MAKE A CHOICE IN MENU	MAKE A CHOICE IN MENU	MAKE A CHOICE IN MENU	MAKE A CHOICE IN MENU	MAKE A CHOICE IN MENU
Water losses / Operational efficiency	Extreme water losses	High water losses	Medium water losses	Little water losses	No water losses

Environmental damage

Environmental damage can be due to soil erosion and the impact of the system on flora and fauna. This criterion is therefore separated into two sub criteria:

- Environmental damage: soil erosion
- Environmental damage: impact on flora and fauna

Inappropriate construction practices and soil protection measures may induce or accelerate soil erosion with possible pollution and siltation of downstream water sources. Next to that, removal of top soil may lead to loss of soil fertility. Also, the (negative) impact on flora and fauna can be considered a kind of environmental damage. This could be for example the loss of wetland plants and associated fauna, or cleared vegetation which may compromise aesthetic value of the sites. These impacts can for example be caused by constructing a pipe in the ground, drilling a borehole or constructing a new water treatment plant.

Information needed:

- How is the system affecting the ground and can this cause soil erosion?

- How is the system affecting flora and fauna in the area the system is implemented in?

Pollution
There are several types of pollution that need to be taken into account in this case: air pollution, soil contamination, water pollution and noise pollution. Air pollution means emissions of air pollutants. Soil contamination and water pollution occur by pollutants entering the soil and the water source. This can for example be caused by processing the waste of treatment incorrectly. Noise pollution occurs when noise, produced by the system, causes negative impacts to humans or animals. Determining the pollution goes for during construction as well as during the lifespan. Information needed:

- The number of air pollutants emitted by the system during both construction and the lifespan;
- The number of pollutants entering the soil and water source during both construction and the lifespan;
- Is there any noise produced by the system that affects humans and/or animals negatively?

Materials
The sustainability of the materials used by construction of the system influences the overall sustainability. The impact of the materials on sustainability can be influenced by the amount of material used (large quantities have a higher sustainable impact than small quantities) as well as the kind of material that is used. Besides, the transport distance of the materials also has to be taken into account. Using local materials has a lower negative impact on sustainability than using materials that have to travel a long distance.

Information needed:

- The environmental impact of the used materials on the environment. This can for example be determined by an Environmental Cost Indicator (ECI).

Energy usage
The energy usage is divided into energy usage during construction and during lifespan. During construction the existing power grid will be used, so for this criterion only the amount of energy influences the sustainability. During the lifespan of the system, the type of energy as well as the amount of energy that is used for the system influences the sustainability. To determine the score of this criterion, first the type of energy has to be determined. A distinction is made between the following types, of which one has to be selected in the tool:

- Renewable energy usage (only renewable energy is used during lifespan)
- Non-renewable energy usage (only non-renewable energy is used during lifespan)
- Combination energy usage (a combination of renewable and non-renewable energy is used during lifespan)

After selecting the type of energy use, a score can be assigned, which covers the amount of energy use. One should be aware that the scores differ per type of energy, so the right type of energy has to be selected before assigning a score.

Information needed:

- The amount of energy used during construction;
- The type of energy used during the lifespan;
- The amount of energy used during the lifespan.

Operational efficiency (water losses)
The operational efficiency considers the amount of water losses in the (piping) systems during its lifetime.

Information needed:

- The amount of water losses in the (piping) systems during its lifetime.

Durability
Durability of a system refers to the quality of being able to last a long time without becoming damaged. The sub criteria that support this category are the following: expected lifespan water source, expected lifespan system, options for extension and maintenance accessibility. Table F.2 gives an overview of the scores which can be assigned to every criterion.

Table F.2: Durability criteria

Criteria	2	4	6	8	10
Expected lifespan water source	1 year	10 years	50 years	100 years	Infinite
Expected lifespan system	<10 years	10- 15 years	16 - 20 years	21 - 25 years	>25 years
Options for extension	No extension possible	Little extension possible	Medium extension possible	Much extension possible	Unlimited extension possible
Maintainability & supply chain	Almost no accessibility	Little accessibility	Medium accessibility	Good accessibility	Perfect accessibility

Expected lifespan water source
The expected lifespan of the water source considers the expected time until the water source is depleted. This influences the durability of the whole system, as no water can be produced by the system when the water source is depleted.

Information needed:

- The estimated time until the water source is depleted. Expected lifespan system

The expected lifespan of the system considers the time until the system has to be replaced by a new system. Most water supply systems in Uganda are designed for a lifespan of 20 years. However, the bigger the life span, the lower the relative investments costs. Therefore, the system is rated for this criterion with a score of 6 when the lifespan is equal to 20 years and the rating is higher for bigger lifespans. The system scores a 10 for a lifespan of 25 years and longer.

Figure F.1 contains the economic life of different parts of a system. This could be used to determine the estimated lifetime of a system.

Information needed:

- The estimated time until the system has to be replaced by a new system.

	Component	Economic Life (Years)	Annual Maintenance Costs - % of Construction Costs
1	Dams	40	0.5
2	Intake works, including boreholes; mass concrete structures such as intakes, underground pits, culverts, etc.	40	1
3	Earthworks generally	40	1
4	Boreholes and wells	20	1
5	Pumps	10	5
6	Diesel engines	10	5
7	Electric motors, cables and switch gears	10	5
8	Piping all types	30	1
9	Treatment works: Treatment works in masonry or reinforced concrete	30	1
10	Storage tanks in masonry or reinforced concrete	30	1
11	Storage tanks: sectional steel including towers	20	2
12	Storage tanks corrugated galvanized steel (C.G.S.) on timber stands	10	2
13	Buildings C.G.S. on timber	20	1
14	Buildings, masonry	30	1
15	Water kiosks, latrines, licensed retailer points etc.	20	2
16	Gantries, steelwork etc.	20	2
17	Permanent tools and plant not mentioned elsewhere	10	2
18	Water meters	10	5
19	Chemical dosing gear	10	5
20	Instruments and testing apparatus	5	5
21	Access roads	30	1
22	Fences, G.S. wire or mesh on timber	10	1
23	Fences, G.S. wire or mesh on concrete posts	20	1

Figure F.1: Annual Maintenance Costs and Economic Life (Ministry of Water and Environment, 2014)

Options for extension
The possibility of extending the system increases the durability of the system. The system could be needing an extension when the water demand is increasing with a higher rate than expected or when another area nearby has to be served.

Information needed:

- The availability of extra space for an extra reservoir, water treatment plant and a pumping station;
- The possibility to bore extra boreholes when using groundwater as a water source;
- The possibility to expand the power grid;
- The amount of extra surface or ground water available.

Maintenance accessibility
The maintenance accessibility rates the system regarding the access to technology for maintaining the system. A high possibility to maintain the system increases the durability. Information needed:

- Can every part of the system be fixed or replaced relatively easily;
- Are there any parts of the system that are difficult to maintain?

Society
This category covers the impact the system has on the society. The sub criteria that support this category are the following: stakeholder participation, health, job opportunities quality of living environment, illegal usage, ability to serve outside scope. Table F.3 gives an overview of the scores which can be assigned to every criterion.

Table F.3: Society criteria

Criteria	2	4	6	8	10
Stakeholder participation	No participation	Little participation	Medium participation	Good participation	Excellent participation
Health	Negative health impact	Slightly negative health impact	No health impact	Slightly positive health impact	Positive health impact
Job opportunities (system)	No job opportunities	Little job opportunities	Medium job opportunities	Many job opportunities	Plenty job opportunities
Job opportunities (area)	No job opportunities	Little job opportunities	Medium job opportunities	Many job opportunities	Plenty job opportunities
Quality of living environment	Negative impact	Slightly negative impact	No impact	Slightly positive impact	Positive impact
Illegal usage	Guaranteed illegal usage	High probability of illegal usage	Medium probability of illegal usage	Little probability of illegal usage	No illegal usage
Ability to serve outside scope	No ability of service	Little ability of service	Medium ability of service	Good ability of service	High ability of service

Stakeholder participation
Stakeholder participation is very important in the decision-making process. Not every stakeholder has the same interest in the project. Therefore, when comparing the alternatives, the probability for cooperation of different stakeholders should be considered. Using a water source that is relatively far away from the project area, could result in a low stakeholder participation, due to the interests of multiple districts for example. Besides this, using a water source or supply system that is already known to be effective and is already familiar by people, will most likely result in a higher stakeholder participation.

Information needed:

- Is the water source located in a district other than the project area's district?
- The familiarity of the water source and supply system.

Health
This criterion considers the health impact on the people by drinking the water. Direct use of untreated or poorly water may result in severe health issues. The way of treating the water therefore influences the water quality. Besides, more people using the water increases the risk of diseases. Besides this, other health issues can occur as well. For example, pools of stagnant water may form in pits, holes and excavated ditches and create suitable habitats for disease vectors such as malaria. Another main issue can be the potential of HIV spread as well as poor hygiene in workers camps.

Information needed:

- The steps in the treatment process;
- The amount of people using the water;
- The probability of stagnant water;
- How well is the worker's hygiene?

Job opportunities
By creating or extending a water supply system, new job opportunities are created. These jobs can be either on site or in the case area. Therefore, this criterion can be divided into two sub-criteria:

- Job opportunities: system
- Job opportunities: area

The first sub-criterion covers the job opportunities created by the implementation of the new system. Examples of new jobs are work on site, for example at boreholes or at the water treatment plant, or the construction of the pipes. The second sub-criterion covers the job opportunities created in the project area. If the project area is highly supplied by water, this might result in economic growth and area development. The place might become more attractive to live and work.

Information needed:

- The number of jobs that are needed for the implementation of the system;
- The number of jobs that can be created in the area due to the extra amount of water supplied.

Quality of living environment
Quality of the living environment can also be seen as the impact of the realization of the water supply system on the environment where people are living. For example, building a treatment plant where houses are located, would have a negative impact on the living environment. The quality is determined by a number of things. For example, disruption of social order, which is about the influx of people in the area which may affect the local economy, cause alteration of culture and introduce behavioural changes.

Information needed:

- Are parts of the system (e.g., reservoir, water treatment plant) planning to be built in an area where currently houses are located and in what quantity?
- The influx of people in the project area caused by the extra amount of water supplied.

Illegal usage
This criterion focuses on illegal usage. This can be scored as the probability that illegal usage will occur, such as tapping water from a borehole when not paying for it.

Information needed:

- The probability of illegally tapping water from the system.

Ability to serve outside scope
Focusing on the long term, a water supply system could be designed which has a higher capacity than the water demand it should be designed for. In this case, areas outside the project scope could also be supplied with water.

Information needed:

- The amount of area available to expand the system: extra reservoirs, extra tanks in the water treatment plant, extra pumps, extra boreholes (if using groundwater supply) and extra pipes;
- The availability of extra water in the source to be able to serve more people;
- The availability to increase the power supply.

Feasibility
The last category of the performance covers the feasibility of the project and the feasibility to serve everyone in the project area with water. The sub criteria that support this category are the following: demand-supply gap, time frame, operational costs vs. revenue and total connection costs. Table F.4 gives an overview of the scores which can be assigned to every criterion.

Table F.4: Feasibility criteria

Criteria	2	4	6	8	10
Demand-supply gap	High gap	Slightly high gap	Medium gap	Small gap	No gap
Time frame	Long (>16 years)	Slightly long (16-12 years)	Medium (8-12 years)	Slightly short (4-8 years)	Short (<4 years)
Operational costs vs. revenue	Unprofitable	Slightly unprofitable	Balanced	Slightly profitable	Profitable
Connection investment costs	High	Slightly high	Medium	Slightly low	Low

Demand-supply gap
The feasibility to serve everyone in the project area with water is influenced by the size of the remaining gap between the demand and the supply. This criterion can be rated using the coverage percentage in the last sheet of the tool. A high coverage, means a small gap, which subsequently means a high score and vice versa.

Information needed:

- The future water demand for the year the system is designed for, including the domestic, commercial, institutional and industrial demand;
- The current water supply.

Time frame
This criterion considers the time until full capacity of the water supply system is used from now on. It is generally accepted that the optimum period of a project is between 5 and 10 years and should rarely exceed 20 years. Besides, systems designed for long-term, are designed to serve water in 25 years. Therefore, it is desired that the system reaches its full capacity a lot earlier than these 25 years. The time frame scores medium, when it takes 8 to 12 years until the system can be used on full capacity.

Information needed:

- The expected time until full capacity of the water supply system is used.

Operational costs vs. revenue
This criterion considers the difference between the operational costs and the revenue per connection. The system is low rated when it is unprofitable and high rated when it is profitable. The ratio between the operational costs and the revenue can be found in the 'Finance'-sheets of the tool.

Information needed:

- The operational costs (determined in the 'Finance'-sheet);
- The revenue (determined in the 'Finance'-sheet).

Connection investment costs
The last criterion of the feasibility is the connection investment costs. These are the investment costs per connection in the system.

Information needed:

- The connection investment costs (determined in the 'Finance'-sheet).

F.3.4. Risk analysis

To compare the risks of different alternatives, the alternatives are classified with so-called risk classes. To classify an alternative with a risk class, in the 'Risk'-sheet the sum is taken of the probability multiplied by the impact.

The probability and impact classes are ranked from 1 to 5. In this case, a very low probability or impact is scored with 1. A very high probability or impact is scored with 5. With the knowledge that a risk is calculated by the product of the probability and impact, the lowest possible risk can be scored with 1 and the highest possible risk can be scored with 25. The risks are then also classified. Scores between 1 and 5 are classified as a very low risk (risk class 1). Scores between 20 and 25 are classified as a very high risk (risk class 5). If an alternative has a score in risk class 5, it should be rejected instantly.

The probability can be estimated if the alternatives are studied. In order to estimate the probability, it is important to know for example the location of the source, the political circumstances and whether groundwater or surface water is used. For every risk, this is explained in detail in the paragraphs below.

The impact means the size of the effect a certain risk has. The impact can be several things, for example financial or environmental consequences. Another impact of a poor risk management could be risking human lives. On top of that, a risk can have a societal impact, for example people fighting over water, resulting in a war and bad living conditions. Some risks lead to the cancelation of the project plans, which is something that should be avoided as well, since a lot of time and money is spend already during the preparation phase of an alternative. If an impact score of a certain risk is given, these consequences should be considered. It is also important to keep in mind that if the coverage of the gap is smaller, so less water is supplied, the impact of a certain risk is also lower. The risks are subdivided into four main categories. A certain importance can be given to the different categories. Therefore, a weight factor is assigned to each of the categories and the sum of these weight factors should add up to 100 in total. The six main categories are discussed below.

The following steps have to be conducted to analyse the risks:

1. Define the risks in every category based on the scope and context.
2. Adjusting the weights (between 1 and 100) of all risk categories is optional. It is also possible to use the weights provided in the tool. If adjusting the weights, check if they add up to 100.
3. Describe the expected probability and impact of all risks for each alternative.
4. Give scores, based on the objective. Score both the probability and impact with a value between 1 and 5. A very low probability or impact is scored with 1. A very high probability or impact is

Economics
In the first category, economics, there is one point considered as a risk. The economic risks are very important in making a decision for a certain alternative, and the higher the risk is on this aspect, the less probable that this will be recommended as an alternative.

- Higher project costs than expected
- High treatment costs

Due to bad maintenance, vandalism, price fluctuations or a poor quality of the materials (causing for example pump failure or leakages in the pipes), the costs of the project turn out higher than expected. The effect is that the project will turn out too expensive and the project might not be executed.

Due to contamination (diseases) of the water source, the treatment costs can be higher than expected. The contamination can be caused by for example the discharge of a nearby factory, the disposal of faecal matter or agricultural activities. The impact of a contamination is for example higher in a small stream or borehole in the village, than in a big lake or sea.

Politics
Secondly, the political risks are considered. The following risks are considered, since they could have an effect on the progress and might even cause failure of the completion of the project.

- Change in plans
- No grant for land

Because of political issues it is possible that plans will change during the implementation, which will slow down the project and could lead to complications in the execution of proposed plans. Another issue that can be a risk is that due to political or societal reasons, it is not possible to get permission to buy the required land for the treatment plant or borehole that needs to be constructed on a certain location. The effect of this risk is that this will slow down the project or might even stand in the way of the completion of the project. For example: if the land, on which for example a treatment plant has to be build, is family property or is owned by the army, it might be hard to buy the land (too costly or it takes too much time to get permission).

Society
The risks in the category 'Society' might be one of the most difficult risks to estimate. The behaviour of the people is something that cannot be exactly predicted and differs in every situation, which makes it an important factor to consider in a risk analysis. The following risks are considered:

- Payment 'loyalty'
- Unsafe working conditions
- Inter-generational inequity
- Sudden population surge

There might be a situation that people are not interested in being connected to the system, because they already have their own source or they do not see the importance of safe and clean drinking water. Or in some cases, people simply cannot afford it to pay for their water. Therefore, there is a possibility that people are unwilling to pay for their water (payment 'loyalty'). The result of this is a lower revenue and that means the pay-back time is longer than expected. The impact is higher in the case of a supply system with higher investment costs.

Due to a challenging construction phase to execute the project, it could be the case that the workers are exposed to unsafe working conditions. This is for example the exposure of workers to occupational safety hazards from activities such as excavations, working with heavy equipment, working under noisy conditions, working in confined spaces, lifting of heavy objects, storage and handling and use of hazardous substances and wastes. For example, building a pipeline that needs to bridge a large height difference, might endanger the safety of the workers more. This risk can be minimized if there will be surveillance, but it is even better to pick a less risky alternative in terms of working conditions.

Thirdly, if the water demand is not met, this could lead to the risk of inter-generational inequity. The effect of this will be that there could develop mutual tensions among the people demanding for the water.

Lastly, because of a rapid economic development or a war in a neighbouring country, the probability for a sudden population surge is increased. This has as an effect that the water demand is much higher than was accounted for. This means the future supply estimation will be an underestimation and there will not be enough water for all the people.

Organization
Depending on which water source is used, there are several risks that should be taken into account from an organizational point of view:

- Unreliable and discontinuous water supply
- Illegal water tapping
- Insufficient monitoring

First of all, if there is limited availability of the water source, there is a higher probability that the water supply is unreliable and discontinuous. There can be periods with little water availability or no water at all. The impact of this risk is high since it is very important to provide the customers with water every day of the year. For example, the risk is lower if the water is extracted from a big lake than when it is pumped from the groundwater or extracted from a river with a fluctuating water level.

There is a higher probability that people will illegally tap water from the system, if the water supply system is not well protected. This will have as an effect that the system will be damaged and there will be high water losses.

If there is no importance given on monitoring the water level of the source or when there is no money provided for people to fulfil these jobs, there is a risk of the insufficient monitoring the source. The effect could be that the supply in the future is not guaranteed. In some cases, (for example a lake with a quite constant water level,) monitoring is not very important, which means a low impact for this risk.

Technology
The risks in the category technology are important to be studied in much detail. Even though, there are still different risks in several parts of the new water supply system. The technical risks are mainly at the point of extraction and consists of the following:

- System failure
- Iron bacteria
- Borehole complications
- Surface water complications

There is a probability that the system or construction will fail, due to bad maintenance, vandalism or poor material quality. As an effect, for example pumps will break down and water cannot be provided to the consumers.

If groundwater is used as a source, there is a higher probability of the water containing iron bacteria, resulting in clogging of boreholes (decreased water supply) and a poor water quality.

Other supply risks could be more groundwater or surface water related. For example, in the case of using groundwater as a water source, there could be a risk of borehole complications. Borehole complications include finding (small) water pockets, empty boreholes, difficulties with drilling, decreasing yields, high salinity close to lake and more. The effect is that the water supply is lower than expected.

In the case of using surface water as a water source, there is a probability of surface water complications. These include clogged intake due to for example noxious water hyacinth, problems in transport of water, temperature fluctuations and more.

Environment
Building a water supply system also has environmental risks depending on which source is used. There are five risks that are considered:

- Floodings
- Climate change affects water supply
- Landslides
- Unfavourable geotechnical conditions
- Seasonality affects water supply

If a treatment plant or borehole is constructed at a location near a place where floodings occur, the probability of floodings is higher. The effect of this is damage to or destruction of the system.

All over the world the climate is changing, so there is a probability that climate change will affect the water supply. Climate change is something that is happening, so it's a fact. Though it depends on the alternative (and water source) whether it forms a risk. For example, climate change can cause a source to dry up or to influence the amount of rainfall. The effect will be less water that is available meaning a limited water supply.

If a treatment or reservoir is built on top of a hill, the risk of landslides is higher than in case the constructions are built in a flat area. This is because landslides occur when slopes become unstable. Depending on the location, the probability of landslides can be higher, having damage or complete destruction of the built constructions as an effect.

In case groundwater is used as a source or long and big pipelines need to be excavated, unfavourable geotechnical conditions can be a risk. The result could be a very low yield or no yield at all in case of boreholes. For the construction of long pipelines, it would be unfavourable since a lot of effort has to be put in the construction underground. If the supply of the source is much smaller than expected, the water demand cannot be fulfilled. Or in case of the pipeline, this will slow down the project and makes the alternative less favourable.

There is a probability that seasonality influences the water supply of the source that is used, since there might be (dry) periods in which the water level is lower. This could be a problem for example in rivers. As an effect, in these periods, the water supply could be lower.

F.4. Evaluation results

In the ‘RESULTS’-sheet of the tool the results can be found. A summary of the results (costs, costs/connection, performance, payback time, risk and estimated gap coverage) is given in the ‘TOTAL SCORE’-table.

The **costs** of the different alternatives are based on the ‘Finance’-sheets. It has to be noted that these are not the exact project costs. The cost values are approximations and can be used to compare the different alternatives in terms of costs.

The **performance** results are based on the four different categories (sustainability, durability, society and feasibility). To assign a value to all alternatives the weight factors can be adjusted according to the objective of the study and the interests of the stakeholder for who this analysis is performed.

Lastly, the **risk** scores are given, which are values between 1 and 25 and result in a risk class. Risk class 1 means the alternative has very low risks and risk class 5 means the alternative has very high risks.

A choice between the alternatives can be made based on the results of the MCA tool. Discussing the analysis with different stakeholders improves the results and makes sure that every interest is considered.

G
Multi-criteria analysis

G.1. Financial

G.1.1. Costs different types of pipelines

The table below shows an overview of the costs of the different types of pipelines and this is part of the financial analysis. The costs are per meter of pipeline and are based on the current price lists that Vidas Engineering Services (common contractor for the Ministry of Water and Environment of Uganda) uses and come from Multiple industries limited and Electrotherm. The price includes a factor for the costs of transport and installation of the pipes 0.5 meter under the ground. This factor is 2 for HDPE and uPVC pipes and 2.2 for Ductile Iron pipes because of the fluctuating iron prices.

Table G.1: Costs pipes

Type	Cost [/ meter]	Type	Cost [/ meter]
uPVC OD75 PN6	UGX 25.666,67	HDPE-OD90 PN10	UGX 40.000,00
uPVC OD90 PN6	UGX 38.666,67	HDPE-OD140 PN10	UGX 94.000,00
uPVC OD140 PN6	UGX 87.000,00	HDPE-OD250 PN10	UGX 374.000,00
uPVC OD315 PN6	UGX 438.000,00	DIP DN100	UGX 135.432,00
uPVC OD400 PN6	UGX 709.666,67	DIP DN150	UGX 191.862,00
uPVC-OD75 PN10	UGX 41.333,33	DIP DN200	UGX 254.144,00
uPVC-OD90 PN10	UGX 57.666,67	DIP DN250	UGX 367.422,00
uPVC-OD140 PN10	UGX 136.333,33	DIP DN300	UGX 497.420,00
uPVC-OD315 PN10	UGX 680.333,33	DIP DN350	UGX 586.454,00
uPVC-OD400 PN10	UGX 1.085.333,33		
uPVC-OD90 PN16	UGX 91.333,33		
uPVC-OD140 PN16	UGX 214.666,67		
uPVC-OD315 PN16	UGX 1.088.333,33		

G.1.2. Power supply network Uganda

In Figure G.1 the current power supply network is presented. This figure can be used to estimate the number of meters that the power grid needs to be extended in order to install the system for an alternative.

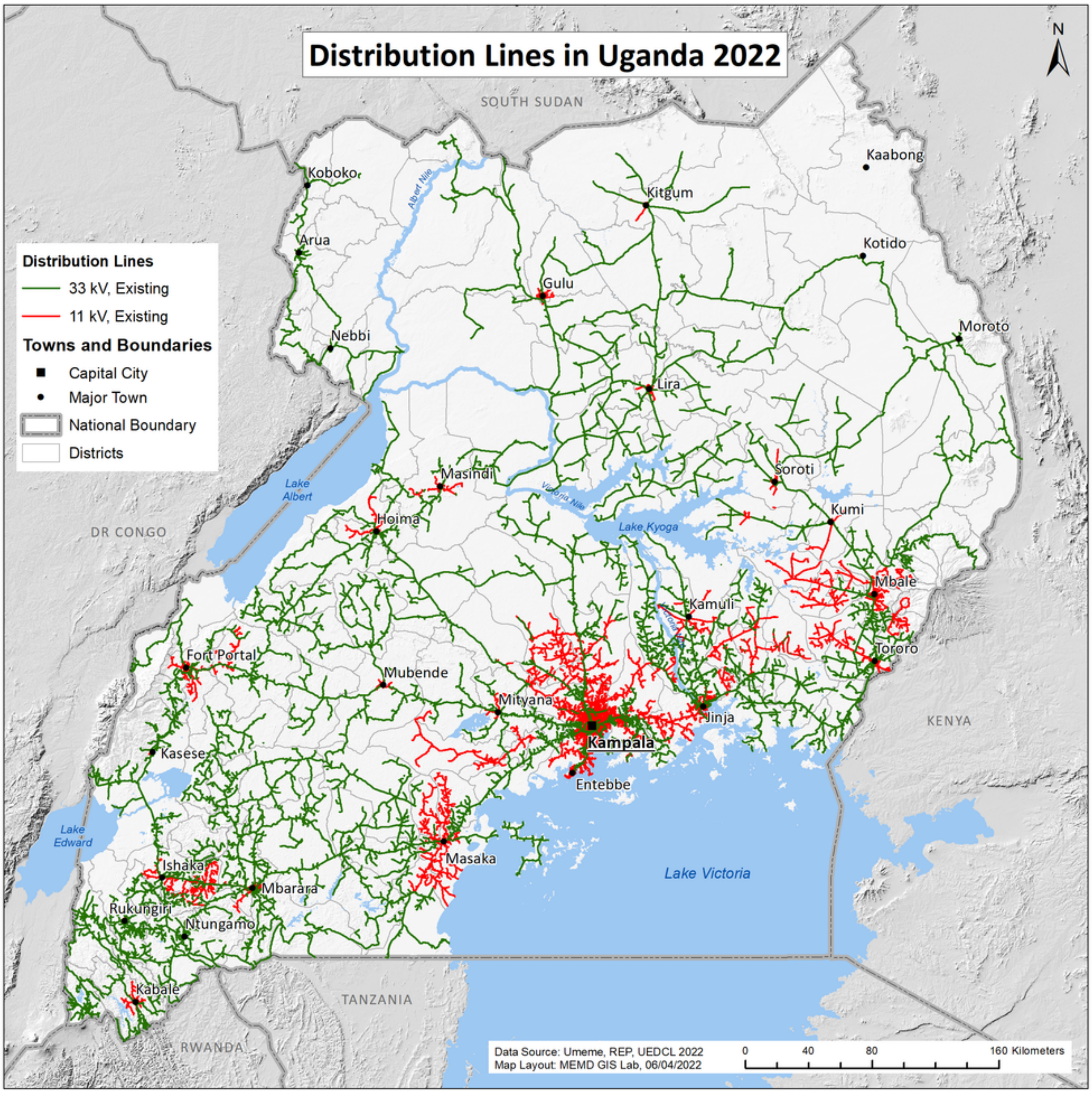


Figure G.1: Power supply network (Energy GIS working group, 2022)