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DIAGNOSTICS FOR THE DEVELOPMENT AND APPLICATION OF AN URBAN WATER FLOW DIAGRAM IN SMALL TOWNS; A CASE STUDY OF MPIGI TOWN COUNCIL.

BY

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DECLARATION

The work embodied in this dissertation is our own and has not been submitted for any other degree or to any other institution before. Appropriate credit has been given where reference has been made to the work of others

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ABSTRACT

Urban water management has proven to be a formidable challenge in rising “yet to be” urban areas. The problem becomes worse around the fringes of small towns due to their “in between” nature. Visualizing the challenges in a more intuitive and friendly way for the end user could be a great first step to mitigating challenges. This research aims to assess the diagnostics in developing and utilizing the output of the urban water flow diagram of the growing city of Mpigi Town Council. The study employed a mixed method approach to collect data from the different sectorial quantities of water usage and water supply. The data was then used to model the water flow diagram using a Sankey-diagram based tool; sankeymatic.

Interventions based on the diagram output led to the assessment of the impact of pit latrines on groundwater quality, quantitative analysis of the uWFD, qualitative analysis of the fecal sludge management and risk assessment of the centralized water supply system within Mpigi town council.

Results from the groundwater assessment showed that ammonia, pH, Turbidity, Nitrates and *E. coli* were the main pollution parameters in this water.

Contamination down the distribution chain of source abstraction, water treatment, storage and final distribution were spotted and practical solutions provided within the water supply system.

The analysis of fecal sludge management showed that the residents mostly used pit latrines for containment of their fecal waste with a few using flush toilets and VIP toilets. Cess-pool services were also on low demand and this is accredited to the high costs of emptying imposed by the utility provider. The wastewater treatment plant in Buwama, set up for treating fecal sludge from all the areas within the district perimeter was under-utilized. An investigation to determine the clarity of the diagram to major service players were done through Stakeholder consultation and engagements. A majority of the influential stakeholders showed a high understanding of the flow diagram which was followed by ideation brainstorming of possible solutions.

Conclusively, uWFDs are a good first step in problem prioritization as a means of transcending the SDG journey.

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LIST OF ACRONYMS

CDO	Community Development Officer
CEDAT	College of Engineering, Design, Art and Technology
cfu/100ml	colony forming units per 100 milliliters
DO	Dissolved Oxygen
EAS	East African Standards
E. coli	Escherichia coli
GIS	Geographic Information System
GoU	Government of Uganda
HDPE	High Density Polyethylene.
JMP	Joint Monitoring Program
KMO	Kaiser–Meyer–Olkin
km^2	square kilometers
L/d	Liters per day
MTC	Mpigi Town Council
MWE	Ministry of Water and Environment
m	meters
m^3	cubic meters
mm	millimeters
mm/hr	millimeters per hour
mg/L	milligrams per liter
NEMA	National Environment Authority
NTU	Nephelometric Turbidity Unit
NWSC	National Water and Sewerage Corporation
PCA	Principle Component Analysis
PSPs	Public Stand Pipes
PVC	Poly Vinyl Chloride
SDG	Sustainable Development Goal
SFD	Shit Flow Diagram
SW	Shallow Well
UGX	Ugandan Shilling
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
uWFD	Urban Water Flow Diagram
µS/cm	micro siemens per centimeter
VIP	Ventilated Improved Pit
WHO	World Health Organization
WSP	Water Safety Plan

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Water Scarcity, exponential population growth, water environmental pollution, flooding, and global warming are typical water-related problems in urban areas around the World (Bouman & Lukas, 2021.). Policymakers and civil society have not wholly been engaged to fully understand the current and future water-related risks (World Water Week, 2021). "To what extent is the problem getting?", "How bad is it?", "How worse could the situation get?" is a dilemma that's still standing amongst stakeholders and policymakers around the globe. In order to clearly understand and visualize the variations brought about by the challenges mentioned earlier in the urban water cycle, innovative approaches have been established and developed so as to enable sustainable urban water management approaches. By sustainable management of water, we mean using water to meet current, ecological, social, and economic needs without compromising the ability of future generations to meet their needs.

Globally, over 600 residents in urban settlements lack access to basic sanitation while 2.2 billion urban residents have access to unsafely managed sanitation facilities (*Envisaging the Future of Cities*, 2022). This poses a threat on the overall success of global economies by degrading the natural environment, impeding economic growth and productivity (Naifar, 2022). Unsafely managed sanitation facilities especially in urban slums of developing countries for example unlined pits results into groundwater fecal contamination which poses a health threat to the consumers of such water facilities (*Sanitation_journey*, n.d.). Spot sampling of groundwater shows a widespread of fecal contamination indicated by an enumerated thermotolerant coliforms ranging from 0 to 10^4 cfc/ 100 ml and increased nitrate concentration which exceed 250 mg/L (Nayebare et al., 2020). Pollution cases may also arise within water distribution systems through increased concentration of heavy metals induced by the chemicals used in water treatment (Alvizuri-Tintaya et al., 2022). This water originates from the point of generation say a lake or river through distribution pipes to the consumers through yard taps for the middle income, public stand pipes (PSPs) for the low income and house connections for the high income.

There has been a far-reaching appreciation of environmental and public health risks of unsustainable solid waste management practices. A more sustainable waste management approach prioritizes practices such as reduced production, waste classifications, reuse, recycling, and energy recovery over the common practices of landfilling, open dumps, and open incineration (Abubakar et al., 2022). All these approaches have been an initiative to reduce on pollution of water through discharge of solid wastes into the existing water sources.

In order to simplify visualization of excreta pathways in such cities along the sanitation service chain, Shit or excreta Flow Diagrams were developed. The SFD methodology has been applied in over 50 countries and cities around the cities for example in Kumasi, Ghana in 2015 to evaluate the methodology and explore its potential beyond an advocacy purpose (Fernández Martínez et al., 2016). This diagrammatic representation of the sanitation systems has been an efficient method in identify bottlenecks and promote sustainable solutions towards improving the sanitation sector. This has also created an increasing rise to simplify visualization the water sector through uWFDs.

The uWFD is an easy-to-understand, holistic diagram to visualize urban water flows and make urban water management tangible for a broad audience (Bouman & Lukas, 2021). The uWFD considers the entire water cycle from source to discharge including reuse and recognizes the interrelations between different water uses drinking and wastewater treatment, and storm water management. It allows showing groundwater and surface water use and recharge, evapotranspiration, drinking water volumes for different types of users, and wastewater that is discharged or reused. This then inevitably creates a rising need for a tool that snapshots the current local urban water situation by visualizing water flows from source to discharge together with the judgment for every flow; whether the management practices are appropriate or problematic. This diagrammatic tool has been used in a few cities around the world in order to study the nature of water management in those cities and these are Rio Pardo de Minas in Brazil, Bern in Switzerland, and Bangalore in India with the aid of Sankeymatic software (Natel De Moura, 2021).

Before using the software, accurate and reliable data has to be gathered, for example, the population of the area under study, the area within the system boundary, sources of water, and the flows and sinks of the water. To generate this information, stakeholders have to be involved at this stage. Besides, the water flow diagram must be communicated to them, to determine whether it is understood and if it can be used in planning for water resources in their area.

In Sub-Saharan Africa, the uWFD has not been used to assess the risks facing water systems. Regarding the aspect of sustainable urban water management, which is inclusive and integrated thus requiring different sectors and concerned stakeholders to find a common language to jointly identify problems and opportunities (Bouman & Lukas, 2021). Like excreta or Shit Flow diagrams being developed in the sanitation sector which illustrate excreta pathways in available sanitation systems within a city (Fernández Martínez et al., 2016), the uWFD can be used to visualize urban water flows could be incorporated to facilitate integrated urban water management. For the case of sanitation systems, stakeholders and policymakers will need guidance (Daudey, 2018) on the different characteristics of each sanitation option, such as their respective costs and benefits. With this, the diagram will serve as a basis for constructive multi-stakeholder dialogue to support better decision-making.

1.2 PROBLEM STATEMENT

The world will continue to urbanize over the next three decades from 56% in 2021 to 68% in 2050 which implies an increase of 2.2 billion urban residents, living mostly in Africa and Asia (*Envisaging the Future of Cities*, 2022.). With rising populations, cities are confronted with several challenges, among which include water shortages, flooding, and pollution. The concern about human and environmental health calls for the need for holistic urban water management more than ever before. Supplying water in the required quantity and quality is becoming more challenging. Because of the lack of space, infrastructure, and high informality, the challenges are particularly challenging in the poor urban areas where most of the current population growth is taking place.

Climate change can also intensify the problems because of more droughts, floods, and changes in resource availability. In order to achieve SDG 6.1 by 2030, we need to move way faster than our legs could carry. An easily understandable diagram to illustrate urban water flows for more sustainable management decisions becomes inevitable. The rationale is to make challenges related to urban water flows visible to a broad range of stakeholders and to create an intuitive tool for people within and outside the sector to highlight areas, which need political support and actions to improve urban water management.

It is estimated that 70% of the people within Mpigi District rely on groundwater as a major source of drinking water and, in most cases, consumed without receiving treatment to improve quality. Peri-urban areas are often characterized by heavily compromised groundwater, with excess levels of nitrate, chlorides and microbial pathogens (Yongxin & Brent, 2006). There is a concern that chemical and microbial contaminants in pit latrines can leach into groundwater sources thereby threatening human health(Dzwairo et al., 2006) . Previous studies on the impacts of pit latrines on groundwater quality have demonstrated deterioration in groundwater quality(Haruna et al., 2005). Thus, the protection of groundwater sources from pollution by pit latrines is critical.

1.3 STUDY OBJECTIVES

1.3.1 Main Objectives

The major objective of this research is to determine the diagnostics requirements for developing the urban water flow diagram for a small town and work with stakeholders to determine how the water flow diagram could be used to improve water management in Mpigi Town Council.

1.3.2 Specific Objectives

i. To identify the system boundaries and conduct a system assessment for the Mpigi Town Council water supply system.
ii. To conduct a comprehensive qualitative analysis of the fecal sludge management practices in Mpigi Town Council.
iii. To quantify the water use per category of each existing water user in Mpigi Town Council.
iv. To develop the uWFD for Mpigi Town Council and enter dialogue with the concerned stakeholders.

1.4 SCOPE OF STUDY

The area of study considers an urban area and in this particular context, Mpigi Town Council as displayed in Figure 1-1. It is located in Mpigi District is one of the 112 districts of Uganda and it was one of the first 39 districts to be decentralized under the then Resistance Councils Statute. The district is a large municipality located in Central Uganda situated about 45 miles west of Kampala City. It lies between latitude 0° 13' 38.4708" N and longitude 32° 19' 29.7264" E with an elevation of 1202.125m above sea level as shown in the sketch map of the area. Mpigi town council occupies a total land coverage of 150.25 km^2 with a total population of 43,178 people including 10,559 households with an average annual rainfall amount of 1,320 mm. It consists of 11 parishes with a few industrial activities taking place but there is a vast number of commercial and agricultural activities like fish farming at Mpigi Fish Farm.

The main source of water within the area is obtained from a swamp. However, the other sources of water are boreholes, shallow wells, and springs (protected and unprotected). The water is mainly abstracted by NWSC being the major supplier and the water is subject to turbidity, microbiological, and advanced treatments before it is distributed. The treatment facility of the Mpigi NWSC branch only does the primary treatment of water collected from the swamps. The wastewater collected from sewers by cesspool emptier is transported away from the town council to Buwama town council where it is treated to reach set standards. There is also no record of water supplied to industries as well as Agricultural farms in Mpigi Town Council by NWSC and this is due to the high cost of the water from NWSC hence resorting to direct abstraction of water from swamps and shallow wells around the area.

Figure 1-1: Satellite Location of Mpigi District

CHAPTER 2 THE LITERATURE REVIEW

This Chapter presents a broad understanding of the currently existing known knowledge and gaps regarding the uWFDs and their application.

2.1 SMALL TOWNS "CAUGHT IN THE MIDDLE"

Small towns have suffered disparities in water service provision across its boundaries. These towns are known for lying across two ends of the spectrum; combining urbanized centers with surrounding areas typical of rural settings. This as a result affects various groups of water users in their access to water. This process of categorization creates a rigid distinction between urban and rural water infrastructures producing binaries and potentially creating structural inequities (Sanchez et al., 2020).

In addition to having implications for the global monitoring of service delivery trends, the categorization of small towns as urban or rural also determines the allocation of budgets and assistance programs, as well as the degree of autonomy granted for the implementation of civil infrastructure projects (Marks et al., 2020). When it comes to water service provision, small towns are often considered "sufficiently large and dense to benefit from the economies of scale offered by piped water systems, but too small and dispersed to be efficiently managed by a conventional urban water utility" They typically include rural socio-economic characteristics while also requiring urban-type technologies for water provision.

In rural areas, the District Office is responsible for the construction, monitoring, and rehabilitation of water supply infrastructure (Sanchez et al., 2020)   The National Water Policy of 1999 promotes the concept of community-based management and indicates that for each water source in rural areas a water user committee needs to be established among residents that use the water source. Under the supervision of these committees, communities are jointly expected to maintain the infrastructure and protect the land around the source. Two members of such a committee need to be assigned as caretakers and become, among others, responsible for organizing preventive maintenance of the spring, overseeing that people stick to the rules set for fetching water and collecting maintenance fees (Caught in the middle).

In urban areas, National Water and Sewerage Corporation, an autonomous parastatal public utility, is mandated to operate and maintain urban water and sewerage services on a sound commercial and financially viable basis (GoU, 1972). In line with the 1995 Water Act, NWSC is supposed to be the sole authority to provide water and sewerage services in any area under their jurisdiction and they are responsible for managing all water resources in their area of operation in ways that are 'most beneficial to the people.

With rising populations, cities are increasingly confronted with water shortages, flooding, groundwater challenges, and pollution. Intensifying concern about climate change and human and environmental health require holistic urban water management more than ever before (Urban Water Flow Diagram-Accelerating Holistic Urban Water Management, 2021.). It is becoming more challenging to supply water in the required quantity and quality and to deal with the produced wastewater in a safe way. The challenges are intensified by increasing extraordinary regional and seasonal fluctuation and extreme weather events such as droughts and flooding.

Typical high-tech infrastructure solutions are neither feasible nor affordable for these contexts. Progress towards the SDGs- and sanitation-specific targets in sub-Saharan Africa is much higher in urban areas. However, such achievements often mask a disparity between the rich and poor in urban contexts and between major urban cities and small towns or rural centers. This is reflected in the relatively higher indicators of deprivations in small towns compared to urban centers (UNICEF 2015; Andersson et al. 2016).

2.2 WATER ACCESS IN SMALL TOWNS

Urban areas in low-income countries are commonly characterized by informal settlements that lack basic amenities (Nakagiri et al., 2015). Water supply, sanitation and hygiene (WASH) conditions in these settlements are often inadequate due to low budgets, lack of capacity, unclear regulations and lack of feasible options to provide services by all branches of government (UNICEF 2015; Andersson et al., 2016). The main drinking water supply typical in small towns are protected springs, unprotected springs, a NWSC tap at home or yard. Boreholes, community taps, rainwater harvesting, and surface water (streams or rivers).

Bivariate comparisons of water quality across source types show that both source and household stored water samples from improved water sources are significantly less contaminated than those from unimproved sources (Marks et al., 2020). The disparity in water quality between the low-income and high-income areas is attributed to inadequate infrastructure and maintenance across the two ends of the spectrum in small towns (Boakye-Ansah et al. 2016).

2.3 EXISTING SANITATION CONDITIONS

Households in small towns used non-sewered facilities providing either a basic (i.e., private improved facility that separates excreta from human contact) or limited (an improved facility shared with other households) level of service to users. However, On-site sanitation (OSS) practices are significant and persistent sources of groundwater contamination hazards in Sub-Saharan Africa (Twinomucunguzi et al., 2021). OSS refers to sanitation (fecal) disposal systems that are not connected to a sewerage network, including pit latrines and septic tanks.

Pit latrines have been adopted and are used because of their low cost, simplicity of construction, and ease of operation and maintenance. However, their use in urban slums is characterized by several challenges(Nakagiri et al., 2015).

The dependence upon these on-site water and sanitation facilities exploits the shallow subsurface not only to contain fecal waste but also to provide potable water via wells and springs (Nayebare et al., 2020).

2.4 THE URBAN WATER FLOW DIAGRAM

In order to solve global world water problems, simplistic and easy-to-understand service models that incorporate both urban and rural characteristics (Marks et al., 2020) are needed in order to generate solutions to address these challenges. One of the innovative technologies that have been established and developed is the uWFD. This diagram focuses on counting statistically two flows of urban water for a wide public in an easy and intuitive way enabling the management of world waters more sustainable in order to achieve the SDGs by 2030 (Natel De Moura, 2021.).

According to the UN JMP progress report as of 2020, two billion people of the global population lacked access to safely managed water and sanitation facilities and therefore this means that there are obstacles and hindrances within water supply systems that need to be identified and tackled so as to enable access to clean water and sanitation. These flow diagrams can easily be related to the already existing technologies like the SFD in such a way that they all indicate the level of risk within the systems they are meant to assess i.e., waste management for the shit flow diagrams and water flow and supply for the urban water flow diagrams. Both diagrams find application mostly in developing countries where the level of development is low, facing a vast number of challenges in their service delivery schemes like inadequate funding, and low maintenance works to mention but a few.

Considering the aspects of water quality, the uWFD can be used to assess the levels of contamination for both groundwater and surface water so as to enable immediate effective, and efficient action to be taken so as to address these contamination hazards that pose a threat to the water consumers that might be in access to these water sources. In the case of groundwater, there are six drivers of groundwater contamination (Twinomucunguzi et al., 2021) and these are land-use management, user attributes, governance, groundwater valuation, infrastructure management, and the operating environment. Surface water contamination is also another major concern with the majority of the world's population having access to surface water with fecal contamination (UNICEF JMP for water supply, sanitation and hygiene, 2021).

2.5 VISUALIZATION OF THE UWFD

The intent of the uWFD tool as a visualization approach to urban water challenges is to have a flawless intuition in regards to the quality of water and quantity of water supplied to the different water users across small towns. Data accuracy is a must-have as it fully embodies the reliability of the obtained data. Reliable data is highly sought as it creates trust in the presented challenges and good stepping stone to triggering action across sectors.

The water balance of a town is clearly read off from the uWFD. A sense of replenishment of the existing water sources quantifies is a good start to better managing the resources otherwise if the resources are experiencing yearly deficits, a different approach to management must be undertaken.

2.5.1 Quantitative Analysis of Water Usage

The quantitative analysis of water use from the uWFD provides evidence to answer the question, of whether the amount of water used by each water user is "appropriate" or "problematic" (Bouman & Lukas, 2021). The schematic representation of the analysis is included in Figure 2-1. As opposed to the qualitative judgment, the answer to this question is strongly dependent on the context (how much water is available) and the distribution (is the water available equally distributed to different users).

This is done through a comparison of the proportions used by the different water users. In addition to the volumes that are being currently used, a series is added for the target water use per sector (Bouman & Lukas, 2021.). The series represents the (perceived) missing/excessive amount for that sector. The target amount is determined by stakeholder interviews, literature research for benchmark values, or expert consultation.

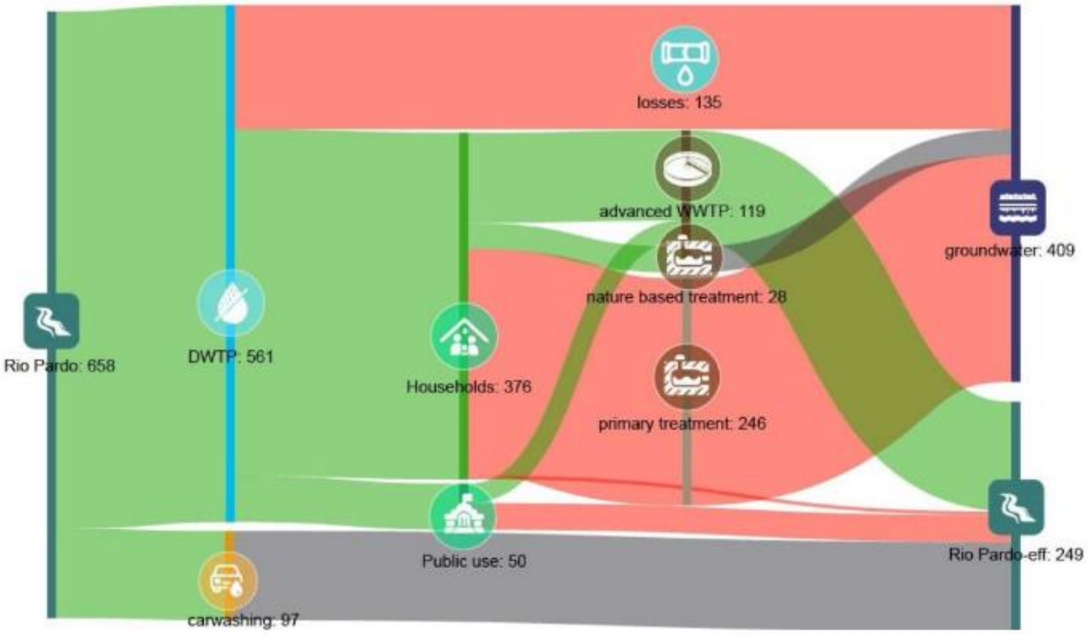


Figure 2-1: Quantitative visualization of the uWFD

2.5.2 Quality-based judgement

For every flow on the uWFD, judgment is made on whether it is "appropriate" or "problematic" according to sustainable urban water management practices. The judgment is made based on the water quality of the input flow into a node (Bouman & Lukas, 2021). Every flow as illustrated in Figure 2-2 is appointed one of the four water quality categories: uncontaminated, (micro-) biologically contaminated, chemically contaminated (and maybe also microbiologically), and unknown.

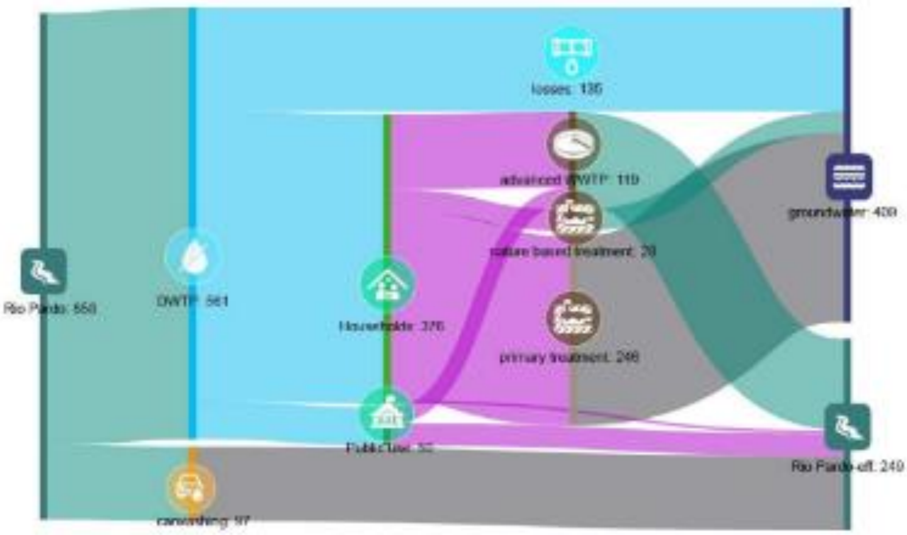


Figure 2-2: Qualitative visualisation of the uWFD

2.5.3 Data accuracy with the uWFD

Different color codes are customized to represent the levels of accuracy of the obtained data. Three categories from "low" to "high" are possible, whereas the lighter the grey, the higher the uncertainties are. The rating of the data accuracy is based on two factors: The type of data source and the type of flow. As portrayed in Figure 2-3, three classes of data sources exist. In class 1 are data sources, that are considered the most trustworthy (e.g., data from water utilities), whereas in class 3 are data sources that are considered the least trustworthy (e.g., expert judgments) (Bouman & Lukas, 2021). In the type of flow, we distinguish between three types, from easy to quantify (e.g., the amount of water treated in a drinking water treatment plant) to very difficult to quantify (e.g., the amount of informal, direct water use from groundwater).

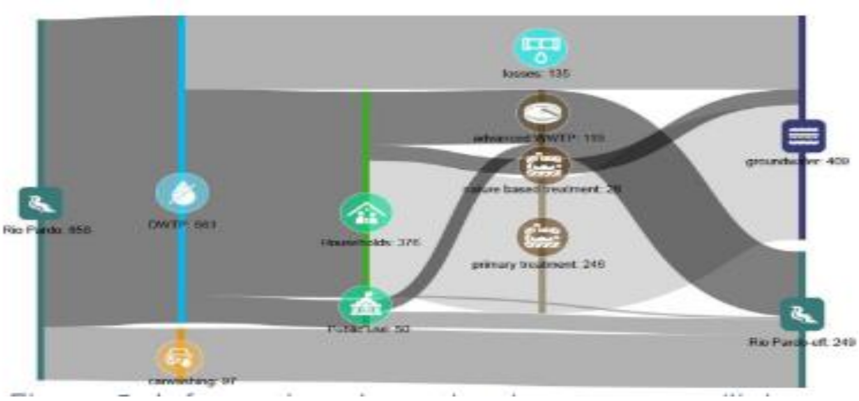


Figure 2-3: Visualization based on data accuracy

2.5.4 A town's water balance through the uWFD

An easy way to get a feeling of the water balance at the city level is to compare the volumes that are removed from one of the three water bodies (surface water, groundwater, atmosphere) and added again. Removal happens via abstraction or rainwater harvesting; addition via infiltration, dis/re-charge, or evapotranspiration. The water balance can be analyzed per water body or over the entire system boundary.

To have a clear view of the water balance, we need to

- Sum up all the different abstractions of surface respectively groundwater and rainwater use for the atmosphere, …). They are located on the left side of the uWFD.
- Sum up all the re/discharges for surface respectively groundwater and evapotranspiration for the atmosphere. They are on the right side of the uWFD.
- All "withdraws" and "deposits" in the water bodies are added to have the overall water balance of the city and evaluate ΔS. Water cycles of cities are always embedded in the entire watershed of the area and are never isolated. The urban water management of a city has impacts on the surrounding area. To put the uWFD and the water balance of the city in context with the surrounding area, the ΔS of the water bodies of a city can be compared to the water balance of the watershed to understand whether the extent of ΔS >0.

2.6 THE STRUCTURE OF A UWFD

In general, a uWFD follows the water from the source to discharge (from left to right) but includes recycling and recharge (right to left). If a Sankey diagram is used, it consists of nodes that are connected with flows. Nodes represent processes, in our case for example water use by households or central wastewater treatment. A flow connects two processes. Its thickness is proportional to the water volume that the flow represents.

System boundary

Primarily, the uWFD has been developed as a tool for urbanized areas. Therefore, it is recommended to use municipal boundaries as the system boundaries. Depending on the context, suburbs of a municipality can be included(Bouman & Lukas, 2021).

Nodes

The nodes in the uWFD represent the relevant processes in the urban water cycle. The nodes are categorized into functional groups (Source, Drinking water treatment, Use, Wastewater treatment, Discharge, and Reuse). For every functional group, a set of possible permutations exist.

Flows

The flows connect the nodes of the uWFD and represent water flows. e.g., the sum of all water flows from a drinking water treatment plant (start node) to private households (end node). Basically, any combination of start and end nodes along the functional groups is possible, including skipping a functional group.

2.7 DATA REQUIREMENTS OF THE uWFD

Prior to developing the diagram with the aid of Sankeymatic software, the particular area of study needs to be clearly defined so as to establish a definitive boundary where the analysis is to be carried out (Bouman & Lukas, 2021). The area of interest may be a municipality or a city council comprising of water supply agencies or bodies with local leaders or policymakers in charge of the area. For this particular case study, we consider Mpigi District a slowly developing and growing urban center.

The following are the data requirements necessary for the development of the uWFD and their significance within the diagram;

1. Population of the area: This aids in determining and estimating the water consumption figures so as to enable a quantitative representation of the water demand figures within the area of study.

2. Precipitation: Since the area of study is located within Sub-Saharan Africa or the tropical region, the main form of precipitation to be considered is rainfall so as to ascertain what percentage of the population uses alternative forms of water sources in terms of rainfall harvesting as well as the contribution of rainfall depth to the major sources of water within the region. If the area of study is within the temperate regions, other forms of precipitation like snowfall can be considered.

3. Area of the system-boundaries: The areal extent of the area needs to be clearly defined so as to establish the catchment area over which hydrological analysis is going to be carried out as well as the consumption patterns.

4. Drinking water sources: This is also a key consideration in the development of the diagram in Sankeymatic software as the main sources of water consumption need to be

determined so as to establish the amount of the volumes extracted from these sources for use by the population.

While working on the volumes of water extracted and used, it is important to express these quantities in yearly volumes (m^3/year) (Bouman & Lukas, 2021).

5. Volume of water treated and distributed to users: This parameter enables the determination of what quantities of water that are subject to treatment processes so as to make it safe for the consumers to readily use as well as supplied to consumers via the necessary levels of service present in the region. The standards of water quality are determined by the drinking water standards of the area under study. In Uganda, the quality of water subject to treatment processes is checked on the basis of the East African Standards of Potable Water since she is part of the East African Community (EAS 12 Potable Water-Specification, 2014).

6. Water losses within the piped network for drinking water: This aids in showing the present water losses as well as pointing out any inefficiencies within the supply system like leakages, and infiltration into groundwater to mention but a few. The losses are deducted from the volume of water distributed from the treatment plant so as know what actual volumes are received and used by the various water consumers.

7. Volume of water for use without treatment: This parameter shows what quantities of water are used by the consumers directly from the water source as well as ascertaining the percentage of fecal contamination, as well as the other contaminants present.

8. Proportion of treated water used as well as the treatment technologies: This assesses what amounts of treated water are used by the consumers mainly determined by the socio-economic status of the population which determines what level of service they can afford. The treatment methods can as well be assessed so as to determine how efficient and effective the method is in making the drinking water safe for drinking.

9. Infiltration from sewers: This helps in visualizing what percentage of wastewater from the sewers is contaminating the groundwater table which may be a major source of water, especially for groundwater sources such as boreholes and protected springs. This infiltration from sewers may also be over drinking water supply pipes which may be hazardous to the water consumers as this may increase the faecal contamination in case of leakages in case of the supplied water.

10. Major urban blue-green infrastructures: Blue-green refers to infrastructure that aims at restoring the naturally oriented water cycle while contributing to amenities by bringing water management and green infrastructure together (Kapetas & Fenner, 2020). Some examples of such infrastructure are rivers, canals, ponds, wetlands, floodplains, and water treatment facilities to mention but a few.

11. Volume of reused water: This parameter emphasizes the amount of wastewater that can be put to use after treatment of such waters has been done so as to reduce the strength of the sewage. Such water may be reused through some avenues like irrigation.

2.8 HYDROLOGICAL FLOWS IN SMALL TOWNS

In Sub-Saharan Africa, many small towns still face challenges in accessing clean water and sanitation. In order to close this gap, developing service models for areas with both rural and urban characteristics (Marks et al., 2020). Hydrology simply refers to the movement of water from the sea to atmosphere by evaporation, transport of water vapor by wind, precipitation on land. It also includes the storage and retention of water in the surface channels of the soil, in the saturated zone beneath the soil, transfer of water between the soil phases (soil water, solids and voids) and eventual disposal into rivers or the sea. In Uganda, the Water Act provides a legal framework for the use of water since she's one of the River Nile Riparian Countries.

Existing water resources in small towns currently suffer from an increasing trend of pollution (human and industrial waste), water abstraction, river channelization as well as damming of the rivers. Therefore, fundamental knowledge of the ecosystem structure and function is necessary to understand how human interference affects the natural processes within the water resources and what interventions are feasible to rectify this (Jannsendzimir, 2020.). Small towns are often characterized by open drains which are common methods of transporting solid waste and excreta in such low-income urban areas resulting into blockages posing exposure risks in terms of pathogenic materials (Berendes et al., 2019).

2.9 CONTAMINANT FLOW FROM SANITATION SYSTEMS TO WATER BODIES

The major aim of sanitation is to reduce on the spread and burden of diseases transmitted through excreta (Manga et al., 2022). Globally, there are 1.7 billion episodes of diarrhea every year in children under 5 years which is accredited to exposure to faecal pathogens due to inadequate management of sanitation systems (Walker et al., 2013). It has also been estimated that over 3.1 billion people worldwide rely on household onsite sanitation systems (UNICEF and WHO, 2019). Such fully lined septic systems act as primary treatment units for solid removal from wastewater and reducing *E. coli* concentrations.

Excreta return from sanitation systems after collection, emptying, transport treatment and disposal to the environment is still a major global challenge in major cities around the world. There are many challenges and knowledge gaps with the fundamental understanding of excreta and pathogenic flow within cities (Eawag, 2022). The excreta associated hazard may however be significantly reduced through pathogen die-off during treatment including long periods of sludge containment in latrines and septic tanks. In Kampala City, three water sanitation and hygiene support tools were used to assess areas with high potential risk due to poor wastewater and fecal sludge management to develop methods on reducing exposure due to poor sanitation management practices (Okaali et al., 2022).

Urban infrastructure can mitigate or facilitate personal exposures to fecal contamination in households and public environments depending on the effectiveness of fecal sludge management, drainage and wastewater systems (Raj et al., 2020). While increased toilet ownership has shown to reduce on increasing enteric infections, safely managed sanitation systems along sanitation chains are necessary to contain excreta and prevent human contact in both household and neighborhood environments (Berendes et al., 2019). However, in the absence of safely managed sanitation plans, densely populated areas pose risks to residents both up and downstream on major discharge areas like rivers due to poor maintenance and cleaning of these systems and uncontained faecal sludge management infrastructure like open drains (Kolsky et al., 2019).

2.10 LIMITATIONS OF THE uWFD

The limitations of these flow diagrams are mainly divided into three main aspects which are human aspects, spatial representation, and temporal representation (Natel De Moura, 2021)

- Human aspects: The aspects related to the human right of access to water are still not contemplated within these diagrams. Some aspects that could be integrated into the tool are for example percentage of people without access to piped water and basic sanitation, which is financially accessible to potable water for vulnerable communities etc.
- Temporal Representation: The diagram shows a temporary cut at the annual level, but in locations where seasoning is an important factor (regions with poorly distributed raindrops during the year) for example more time detail would be interesting, depending on the objective that the tool is intended to give.
- Spatial representation: The definition of the boundaries of the system can interfere with the shape of the diagram including the rural area in the system could, for example, provide a better vision of sustainable management of the water in a region. However, in rural areas, the uses of water differ greatly from those within the city.
- Accuracy: The uWFD is not a highly precise diagram. It's a quick analysis of the urban water management of a city and may be the starting point of further assessments. However, the uWFD is an appropriate tool to make the urban water flows visible and put their volumes in relation to each other. It allows making general statements about the state of a city's urban water cycle.
- No solutions: The diagram can reveal challenges in urban water management, but does not provide solutions to the challenges.
- No planning tool: The diagram gives an overview of the urban water management of a city. However, for detailed planning of interventions or decision-making, more in-depth analysis is required.
- Data availability: The diagram's power strongly depends on the data availability and willingness of the stakeholders to share the data of interest. If only limited data is available, also the messages and take-aways from the diagram are limited.
- Virtual/imported water: The tool does not consider imported water or virtual water in products that are imported into the city.

2.11 IMPROVEMENTS TO BE CONSIDERED

According to the recommendations reviews that were made during the World Water Week of 2021, there were inadequacies that were noticed within the flow diagrams that had already been developed for cites like Bern in Switzerland. Among the suggested improvements that were made are (Natel De Moura, 2021)

- Natural hydrological cycles could be implemented within the diagram to consider realistic natural losses in terms of evaporation as well as consider alternating dry and wet seasons within the area of study.

- The diagram should be able to consider the flows within the rural areas which may have similar characteristics to those of urban areas.
- The proportion of the population without access to water supply services should be considered as well as the inequalities in access.
- Sustainable management scenarios, - how different scenarios impact the quantity and quality of water for the population in the short and medium term.
- In the existence of water quality data, one can think of a water quality diagram working as a concept of pollutant loads.

2.12 QUALITATIVE ANALYSIS OF FECAL SLUDGE MANAGEMENT IN MPIGI TOWN COUNCIL

In order to achieve the sixth Sustainable Development Goal of access to clean water and sanitation, there is need to target equitable and adequate sanitation for all people across the world by ending open defecation, paying special attention to the needs of women and children in vulnerable situations. One of the major key indicators is the assessment of the numbers using safely managed sanitation services. Safely managed sanitation simply means sanitation technologies that are improved and not shared by households. The excreta produced from these facilities can either be treated and disposed on-site, or stored and transported off-the site for treatment using various methodologies like cesspools. Therefore, safely managed sanitation can be categorized into on-site sanitation and off-site sanitation.

On-site sanitation facilities may include pit latrines and septic tanks while off-site sanitation facilities include sewer system. In Uganda, nearly a tenth of the population practices open defecation and it is mainly the poor people who experience the greatest burden of poor sanitation. The poorest 20% of the population is 13.5 times more likely to defecate in the open as compared to the rich 20% according to World Bank.

In this research study, we assess the practices and challenges along the sanitation value chain regarding five major aspects. These include containment, emptying, transportation, treatment and recycling of fecal sludge within Mpigi Town Council.

CHAPTER 3 METHODS AND MATERIALS

In this chapter, the materials and methods that were used in the execution of the project objectives are discussed.

3.1 ESTABLISHING THE SYSTEM BOUNDARY

Mpigi Town council was chosen as the municipal boundaries to fully assess the urban water challenges. The Town Council is made up of 11 parishes as depicted in Table 3-1 and Figure 3-1. The choice of the boundaries was based upon an all-inclusive zone of service areas of the water utilities and public authorities as data is usually collected and aggregated over the service area.

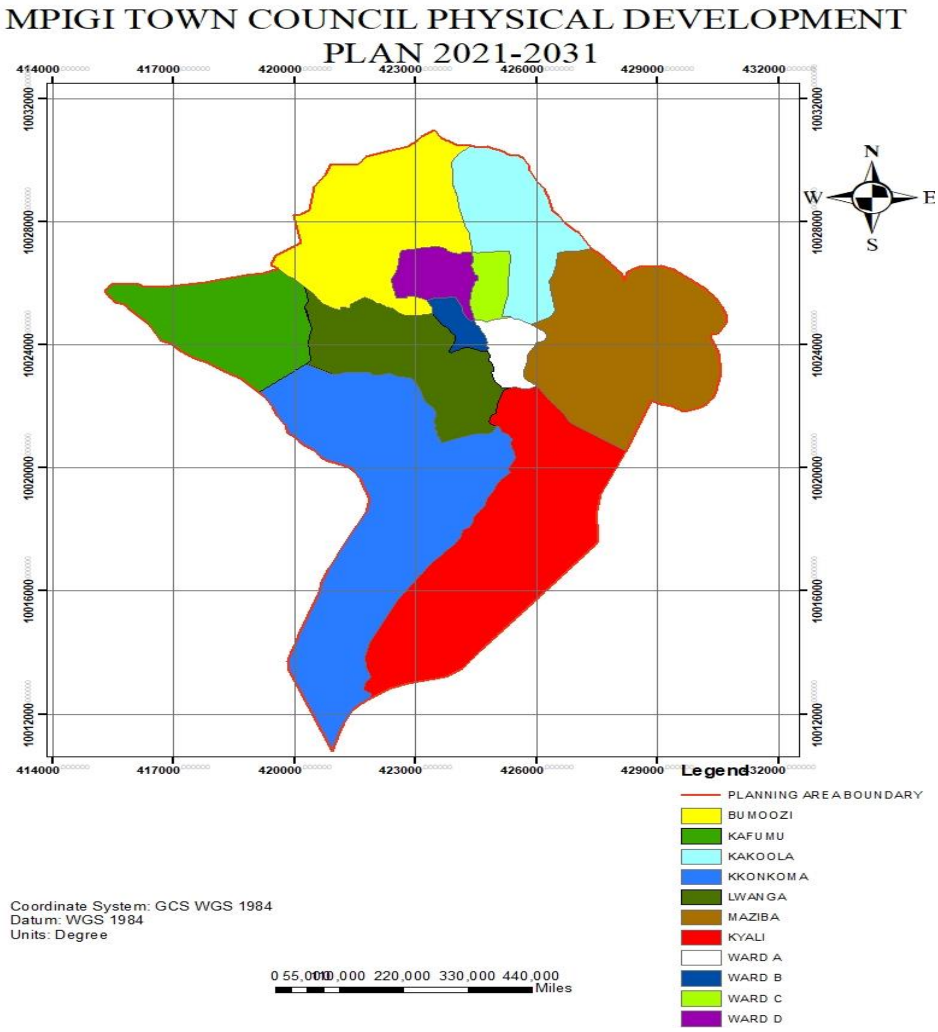


Figure 3-1: System Boundary for Mpigi Town Council uWFD

Table 3-1: Parishes and Villages of Mpigi Town Council

SUBCOUNTY	PARISH	VILLAGE
MPIGI TOWN COUNCIL	Ward A	• Church Centre A • Lufuka • Police Zone • Church Centre B • Mpami-Bikondo • Kafumu • Katulo • Park Village
	Ward B	• Kalagala A • Kalagala B • Ssabwe • Kyasanku • Mawonve
	Ward C	• Bukakala • Kabanga • Nsamizi • Lwanga • Mbaale
	Ward D	• Bboza • Prison Centre • Mayembe Lower • Mayembe Upper A & B
	Bumoozi	• Namiryango • Bboza • Bugayi • Kikamula • Nnono • Kigwanya • Bumoozi A • Bumoozi B • Kimbugu
	Kafumu	• Bulilo • Namabo • Kitawanulwa • Bulyasi • Bumwuka • Nanyinzi • Kisaliza
	Lwanga	• Lwanga • Kizzi • Kalagala • Nyomerwa
	Kyali	• Bubezi • Gayaza • Kasamu • Nsamu
	Kkonkoma	• Kkonkoma • Nseke

SUBCOUNTY	PARISH	VILLAGE
		• Bwanya • Ijanya • Nakigudde
	Kakoola	• Kakoola • Bunamweri • Ggala
	Maziba	• Lungala • Bugombe • Bume

The population of Mpigi town council was obtained from Uganda National Bureau of Statistics in Kampala. The areal extent data of Mpigi town council was acquired from the Mpigi District Local Government Offices. The annual precipitation of the chosen system boundary was obtained from Uganda National Meteorological Authority.

The most effective means of consistently ensuring the safety of a drinking water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps of water supply from the catchment to the consumer. Defining the water supply system means mapping the water boundaries but not the boundaries of the town council.

A detailed description of the water supply system within the town council was done so as to support the subsequent risk assessment process. It provided sufficient information to define the water system where it is vulnerable to hazardous events, relevant types of hazards and control measures. The following was included in the description;

a) Existing water quality standards,
b) Sources of water including the existing losses,
c) Known or suspected changes in water quality associated to weather or other conditions,
d) Interconnectivity of water sources,
e) Detailed land use within the catchment,
f) Abstraction point,
g) Treatment methods used,
h) Storage water facilities,
i) Identification of the uses and users of water.

The diagram was then developed and validated through the onsite field checking and used in the risk assessment process.

3.2 IDENTIFICATION OF STAKEHOLDERS

The relevant stakeholders were identified and engaged in the entire process of the generation of the diagram. For the case of this process, the relevant stakeholders were the public utility in charge of water supply within the country, NWSC, the households, commercial and institutions, district mayor, and the district water Engineer. The decision making or final judgement was done basing on the current roles, responsibilities and influence (Zurbrugg, 2020.) within the urban water cycle.

3.3 DATA COLLECTION

All the drinking water sources used in Mpigi Town Council were ascertained. Consultation from National Water and sewerage corporation, the only water service provider, was made to investigate all the water abstraction points. The non-treated water abstraction points inquiries were made from the Town council Authority as they are responsible for their operation. Additionally, the non-treated water abstraction points by different civilians in the area were ascertained by an on-ground survey in the different villages in their respective parishes across the boundary. Operational and nonoperational groundwater sources were considered. Data in this regard was then obtained from the Town council board offices in Mpigi district.

The volume of drinking water that is treated and distributed to households, public premises and institutions, industry, agriculture was obtained through consultation from NWSC, the only existing water utility company within the fringes of the study area. Data in regards to pipe losses in the network was additionally obtained from NWSC.

3.3.1 Sampling Procedures

During sampling, the data was collected using qualitative methods. The areas within the town council that were sampled for representativeness were those that were densely populated-low-income settlements which are the Wards of A, B and C. In Ward A, we sampled the parishes of Kafumu, Mpami-Bikondo, Church Center A and Church Center B. Within Ward B, the parishes of Kalagala A and B, Ssabwe, and Mawonve were sampled while for Ward C, Nsamizi, Lwanga, and Mbaale were sampled making a total of 180 sampling stations. The sampling stations consisted of 87 households and 93 commercial areas.

The respondents were selected as participants of household surveys which included hostels and lodges plus Focus Discussion Groups. The data obtained from the focus group discussions was used to complement that from the household interviews. There was also an in-depth interview that was conducted with the NWSC engineer and the cesspool emptiers, and the management staff of the treatment plant. The focus discussion groups were conducted with community members as well as the community leaders in particular the health inspector of the area. A total of three group discussions were conducted for with each ward having one group discussion and they were mainly conducted in school main halls as well as church yards.

3.3.2 Household Surveys

Data was obtained through the aid of question-answer approach during the household surveys as depicted in also known as questionnaire method. The questionnaire consisted of 9 easy to answer questions. The questions covered areas of sanitation practices, opportunities and challenges available along the sanitation chain as well as areas for improvement. The interviews were carried out in both English and Luganda. An extract of the questionnaire that was used during the interviewing is provided for in **appendix two.**

3.3.3 Focus Group Discussions

These meetings and gatherings were carried out to supplement the information obtained from household interviews. These were carried out at the council offices hall as per the permission obtained from the health inspector, primary school dining halls and yards of church premises. The meetings comprised of youth, elderly and household wives. The discussions were held mainly in Luganda for the sake of easing communication. Notes were taken during response of feedback on questioning the members of the group. The questions that were asked were in line with the sanitation practices along the sanitation value chain as described earlier. Pit emptier operators were interrogated to have a better intuition of what happens during operation of the fecal sludge. A total of 4 discussion groups were conducted. The Aquaya sanitation form containing the guiding questions were used as shown in **appendix three.** Surveys were also carried in commercial premises using the same questionnaire that was used for household surveys following the same protocol. The NWSC engineer was also interviewed using a different questionnaire as shown in appendix three. The operator at the management plant was interviewed however his information was recorded using a voice recorder.

3.3.4 Ethical Considerations

Prior to conducting these surveys, the local council one was sought to obtain authorization so that the locals would not be suspicious of our research activity. The household members were approached in a friendly manner and they were kindly asked to per take in the interview willingly without being forced. The reason for having interviews was explained to them before the actual interviewing started.

3.4 WASTEWATER DATA

Mpigi Town council is not connected to the sewer network of NWSC and so most of the dwellers use onsite sanitation management practices for their wastewater and fecal sludge. The wastewater collected by cesspool emptier is transported away from the town council to Buwama town council where it is treated to in an existing fecal sludge treatment plant. Consultation from the different cesspool service providers was made to ascertain the volume of the fecal sludge collected in a year that is treated including all the treatment technologies applied to them. This means that records of the wastewater volume treated at the Buwama Sludge Treatment plant had to be cross checked for a more accurate analysis. The records collected are included in Table 3-2.

Table 3-2: Sources of data and the responsible stakeholders

DATA COLLECTED	SPECIFICS	WHERE TO OBTAIN RECORDS
Volume of Water for Domestic Use	Treated Drinking Water Non-treated Drinking water	- NWSC - Mpigi Town Council Authority
Volume of Wastewater	Treated Wastewater	-Buwama Faecal Sludge Treatment Plant

3.5 GENERATING THE DIAGRAM

The data collected (m^3/year) was compiled in an excel file template called "2_processes_description" that is available in the package. An extract of the excel fill in data template is shown in Figure 3-2. The excel generated was imported into the website https://sankeymatic.com/build/ and the first draft of the diagram thus generated diagram was adjusted for color placement of all the flow origins at the left edge and all flow endpoints at the right edge. The diagram size and background were adjusted in the preliminary editing using the Sankeymatic tool.

	A	B	E	F	I
1	**Nodes**		**d Judgement**		
2	Functional Group	Name	Quality judgement	Outputs	Description / comments
7	A1	**Precipitaiton (rain and runoff)**	-	0 (default)	Rain/snow directly from the sky
8			-	b or c	Stormwater runoff (e.g. from roads)
9			-	u	Unknown water quality
10	A2	**Surface water (lakes and rivers)**	-	b (default)	Standard surface waters
11			-	0	Only applies to special cases, where evidence exists, that the surface water is not biologically nor chemically contaminated, like mountain lakes, ice water, water bodies far away from civilization
12			-	c	Surface water close to industrial activities, mining, intense agriculture, brakish or sea water etc. or in areas with high geogenic contamination that do not treat their effluents properly before draining into the environment
13			-	U	unknown water quality
14	A3	**Groundwater (springs and aquifers)**	-	0 (default)	Standard (deep) groundwater
15			-	b	(Shallow) groundwater, close to pit latrines or human activities
16			-	c	Groundwater affected by chemicals from industry, fertilizers from agriculture, mining effluents, brakish/saline groundwater or geogenic contaminated
17			-	U	unknown water quality

Figure 3-2: Extracts from the Excel "fill-in" data template

3.6 DISSEMINATION OF RESULTS

After the water flow diagrams basing on quality, quantity, management practices and data accuracy have been developed, interpretation of the color code was used in the assessment of the nature of the final output of the diagram in order to trigger some action. This was done through the presentation of the developed schematic to the important stakeholders (Bouman & Lukas, 2021) like households, district as well as town council technical and political and officials in NWSC. The interpretation was based on the key mentioned at the bottom of the diagrams. Basing on the analysis made, the challenges presented by the water flow diagrams were easily identified as well as the opportunities that could be optimally utilized so as to solve water related issues like water scarcity.

A workshop was organized with the relevant key stakeholders where the uWFD for Mpigi town council was presented so as to assess the level of understanding of the diagram. The aim of the meeting was to,

- → Enter into dialogue with the technical and political staff of Mpigi town council;
- → Enter into dialogue with the households, commercial and institutional agencies;
- → Enter into dialogue with public utilities responsible for water supply i.e., NWSC.

3.7 STAKEHOLDER MAPPING

Stakeholder mapping is the process of systematically identifying and analysing the relevant stakeholders, their relationship to each other, their level of interest, and their roles and responsibilities in relation to the power they hold.

Mapping the levels of interest of different stakeholders in relation to their interest or power was done using influence interest matrix. Their relative power and interest as shown in Table 3-3 were categorized into four groups: those with high interest but little power (A), high interest and high power (B), low interest but high power (C) and low interest and little power (D).

Table 3-3: Influence- Interest Matrix for the various stakeholders

		INFLUENCE	
		High Influence	**Low Influence**
INTEREST	**High Interest**	➢ Town Clerk ➢ Mayor ➢ Physical Planner ➢ Health Inspector ➢ Head of research, NWSC ➢ Water Officer ➢ Area Engineer ➢ Community Development Officer ➢ Mpigi Branch Engineer, NWSC ➢ Ministry of Water and Environment, Urban Water Supply	➢ Mr. Paul Ssebinyansi ➢ Cesspool operators ➢ Water treatment Plant Operators
	Low Interest	➢ Commercial/Production Officer	➢ Agricultural Officer ➢ Data Clerk ➢ Consumers

3.7.1 STAKEHOLDER METHOD OF PARTICIPATION

The participation process of the stakeholders was multifaceted. Letters were written officially to the various Ministries that have statutory functions to play in the project, detailing them about the project and requesting for their involvements. This was also followed up with visits to the ministry for collection of relevant documents relevant for uWFD study. In response to the request for participation, MWE were present to work with us for any form of consultation. Tools of information gathering included an In-depth interview.

3.8 SPATIAL VARIATION OF GROUND WATER SOURCE CONTAMINATION

The deductions from the urban water flow diagram data indicate that poor groundwater quality is prevalent in Mpigi Town Council. Coupled with the highly exponential population growth, the prevalence of pit latrines also increases. This emphasizes the need to assess the impact of pit latrine infiltration on groundwater quality, as the high pit latrine density in the area raises concerns about potential contamination of groundwater sources

3.8.1 System Boundary

The analysis was chosen for Wards A, B and D. As a result of being an in-between subcounty, 3 parishes of the 11 are predominantly urban. Pit latrine density in this zone is higher than the more rural counter parts. Finding one pit latrine within a radius of 100m was very much common in the latter zones. The higher pit latrine density around water points raised a point of concern to investigate the effect of pit latrines to the ground water quality.

3.8.2 Sampling of the groundwater points

Thirteen ground water points were sampled across Mpigi Municipal council. There were eight main parameters that were to be analyzed. These were pH, turbidity, ammonia, nitrates, chlorides, electrical conductivity, dissolved oxygen and *E. coli*. The sampling procedure was carried with utmost care and while in conformity with the EAS of Potable Water, 2014 as shown in Figure 3-3. Prior to sample collection, there was a sanitary inspection analysis that was done using the WHO sanitary inspection forms of 2020 for borehole and spring sources respectively as attached in **appendix one**.

A Bunsen burner was then used before collecting the water in a container to heat the outlet of the borehole and spring. This was done to kill any form of contamination for example pathogens that would cause inaccuracy in the laboratory analysis. The heating was done for about 10 minutes. With Gloves, the bottle and cap were rinsed three times with sample water and fill the bottle to within one to two inches from the top. Some of the parameters were tested on site using a multi-parameter meter. These were pH, electrical conductivity, and dissolved oxygen. The sampling bottle with the sample were placed into a cooler with ice for immediate delivery to the laboratory. Eight parameters were analyzed from the Directorate of Government Analytical Laboratory under the Ministry of Internal Affairs. The reason for the choice of the parameters and the method of testing is explained in Table 3-4.

Spatial analysis was carried out in a GIS environment. In GIS, spatial interpolation of the groundwater points was applied using the Inverse Distance Weighting interpolation method to create raster surfaces for all the parameters.

Figure 3-3: Sample Collection at Mawonve Borehole

Table 3-4: Justification and choice of parameters

PARAMATER	REASON FOR TESTING	METHOD OF TESTING
Ammonia	The ammonia in excreta is because of the breakdown of urea excreted in water.	Kjeldahl method
Nitrates	Chemical indicator of groundwater contamination by latrines due to high concentrations in excreta and its relative mobility in the subsurface.	DR-600 Spectrophotometer
Chlorides	Chemical indicator of groundwater contamination by latrines due to high concentrations in excreta and its relative mobility in the subsurface.	Mohr's method
Electrical conductivity	Affected by the presence of dissolved ions such as nitrates and chlorides in water which are attached to fecal contamination.	Seven excellence meters
Dissolved Oxygen	It often controls the fate of dissolved organic contaminants by constraining the types and numbers of microorganisms present within a water source.	Seven excellence meters
pH	One of the most important and most frequently used tests in determining water quality.	Seven excellence meters
Turbidity	Latrines are associated with increased well water turbidity.	Seven excellence meters
E. coli	The presence of *E. coli* in drinking water indicates the presence of faecal material and that intestinal pathogen could be present.	Membrane Filter Technique

3.8.3 Statistical data analysis

Stata software was used for all statistical analysis. Pearson's correlation test will then be used to determine the degree of association (positive or negative linear relationship) between the water quality results at each sampling point and the number of pit latrine densities in a radius of 15 m, 30 m, 50 m and 100 m. A critical value for a 95% confidence interval from the sample size (N) and the Pearson Correlation Coefficient (r) will then be determined.

Groundwater quality suitability was determined by comparing with the East African Drinking Water Standards and any recommendations made in that regard. Principal component analysis (PCA) was used to determine major water quality parameters. The Kaiser Criterion of the Eigenvalue of the scree plot was used to extract the principal components of groundwater contamination.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 QUANTIFY WATER USE PER CATEGORY

4.1.1.1 National Water and Sewerage Corporation

Losses in the pipe network, Proportions to each water user and water sales among others are deductions that can be made from knowing the quantity of water abstracted, treated and sold. Through a visit to NWSC Mpigi area offices, data regarding surface water was collected henceforth. In reference to the year of 2022, NWSC gathered data in regard to volume abstracted, volume treated, volume sold as depicted in Table 4-1.

Table 4-1: NWSC water supply data as per 2022

Time	**Volume abstracted (m^3)**	**Volume treated (m^3)**	**Volume sold (m^3)**
Jan-22	23750	21622	17515
Feb-22	20536	19522	16360
Mar-22	20415	19126	15445
Apr-22	18961	17699	14031
May-22	19905	18410	13081
Jun-22	18657	16849	16218
Jul-22	24873	22883	18535
Aug-22	19976	18578	15420
Sep-22	19325	17395	13742
Oct-22	18446	16969	13915
Nov-22	17770	15818	12637
Dec-22	16654	15156	11798
TOTAL	**239268**	**220027**	**178697**

The highest water abstraction occurred in July 2022, with 24,873 m^3, while the lowest was in December 2022, with 16,654 m^3. The highest volume of water sold occurred in July 2022, with 18,535 m^3, while the lowest was in December 2022, with 11,798 m^3. The disparity is highly attached to the weather patterns within these two months; December experiences heavy precipitation in form of heavy rainfall which as an intensity of 14mm/hr as per the data obtained from UMA compared to July which was considered a hot month experiencing low or no rainfall during the days of July. Water usage is generally higher is hotter months than colder months for Agricultural and household use.

Volume Abstracted Vs Volume Treated and Volume Sold:

There is a consistent trend of the volume abstracted being higher than the volume treated and volume sold throughout the year. This indicates that there is a significant amount of water loss or non-revenue water between the treatment stage and the point of sale. The total water losses for the year were 41,330 m^3. NWSC is faced with a problem of water losses that currently stand at about 19% of water supplied. The water losses are mainly attributed to; old water networks that are prone to leaks and bursts; illegal water use by some customers and old water meters which under register consumption (NWSC, 2022).

Monthly Analysis

The volume treated and volume sold generally follow similar patterns, which indicates that the treatment processes are effective in delivering water to customers. There is a notable decrease in volume sold starting from May 2022, which continues until the end of the year. This could indicate a decrease in water demand or other factors affecting sales.

Consumer Categories of NWSC

The water supply system of MTC serves a total of 2753 customers out of which 2186 are households, 65 are PSPs, two are Ministry Departments, 418 commercial enterprises and 82 are institutions. There is always a 24-hour supply of water unless in situations of water shortages during maintenance activities. With the pro-poor strategy in mind, NWSC offers a tariff plan that is differentiated for all consumer categories as highlighted in Table 4-2.

Table 4-2: Consumer Categories of NWSC

Consumer Category	Remarks	Cost per unit (UGX)
Public stand Pipe	Applicable to individuals who strictly sell water to the public	1060/=
Domestic	Applies to residential properties and blocks (homes)	3727/=
Institution	Compliments institutions like hospitals, schools among others	3771/=
Commercial	For properties such as student hostels, supermarkets, arcades, malls and also applicable in the case of construction	4473/=
Ministry	Caters for government establishments such as Police and Prisons department	3771/=

Nodes in the uWFD require clarity in regards to separate consumption for the different water users. In 2022, each consumer category had a water consumption level depicted in Table 4-3 .

Table 4-3:NWSC Category Consumption as per 2022

Period	Commercial (m^3)	Domestic (m^3)	Institutional (m^3)	Ministry (m^3)	Public Stand Post (m^3)	TOTAL
Jan-22	3149	8633	2968	381	2350	17481
Feb-22	2802	7393	3970	322	1865	16352
Mar-22	2598	6762	3853	287	1910	15410
Apr-22	2428	6380	3100	444	1675	14027
May-22	2363	5220	3486	393	1619	13081
Jun-22	2744	6715	4443	350	1945	16197
Jul-22	2832	8888	4131	392	2238	18481

Period	Commercial (m^3)	Domestic (m^3)	Institutional (m^3)	Ministry (m^3)	Public Stand Post (m^3)	TOTAL
Aug-22	2796	7966	2317	341	1987	15407
Sep-22	2419	5757	3190	651	1699	13716
Oct-22	2221	5612	3784	540	1694	13851
Nov-22	2056	5716	2892	588	1385	12637
Dec-22	2060	6113	1671	507	1447	11798
TOTAL	**30468**	**81155**	**39805**	**5196**	**21814**	

Monthly Water Usage Patterns

Water usage across all sectors shows some variations throughout the year. The highest total water consumption occurred in July 2022, with 18,481 m^3, while the lowest was in December 2022, with 11,798 m^3. The commercial and domestic sectors consistently demonstrate higher water usage compared to other sectors.

Sector Comparison

The domestic sector consistently has the highest water usage among all sectors throughout the year. The commercial sector also demonstrates substantial water usage but is lower than the domestic sector. The institutional sector shows relatively lower water usage compared to the commercial and domestic sectors. The ministry sector has the lowest water usage, indicating relatively lower water demands. This is because the water users are only Police and Prisons. Public stand posts provide a significant volume of water consumed, indicating its importance in supplying water to the community.

Monthly Water Usage Fluctuations:

Water usage shows some monthly fluctuations. For example, water usage tends to be higher during the summer months (June, July, and August) and lower during the cooler months (December, January, and February). These fluctuations may be attributed to the fact that people's water usage habits change seasonally based on cultural practices. Individuals engage in more water-intensive activities in contrast cooler months.

The total water consumption for the year sums up to 218,138 m^3 compared to 159048 m^3. The water usage pattern across different sectors and monthly variations can be useful for identifying trends, planning water resource management, and considering strategies for promoting water conservation and efficiency within each sector.

Knowing the active waters users at the start of the year to the end of the year provides a better intuition of the progress in regards to water coverage or rather a decline with the number of actively connected users. On supply water users at both the beginning and end of the year is portrayed in Table 4-4 for all category levels.

Table 4-4: On-supply water users of NWSC

CATEGORY	JAN 2022	DEC 2022
Commercial	457	379
Domestic	2,266	2105

CATEGORY	JAN 2022	DEC 2022
Institutional	89	77
Ministry	2	2
Public Stand Post	62	67

Overall, the analysis of on-supply water users reveals a general trend of decreasing numbers in the commercial, domestic, and institutional categories. However, the ministry category remained consistent, and the public stand post category saw a slight increase. The decreasing trend could be attached to the increasing price instigated by NWSC for domestic usage. Public Stand Pipes (PSPs) are a convenient way through which the economically disadvantaged members of the community can access clean and affordable water. The tariff at the public stand pipes is subsidized to UGX 21 per 20-liter jerrycan compared to the domestic tariff of UGX 70.

4.1.1.2 Private water supply in Mpigi Town Council

From Sebinyansi Spring, Mr. Paul Ssebinyansi, a retired Marine Engineer and proprietor of Mpigi Fish Farm & Water Supply company abstracts water and it is disinfected with chlorine. It is then moved using pumps from the swamp to three tanks in his residential compound that's located in Ward A.

The water is sold to nearby households, Institutions such as schools and hospitals, Commercial enterprises such as hotels. Sales average up to 50,000 L/d in the dry season and half of that amount in the wet season. As a form of quality assurance, the Ministry of Water and Environment test samples from this enterprise and necessary recommendations made to the chlorine dosages to be added.

In comparison to an average volume of 490 L/d sold by NWSC, the higher volume sold by this private supplier is attached to the affordability of his product; 40 % cheaper than NWSC. Additionally, Mr. Paul has a significant customer base because he was the initial private water supplier to the residents of the town council, making his services widely sought after.

4.1.2 Agricultural Water Use

As we strive to ensure the sustainable utilization of water and meet the evolving needs of our growing population, it is crucial to recognize the vital role that agriculture plays in water consumption. By incorporating this key information, we can paint a more accurate picture of water availability and allocation within our urban water flow system.

4.1.2.1 Mpigi fish farm

Mpigi Fish Farm and Water supply (Proprietor is Mr. Paul Ssebinyansi) Fish farming is done for three different kinds of fish i.e., Mill carp, Tilapia and Catfish. The farm adjacent to a flowing stream has six constructed ponds with four having a cross-sectional area of $200m^2$. The remaining two are of $500m^2$ and $470m^2$ cross-sectional area. In terms of depth, all the fish ponds have a slanting floor with the shallow end of 2ft and deep end of 3.5ft. It is estimated that the farmer averagely drains half of the water monthly in each pond and replaces it with more fresh water from the flowing stream by opening inlets and outlets that connect each pond to the stream. This draining process is done to create a favorable environment for fish by maintaining a balanced pH of water that varies with variations in ammonia content as well as other chemical components generated in the pond. This process also facilitates an enhanced supply of oxygen into the pond. The 2022 water usage of the fish farm is displayed on Table 4-5.

Volume = Cross-section

Table 4-5: Monthly volumes used in Mpigi Fish Farm

Month	$200m^2$ (1)	$200m^2$ (2)	$200m^2$ (3)	$200m^2$ (4)	$470m^2$	$500m^2$
January	167.64	167.64	167.64	167.64	419.1	393.954
February	83.82	83.82	83.82	83.82	209.55	196.977
March	83.82	83.82	83.82	83.82	209.55	196.977
April	83.82	83.82	83.82	83.82	209.55	196.977
May	83.82	83.82	83.82	83.82	209.55	196.977
June	83.82	83.82	83.82	83.82	209.55	196.977
July	83.82	83.82	83.82	83.82	209.55	196.977
August	83.82	83.82	83.82	83.82	209.55	196.977
September	83.82	83.82	83.82	83.82	209.55	196.977
October	83.82	83.82	83.82	83.82	209.55	196.977
November	83.82	83.82	83.82	83.82	209.55	196.977
December	83.82	83.82	83.82	83.82	209.55	196.977
TOTAL	**1089.66**	**1089.66**	**1089.66**	**1089.66**	**2724.15**	**2560.701**

This brings water usage at the fish farm to a tune of **9,643.491m^3** per year. The water usage appears relatively consistent throughout the year for each pond size. However, it's worth noting that certain months, such as January and July, show higher water usage compared to others. This could be due to factors like increased evaporation during hot and dry periods.

4.1.2.2 Mbulamu Agro-Farm

Mbulamu Agro-Farm is a farm that engages in crop farming on 15 acres of land in Mpigi town council. The farm deals in Irish potatoes, pumpkins, beans, water melon, maize and cabbages among other several other crops. The farm uses the irrigation facility it received from the government to pump and fill the 30,000-liter water tank on a daily basis. The water is pumped from the nearby swamp and is lost to ground-water infiltration and evapotranspiration. This translates to **10,950m^3** of water per year.

4.1.2.3 Kakuuto Farm Supply

This agricultural farm deals in coffee, banana, cabbage, watermelon and passion fruits. The farm also received an irrigation facility from the government to enhance production. This smaller farm has a 10,000-liter tank that is filled twice a week and all this water is fed to the crops using the set-up irrigation facility provided. The water is pumped from the nearby swamp and is lost to both ground-water infiltration and evapotranspiration. This translates to **521.429m^3** of water per year.

4.1.3 Industrial Water Use

Urban water flow to industries is an all-inclusive component in the development of the uWFD. Industries far and wide of the town council as shown in Table 4-6 were visited as portrayed in with water related inquiries made.

Table 4-6: Industries, their source and consumption within MTC

INDUSTRY	PRODUCT	QUANTITY (l/d)	SOURCE OF WATER
Nick Industries Ltd	Cosmetics	10,000	Groundwater
Tukorelewamu Growers Cooperative	Maize Flour	40	NWSC
Augar Construction company Ltd	Construction materials	100	NWSC
Mugies Complex Ltd	Soap	2800	Groundwater
Mbugo Area Cooperative Enterprise	Coffee Milling	40	Groundwater
Jes & E Technical Service	Construction Material	1874.1631	NWSC
Hualong Energy Company Ltd	Diesel, Engine Oil and Fuel Oil	12000	Groundwater
Njuba Grain Millers	Maize milling	60	NWSC
Hill Water	Bottled drinking water	60,000	Groundwater
Luggeye & Sons Enterprise Grain Millers	Maize and Coffee Millers	80	NWSC
Mussanje Quality Feeds	Poultry feeds	20	NWSC
Emaar Bakery	Bread	60	NWSC
Ssenteza Grain Millers	Maize and Coffee Millers	60	NWSC

The water usage among the industries varies significantly. Hill Water, which produces bottled drinking water, has the highest water usage of 60,000 L/d, indicating its large-scale operations. Other industries, such as Hualong Energy Company Ltd, Nick Industries Ltd, and Jes & E Technical Service, also consume a considerable amount of water.

Given the significant water usage by the industries, there is a potential for water conservation measures to be implemented. This could include adopting water-efficient technologies, recycling and reusing water where feasible, implementing proper leak detection and maintenance practices, and promoting awareness among employees about the importance of water conservation.

4.1.4 Groundwater Usage

Groundwater counts as the major water resource to the residents in Mpigi Town Council. As a result of its widespread distribution, low development cost, and generally excellent quality, it has been the fundamental resource allowing the rapid development of improved domestic water supplies for the rural population and in many areas has also supported a major increase of highly productive industrial and agricultural usage. Groundwater resources in this region are thus vital for meeting an array of basic needs, from public health to poverty alleviation and economic development.

Groundwater sources within the area include springs, shallow wells and deep boreholes. There are 64 springs, 56 shallow wells and 17 deep boreholes. Data collected from the Town Health inspector regarding all the existing groundwater sources as shown in Table 4-7.

Table 4-7: Grounwater sources, their location and status

PARISH	VILLAGE	WATER SOURCE	STATUS
BUMOOZI	Namiryango	Ssendaula Shallow well Kissinyi Shallow well Bakunga Shallow well Bugembe Shallow well Nsambu Shallow well Wasswa Shallow well	Operational Operational Operational Operational Operational Operational
	Bboza	Kisitu spring Anania spring Buyingiro spring	Operational Needs repair Operational
	Bugayi	Lumu Shallow well Lubuzi Shallow well Fenehansi spring Nakasozi Shallow well	Operational Operational Operational Operational
	Kikamula	Ssemiga spring Nnalongo spring Kamoga spring Kkonge SS Borehole Ntambi spring	Operational Needs protection Operational Needs repair Operational
	Nnono	Wakyato Shallow well Kamiri Shallow well Nababirye Shallow well Bazuri Shallow well	Needs protection Needs protection Operational Needs protection
	Kigwanya	Katabalalu Shallow well Simeo Musisi Shallow well Kayikuzi Shallow well Munyansuli Shallow well Lutwama Shallow well Ssengendo Shallow well Namukangula Shallow well Kkonge P.S Borehole	Operational Operational Operational Operational Operational Operational Operational Needs repair
	Bumoozi A	Wakifu spring Nabirye spring Kalinda Kato spring Kalinda Simon spring Mpoza Kalinda spring	Operational Operational Operational Operational Operational
	Bumoozi B	Misenyi spring Mupolanda spring Lutakome spring Nuludin spring Ffunvu spring	Operational Operational Needs protection Needs protection Needs protection
	Kimbugu	Nambeya spring Kizza spring Nkayivu spring Nsigalira spring	Operational Operational Needs protection Needs protection

PARISH	VILLAGE	WATER SOURCE	STATUS
		Masagazi spring	Needs protection
KAFUMU	Bulilo	Kaziba Spring Banda Spring	Functional Functional
	Namabo	Namabo Spring Namabo Shallow well	Functional Functional
	Kitawanulwa	Nakivubo Shallow Well	Functional
	Bulyasi	Bulyasi spring	Functional
	Bumwuka	Kanyeera spring Kafumu P/S spring	Functional Functional
	Nanyinzi	Walugembe spring Domi spring	Functional Functional
	Kisaliza	Kisaliza shallow well Muzungu spring Kaddu shallow well	Functional Functional Functional
LWANGA	Lwanga	Lwanga Shallow Well	Functional
	Kizzi	Kizzi Shallow Well	Functional
	Kalagala	Mpanga borehole Kanyolo borehole	Functional Functional
	Nyomerwa	Herm Spring Bega kwa bega spring	Functional Functional
KYALI	Bubezi	Nababirye deep borehole	Functional
	Gayaza	Lufuka deep borehole	Functional
	Kasamu	Kasamu borehole Mubikafa spring	Functional Functional
	Nsamu	Nsamu borehole	Functional
KKONKOMA	Kkonkoma	Muyizi spring Kasimiri Shallow well Buyungo Shallow well Mukosi spring	Needs protection Poor condition Poor condition Operational
	Nseke	Luwala spring Kigungu spring	Poor condition Operational
	Bwanya	Kiyingi spring Kasanvu spring Kabogoza spring Mbuga spring Luka spring Chairman spring Bwanya spring	Needs repair Needs repair Needs repair Needs repair Needs repair Needs repair Needs repair
	Ijanya	Ssewagudde spring Nvule spring Kiteredde spring Ijanya PS Borehole	Needs repair Operational Needs repair Needs repair
	Nakigudde	Kigula spring Ssempala spring Lukungu spring Mulepi spring Ssemwanga spring Mwanga spring	Needs protection Needs protection Needs protection Needs protection Needs protection Needs protection

PARISH	VILLAGE	WATER SOURCE	STATUS
		Zefaniya spring	Needs repair
WARD A	Park village	Kakopo spring Lubinja spring Uganda Company Spring Uganda Company Bore Hole	Poor condition Operational Poor condition Needs repair
	Church center	Pilote spring Pilote Shallow well	Needs repair Needs repair
	Police Center	Police borehole Kadiba spring	Needs repair Needs protection
	Lufuka	Nalugidde spring Kikombo spring Temamutwe spring Nkonge spring	Needs protection Needs protection Operational Needs protection
	Mpami/ Bikondo	Bikondo Borehole Mbilidde spring St. Bruno Shallow well	Operational Operational Operational
WARD D	Mayembe Upper	Senkungu spring Kikwabanga spring St Kizito Borehole	Poor condition Operational Needs repair
	Mayembe Lower	Lwanga spring Mukasa spring Nabunya spring Mpigi Modern Shallow well	Poor condition Operational Operational Needs repair
	Prison Center	Prison Shallow well Mpigi central SS spring Kalule spring	Needs repair Operation Needs repair
WARD B	Kyasanku	Kayanja well	Needs repair
	Mawonye	Kakopo spring Kamiyati spring	Needs protection Needs protection
	Kalagala	Byangwe spring Waggumbulizi well Waggumbulizi borehole Kasaja spring	Needs protection Operational Needs repair Needs repair
	Katwe	Katwe Borehole	Needs repair
WARD C	Mbaale	Nabunya spring Aidah spring	Needs protection Needs repair
	Kabanga	Ddungu – Semunywa	Operational
	Bukakala	Mutoole – Canon spring Ssessanga spring Matia spring	Need protection Needs repair
KAKOOLA	Kakoola	Kisiramu spring Namunyerere spring Buwala spring Mundu spring	All Functional
	Bunamweri	Kikandwa spring Nakagga spring Nkizi spring Kibindiizi spring	All Functional
	Ggala	Kadiba spring Kitavujja spring	All Functional
MAZIBA	Lungala	Zimbwe borehole Seninde Borehole Kibindiizi Borehole	Needs repair Operational Operational

PARISH	VILLAGE	WATER SOURCE	STATUS
		Kibindiizi spring Kiyanja borehole	Operational Needs repair
	Bugombe	Kanamugina spring Kalule spring Kataba/ Kinene spring Kabwama spring	Operational Operational Operational Operational
	Bume	Kawaali spring Gaava spring Sepiliya borehole Kiyanja spring Katamba spring	Operational Operational Needs protection Needs protection Operational

The following was observed from Table 4-7;

Springs:

Operational Springs: 45

Springs Needing Repair: 4

Springs Needing Protection: 11

Springs in Poor Condition: 4

Shallow Wells:

Operational Shallow Wells: 49

Shallow Wells Needing Repair: 4

Shallow Wells Needing Protection: 3

Boreholes:

Operational Boreholes: 13

Boreholes Needing Repair: 4

Quantity: Springs have the highest quantity, with 45 operational springs compared to 49 operational shallow wells and 13 operational boreholes.

Maintenance Needs: Springs have the highest number needing repair, with 4 springs requiring repairs. Shallow wells and boreholes also have 4 each needing repair.

Protection Needs: Springs have the highest number needing protection, with 11 springs requiring protection measures. Shallow wells have 3 needing protection, while no specific data is provided for boreholes.

Condition: Springs have the highest number in poor condition, with 4 springs categorized as such. No specific data is provided for the condition of shallow wells and boreholes.

4.1.4.1 Discussion

The analysis highlights the importance of regular maintenance, repair, and protection of water sources in Mpigi Town council. Timely repairs and preventive measures can enhance the sustainability and longevity of the springs, shallow wells, and boreholes, ensuring a consistent and safe water supply for the communities.

There are more springs within the area because geologically, the presence of permeable rock formations, such as limestone and fractured volcanic rocks, allows for the storage and movement of groundwater, leading to the emergence of more springs (Owor et al., 2021). From past geotechnical investigations done for construction projects, some locations within MTC were found to be rich in karst rock especially in Ward B. Deep boreholes are also still few within the town council because of few government and private initiatives to construct boreholes.

Engaging the local communities in the maintenance and protection of the water sources is crucial. Community involvement can include awareness campaigns, training on sustainable water management practices, and establishing community-based committees responsible for the upkeep of the water sources.

4.1.4.2 Estimation of Groundwater Quantity

Using local data and expertise, an average of 150 20-litre jerrycan at every borehole was recorded on a daily basis. This piece of secondary data was collected from the Community Development Officer. This amounts to approximately $3m^3$ per day.

This is in conformity to A standard size borehole in Africa. It typically refers to a borehole with a diameter of around 6 inches (15 centimeters) and a depth ranging from 50m to 100m. The amount of water abstracted from a borehole per day can depend on several factors, including the pumping rate and the water table depth. A typical estimate for a standard borehole in Africa would be around 5 to 20 cubic meters per day (5,000 to 20,000 l/d) (Posted by Jeff Greene on 22 March 2022).

4.2 ASSESSMENT OF THE WATER SUPPLY SYSTEM IN MPIGI TOWN COUNCIL

The assessment of the water supply system for NWSC was carried out to ascertain the level of is the safety, reliability, and sustainability of the water provided to the community. Conducting a thorough assessment allows for the identification and evaluation of potential hazards, vulnerabilities, and risks associated with the water supply system. This assessment aids in understanding and mitigating risks related to water quality, infrastructure integrity, operational practices, and external factors such as natural disasters or contamination sources.

4.2.1 Land use in Kiyanja Catchment

The head work is located in Ward A where large scale water treatment is done to the swamp water before distribution to the locals. The area is predominantly represented by a forested wetland however there are anthropogenic activities carried out within the swamp like grazing of domestic animals especially cattle, car washing, disposal of solid waste, road construction, building of houses. This encroachment is due to negligence in the enforcement policy of NEMA to protect wetlands as per the (National Environment Act, No. 5 of 2019) under the management of wetlands.

These human activities in the catchment are disastrous and this is evidenced by the trapping of dead fish at the Kiyanja intake due to spillage of car oils from engines during car washing that cuts off the oxygen supply to aquatic life leading to suffocation.

4.2.2 Water Abstraction from Kiyanja

The water intake facility was constructed in 2007 under the “small towns water and sanitation” project funded by the African Development Fund. This was done to improve the standard of living and promote development in the towns of Apac, Iganga, Kigumba, Mityana, Mpigi, Nebbi and Pakwach by providing them with improved quality and delivery of water supply and sanitation services.

The sources of the Kiyanja head works start from the moving stream of the Kiyanja swamp. Water is abstracted through a water sump located at 553 m above sea level. The size of the sanitary zone of the head works is about 70 m^2 and is located 1Km away from the treatment plant. The headwork consists of two water collector points with the following specifications: N1 - collector well, 2.6 m x 3.8 m and 4.84 m deep, with a concrete bottom. The second collector has the same specifications and is used as a standby collector in case of emergencies like during hours of peak demand.

The head work and sanitary zone are not fenced or guarded/supervised as shown in Figure 4-1, which poses a threat to the water quality in terms of anthropogenic activities. There is also a gravel road along the intake which leads to pollution in form of dust into the water.

Comparing this to Ggaba water treatment plant, the intake is also not protected and the main source of pollution is wastewater discharge by the local population and industries within the area which leads to high costs of water treatment. However, for Katosi water treatment plant, the intake is located in a forest conservation reserve by NEMA hence pollution due to anthropogenic activities is not a major issue.

4.2.3 Water quality issues at the source

Routine deterioration of the water quality is predominately caused by heavy rains, which wash sediments from the nearby road and increase the turbidity of the swamp water. The decay of the papyrus in the swamp deposits organic matter which is a felt at the treatment process. The Kiyanja swamp is predominantly covered by papyrus and with each day that passes, so many of these plants decay posing a threat to the quality. These overall increases the costs of water treatment in terms of the chemicals need to eliminate pollutants from the water.

Figure 4-1: Unprotected intake at Kiyanja Swamp

4.2.4 Water conveyance and distribution

From the head works water flows into the water mains with a total length of about one kilometer to the treatment plant. Water mains have not been renovated since their commissioning (bursts and leaks rarely happen with these). High Density Polyethene pipes are used because of their durability, resistant to corrosion, biological growth and degradation caused by exposure to moisture and oxygen (Mohammed et al., 2021). At the treatment plant, the water's quality is fully altered to a safe product for the end consumer by being subjected to a series of processes that include Aeration, Pre-chlorination, Coagulation, Flocculation, Sedimentation and finally disinfection. The treated water is then pumped through the transmission mains to the reservoirs.

Ten kilometers away from the plant is the first reservoir having total capacity of 150 m^3 located at Ssabwe Hill. It is made of ductile iron as that of Katosi water treatment plant. There is a second reservoir located five kilometers away from the plant located at the Kulumba having the same capacity. No Chlorination with liquid chlorine takes place at the reservoir because of the presence of residual alum and residual chlorine that's dosed at the treatment plant which keep the water safe even in transit. From reservoirs, disinfected water is routed to the distribution network. The area of the reservoirs is fenced with chain links with barbed wires on top.

Water quality or quantity monitoring is carried out at the reservoirs. Ductile iron is used because of its durability, high flexural strength and resistant to corrosion. In general, the plant has a yield of 5000m^3/day and this is due to the small growing population within the area and given that its coverage is within four parishes out of the 11 parishes. This capacity is less than than that of Katosi and Ggaba which have 160,000m^3/day and 72,000m^3/day respectively which serve greater Metropolitan Kampala. The pipe network consists of 90% HDP pipes, 8% UPVC pipes and the remaining 2% has DI pipes. The water pressure regime in the main pipes is balanced from the reservoirs and with additional use of brake pressure tanks.

4.2.5 Water quality testing, monitoring and compliance with set standards

Water quality testing is frequently carried out to ensure that the quality is in conformity with the set standard limits as per the East African Standards of Potable water, 2014. Regular monitoring of the water quality is done at selected locations so as to identify pollution sources in case of non-conformity and rectify such problems that may arise in the system. Such sources are usually as a result of leakages or burst pipes which allow the entry of silt and organic matter underground since the pipes are laid underground. The parameters that are tested for by NWSC are; pH, electrical conductivity, true and apparent color, total suspended solids, alkalinity, hardness, residual aluminum, total iron, residual chlorine, Fecal coliforms and *E. coli.*

Water quality monitoring points are set up by the head office of NWSC. For all water supply systems, control points should include; water intake, transmission mains, distribution mains and the two reservoirs. It is carried out by the laboratory at the treatment plant of NWSC. The Laboratory is in satisfactory condition, though the chemical analysis equipment is old. Samples from points at the treatment plant are taken on a daily while the samples in the distribution network and the reservoir are taken once in a month. Results of the 2022 lab analysis was summarized as displayed in Table 4-8.

Table 4-8: Assessment of drinking water parameters of NWSC

Water Quality	Ingredients	Indicator	Actual performance
Compliance with National standards for drinking (potable) Water 2008	(No of samples passing national standards/total samples tested) x 100	Bacteriological quality (%)	99.8
		Color (%)	87.1
		Turbidity (%)	97.8
		Chlorine residual (%)	98.7
		pH (%)	100.0
		Electrical conductivity (%)	100.0
		Alkalinity total (%)	100.0
		Hardness total (%)	100.0
		Average (%)	**98.0**

The table shows that although most components of the water supply system followed the National Standards, however there were instances of non-compliance. The figures in the table show that on average of the total samples collected from the control points, 98% met the drinking water standards and 2% of the samples did not meet requirements. This might be caused by the damaged distribution system, inadequate chlorination process and/or water interruptions.

In order to identify issues related to particular parameters, additional information was requested from the laboratory staff. Based on this information it was learned that non-compliance of water quality with the national standards was generally due to microbiological contamination – noncompliant concentrations of total coliform bacteria and *E. coli*. Physical parameters in general sometimes never met the national standards. According to chemical parameters, water quality met national standards. However, concentration of residual chlorine was sometimes lower than the national standard (0.2 – 0.5 mg/L). It is unknown if chlorination was not conducted in these instances or if it was conducted insufficiently.

4.2.6 Identification of hazards, their sources and potential hazardous events

For identification of hazards, their sources and potential hazardous events/situations and assessment of risks, visual observation of the water supply system was conducted jointly with the representatives NWSC. In addition, a sanitary inspection questionnaire was developed, handed out and filled in by the town engineer of the Mpigi Water Supply System. It consisted of 10 questions as shown Table 4-9 in with “Yes” or “No” answers. The sum of the “Yes” answers gave the scale/level of the risk divided into following classes: 9 -10 = Very High, 6-8 = High, 3 -5 = Medium, 2-0 = Very Low/no risk. Stemming from the fact that the situation in all head works is the same (with little differences), sanitary inspection questionnaire was elaborated for entire water supply systems and not for particular elements.

Table 4-9: Sanitary Inspection Questionnaire for NWSC water supply system

#	QUESTION	YES	NO
1	Is the area around the catchment not protected?	X	
2	Do animals have access to the area around the catchment?		X
3	Are there any solid or liquid waste collecting sites within 30 m of the catchment		X
4	Is there any source of pollution within 10m radius of the catchment (e.g. animal breeding, cultivation, roads, industry etc.)	X	
5	Are coagulation and sedimentation tanks absent?		X
6	Is the main pipeline corroded or damaged?		X
7	Is water treatment plant absent		X
8	Is the chlorine tank improperly arranged?		X
9	Has there been a discontinuity in water supply in the last 10 days?		X
10	Did the community report any pipe breaks in the last week?	X	
Total		3	7

As shown from the aggregate responses to the questions of the Inspection Questionnaire, 3 positive responses out of 10 questions were received indicating that the system belongs to the medium risk category. Thus, the following hazardous events/situations/sources of water contamination were identified.

- Absence of a sanitary protection zone around the head works, leaving these structures easily accessible to wild animals and livestock.
- Frequent interruptions in water supply.
- Frequent accidents in distribution systems.

All the listed hazardous events/situations/hazard sources may lead to any of three hazards; deterioration of physical properties of the drinking water, microbial contamination of the drinking water and chemical contamination of the drinking water. Bacteriological hazards may cause the spread of water borne diseases, in particular during heavy rains, floods, increased air temperatures and droughts. Chemical contamination and deterioration of organoleptic (physical) properties of drinking water are also possible, though no significant chemical pollution source was found in the catchment of the water source.

4.2.6.1 Prioritization of hazards

In accordance with WHO WSP guidelines (2005), hazards revealed for the whole water supply scheme were prioritized by application of a risk assessment matrix. Risks were quantified according to categories of hazards (e.g., microbial, chemical, etc.) for various hazardous events/situations/sources of hazards, as suggested in the WHO WSP guidelines.

The risk of hazards in Table 4-10 was assessed by two factors: likelihood and potential impacts (results of water quality self-monitoring of the water supply system). The likelihood was expressed by anticipated occurrences of hazards identified through the sanitary observation of the system. Hazards threatening the water supply system were prioritized using a matrix. The priority matrix is based on risk scores of the sanitary inspection questionnaire and water quality monitoring data received from NWSC.

Table 4-10: Hazard prioritizing matrix of NWSC supply system

Deviations from drinking water quality standards,%	**Sanitary inspection score (SIS)**			
	0-2	**3-5**	**6-8**	**9-10**
71-100	0	0	0	0
31-70	0	0	0	0
11-30	0	0	0	0
1-10	0	X	0	0
Risk level	Low	Medium	High	Very High
Priority action level	none	low	High	Urgent

With 2% that deviated from the standard according to the results (score 3) of the sanitary questionnaires, the entire system, including the distribution network, is assessed at medium risk. The water supply points scored as “yes” on the sanitary inspection form represent the potential sources/factors of hazards for microbiological contamination of drinking water.

Thus, on the basis of the sanitary questionnaire and hazard prioritizing matrix for Mpigi water supply system, biological, chemical and physical contamination risk factors were identified that have a negative impact on the quality of drinking water and cause a hazard of exposure to water borne diseases or chemical contamination. In more detail, on the basis of visual inspection and the results of the sanitary observation questionnaire, the following components/steps of water supply system were identified as the most probable causes of contamination of potable water; water treatment points, head work, reservoirs, main pipes and distribution mains.

To calculate a priority score (based on WHO guidelines) for each identified hazard, a semiquantitative risk assessment and a prioritization matrix included in Table 4-11and Table 4-12. The objective of this matrix is to rank hazardous events and identify the most significant hazards. Risk ratings, calculated based on the likelihood and severity of impact.

Table 4-11: Impact Categories used in hazard prioritization of NWSC supply system

Rank	Level Of Likelihood/Impact	Description Of A Level Of Likelihood/Impact
Likelihood		
A	Very high likelihood	Very frequent (e.g., to happen continuously or at least once a day)
B	High likelihood	Frequent (e.g., to happen at least once a week)
C	Moderate likelihood	Moderately frequent (e.g., to happen at least once a month)
D	Low likelihood	Rare (e.g., to happen at least once a year)
E	Very low likelihood/Unlikely	Very rare (e.g., to happen at least once every 5 years)
Impact/Consequence		
5	Catastrophic: Public health impact	Mortality expected from consuming water
4	Major: Regulatory impact	Morbidity expected from consuming water
3	Moderate: Aesthetic impact	Major aesthetic impact possibly resulting from the use of alternative but unsafe water sources
2	Minor: Compliance impact	Minor aesthetic impact causing dissatisfaction but not likely to lead to use of alternative less safe sources
1	Insignificant: No impact or not detectable	No detectable impact

Table 4-12: Qualitative risk matrix analysis

Consequences					
Likelihood	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
	1	**2**	**3**	**4**	**5**
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H

Note: The number of categories should reflect the need of the assessment.

E – Extreme risk, immediate action required; H – High risk, management attention needed; M – Moderate risk, management responsibility must be specified; L – Low risk, manage by routine procedures.

Based on the matrices, each identified hazardous event/situation/hazard source was ranked against the level of hazard risk as explained in Table 4-13 below

Table 4-13: Risk hazard evaluation of NWSC

Drinking water supply system component	**Hazardous event/situation/hazard source**	**Hazard**	**Likelihood**	**Impact/ Severity**	**Qualitative risk**
Water treatment	Inadequate disinfection Insufficient amount of residual chlorine in water system	Microbial pathogens	D Recently manual chlorination lime was replaced with liquid chlorine that guarantees more effective water disinfection and minimum human error	4	H (High risk management attention needed)
Water treatment	Increased water turbidity and changed color during heavy (seasonal) rains	Physical	C The swamp is easily impacted by heavy rains.	3	H (High risk, management attention needed)

Drinking water supply system component	Hazardous event/situation/hazard source	Hazard	Likelihood	Impact/ Severity	Qualitative risk
Water abstraction points	Domestic and wild animals can access the water catchment area, which could result in the animal faecal matter entering the water supply system	Microbial pathogens	D The head works is located in areas not easily accessible by humans and animals; the likelihood of contamination is not high	4	H (High risk, management attention needed)
	People may access the water catchment area and purposefully or unintentionally discharge chemicals into the swamps leading to chemical pollution of the source water; Significant source of chemical pollution may exist in the catchment and may pollute source water	Chemical	E Head works is fenced but not guarded/ supervised 24 hours a day. However, the area is not easily accessible by humans; besides, there no single case of the source water chemical contamination recorded; No serious source of chemical pollution was detected in the catchment; Therefore, the likelihood of source water chemical pollution is very low	5	H (High risk, management attention needed)
Head works and water abstraction points	Increased water turbidity and changed color during heavy (seasonal) rains (especially at the Kiyanja intake facility)	Physical	C Water source represents swamp which is easily impacted by heavy rains. Besides, technological treatment of water is not carried out	3	H (High risk, management attention needed)

Drinking water supply system component	Hazardous event/situation/hazard source	Hazard	Likelihood	Impact/ Severity	Qualitative risk
Main pipes and distribution network	Damaged pipes and insufficient pressure and water interruption can result in backflow from customer systems into the network	Microbial pathogens	B At some points of the pipes are damaged, backflow prevention devices are not installed in all service connections	4	E (Extreme risk, immediate action required)

4.3 DEVELOPING uWFD AND STAKEHOLDER CONSULTATION

Assumptions for the generation of the diagram

- Public use constitutes both ministry and institutional consumption,
- PSP are part of the Microbial un-piped and entirely used by households,
- 57% of water supplied by the fish farm is used by households and 40% used by public,
- 3% of the volume sold by the fish farm is lost during transit,
- 75% of the water used by the public institutions is converted to wastewater discharged into the septic tanks,

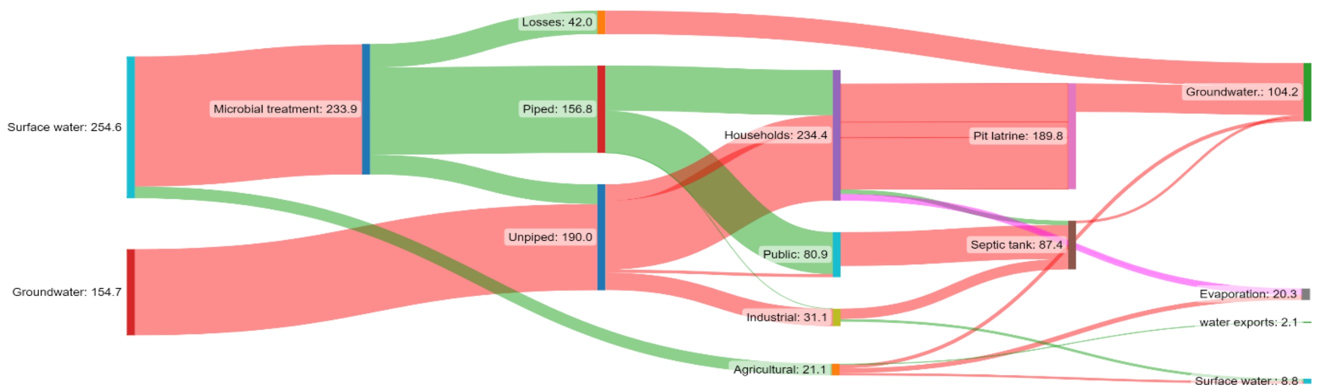


Figure 4-2: Quality based uWFD for Mpigi Town Council

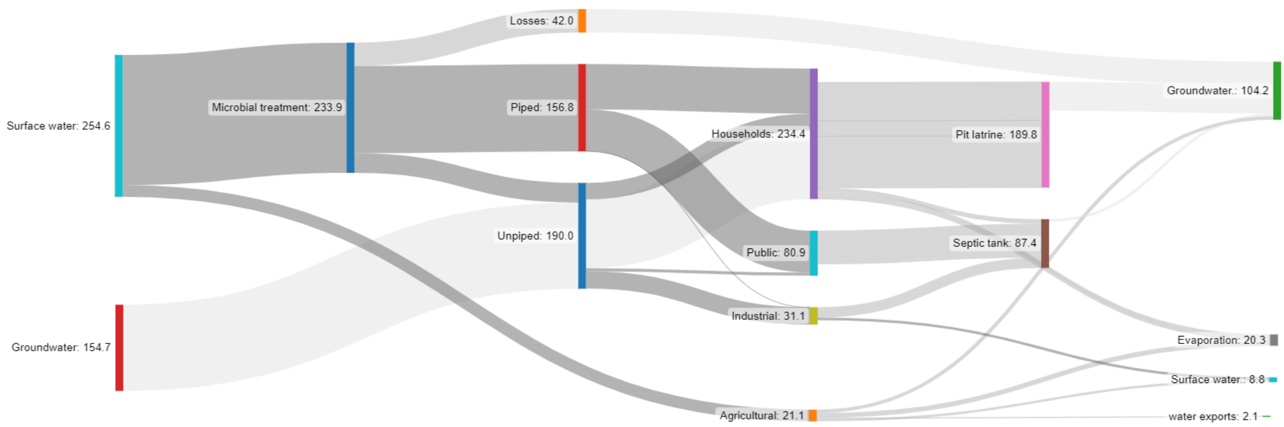


Figure 4-3: Accuracy based uWFD for Mpigi Town Council

4.3.1 Quality-Quantity Discussion

The Sankey diagram in Figure 4-2 presents a comprehensive representation of the urban water flow in Mpigi Town Council. It highlights the quantity and quality aspects of the water sources, treatment processes, distribution systems, and usage patterns within the region.

In terms of water quantity, the diagram demonstrates a reliance on surface water as the primary source, which accounts for a significant initial supply. However, it is essential to consider the sustainability and availability of surface water sources, especially in the context of potential climate variability and increasing water demand.

The microbial treatment process is significant in addressing water quality concerns, indicating a commitment to ensuring safe water supply. However, the presence of losses within this process implies a need for closer examination of treatment efficiency and potential improvements to minimize water losses.

The distribution systems, both piped and un-piped, play vital roles in supplying water to households, public facilities, industries, and agricultural activities. The piped system appears to provide water of appropriate/good quality, ensuring reliable access to safe water for domestic and public use. On the other hand, the un-piped system poses challenges, particularly in terms of water quality associated with household and industrial usage. Addressing these challenges is crucial to improve access to safe water for those relying on the un-piped system.

Sanitation practices, including the use of septic tanks and pit latrines, are prevalent in the area. However, the data indicates that the quality of water associated with these sanitation systems is problematic, suggesting potential risks to groundwater contamination. It highlights the importance of implementing appropriate sanitation solutions and promoting proper management practices to safeguard water resources and public health.

The allocation of water for agricultural purposes signifies the significance of irrigation in the region. However, further exploration of agricultural practices, water efficiency, and potential impacts on water quality would be beneficial for sustainable water resource management and minimizing environmental impacts.

The groundwater system receives a substantial amount of water, but concerns arise regarding its quality due to potential contamination sources, such as agricultural usage, septic tanks, and pit latrines. It underscores the need for monitoring and implementing measures to protect groundwater resources from pollution and ensure its long-term sustainability.

The presence of water exports suggests potential opportunities for economic activities related to water resources. Understanding the reasons and implications of water exports can contribute to strategic planning and sustainable water management.

Overall, the data from the Sankey diagram provides valuable insights into the urban water flow in Mpigi Town Council. It identifies critical areas such as water treatment efficiency, sanitation practices, groundwater protection, and sustainable agricultural water use that require attention and targeted interventions for improving water quantity and quality. These findings can guide policymakers, water resource managers, and stakeholders in formulating effective strategies for sustainable water management and enhancing the well-being of the community.

One of the quantitative analysis methods was a water body balance for the water supply system.

4.3.1.1 Water Body Balance from the uWFD

Water balance in Mpigi Town Council is done to compare the volumes that are removed from one of the three a water bodies (surface water, groundwater, atmosphere) and added again. Removal happens via abstraction or rain water harvesting; addition via infiltration, dis/re-charge or evapotranspiration.

Abstractions from the system

Groundwater Abstraction- $254.6 \times 10^3\ m^3/\ year$

Surface Water Abstracton-$154.7 \times 10^3\ m^3/\ year$

The sum for the abstraction is $409 \times 10^3\ m^3/\ year$

Re/discharges from the system

Surface water- $8.8 \times 10^3\ m^3/\ year$

Groundwater- $104.2 \times 10^3\ m^3/\ year$

Evapotranspiration-$20.3\times 10^3\ m^3/\ year$

As a simplification, it can be assumed that the precipitation, which is the amount of sustainable water resource in a watershed, is equally distributed among evapotranspiration, surface water runoff and groundwater recharge. Thus, every water body receives a third of the total precipitation in the watershed.

Annual precipitation in Mpigi Town Council is 1320mm for 150.25 km^3

This translates to $198330 \times 10^3 m^3/\ year$

Based on the assumption, the total discharges to the water bodies are

Surface water- $8.8 \times 10^3 + \frac{198330}{3}\ \times 10^3 \mathrm{m}^3/\ \mathrm{year}$

Groundwater- $104.2 \times 10^3 + \frac{198330}{3} \times 10^3\ \mathrm{m}^3/\ \mathrm{year}$

Evapotranspiration-$20.3\times 10^3 + \frac{198330}{3} \times 10^3\ \mathrm{m}^3/\ \mathrm{year}$

Summing up the discharges into the system gives $198{,}463.3\ \times 10^3\ \mathrm{m}^3/\ \mathrm{year}$

Change in Storage

$\Delta S =$Input into the System-Output of the System

$\Delta S = 198{,}463.3\ \times 10^3\ \mathrm{m}^3/\ \mathrm{year}$ - $409 \times 10^3\ m^3/\ year = 198{,}054.3\ \times 10^3\ \mathrm{m}^3/\ \mathrm{year}$

From the analysis above, it can be observed that in 2022, the rate at which the water bodies are replenished is greater than the system abstraction which creates a water surplus. Ground stores fill with water which results in increased surface runoff, higher discharge and higher levels within the Kiyanja Swamp. This means there is a positive water balance. The management practices of civilians within this system boundary are suitable and in conformity with the concept of sustainability.

4.3.2 Accuracy-Quantity Discussion

It can be observed from Figure 4-3 that there is a variation in the confidence level associated with different components of the urban water flow diagram. The accuracy classifications help to distinguish between data that can be relied upon more confidently and data that may have a higher degree of uncertainty.

The accuracy classification highlights the need for further scrutiny and validation of data related to losses, groundwater, and certain aspects of household usage, such as septic tanks and pit latrines. These areas may require additional investigation and data verification to improve accuracy and reliability.

It can be deduced that the accuracy of the urban water flow diagram in Mpigi Town Council is generally high for surface water, the piped system, industrial usage, and public usage. However, there is a need to improve the accuracy of data related to losses, groundwater, and specific components of household usage, such as septic tanks and pit latrines, which are classified as lower in data accuracy. These areas warrant further attention to ensure more reliable and precise measurements in future assessments and studies.

Considering the varying levels of data accuracy, it is essential to approach the interpretation and utilization of the urban water flow diagram data with caution.

4.3.3 Stakeholder Consultations

Gratitude from the community leaders and stakeholders was shown towards the project. Promises were made as well as their input to support the project. Their concerns were as follows;

Equitable water access: Stakeholders raised concerns about the equitable distribution of water resources within the urban water flow system. They observed disparities in water access between different areas or social groups and express concerns about ensuring fair and inclusive water services.

Financial sustainability: Stakeholders raised concerns about the affordability of water services, the cost implications of infrastructure improvements, or the long-term financial sustainability of the system.

Aging water supply infrastructure: Observations were made regarding the age and condition of the infrastructure depicted in the diagram, such as pipes, pumps, and storage tanks. Stakeholders expressed concerns about the need for infrastructure upgrades or maintenance to prevent leaks, bursts, or system failures.

4.3.3.1 Questions and Responses

The following questions were raised by the stakeholders;

1. How are the different water sources represented in the diagram, and what are their respective contributions to the overall water supply??
2. Are there any problems with the water system that we should be aware of?
3. Are there any identified areas of concern or potential vulnerabilities within the water flow system that are highlighted in the diagram?
4. What are the main factors affecting water quality within the urban water flow system, and how are they represented in the diagram?
5. Are there any specific strategies or technologies mentioned in the diagram that can be implemented to improve water conservation and efficiency?

6. Are there any identified areas of concern or potential vulnerabilities within the water flow system that are highlighted in the diagram?
7. Are there any economic considerations, such as cost implications or financial sustainability, that are addressed in the diagram?
8. Can you provide insights into any ongoing or proposed initiatives aimed at optimizing the urban water flow system and their potential benefits?

4.3.3.2 Responses to the Questions

The listed questions were addressed as follows:

QUESTIONS	ANSWERS TO THE QUESTIONS
How are the different water sources represented in the diagram, and what are their respective contributions to the overall water supply??	Kiyanja swamp and the various groundwater sources (shallow wells, boreholes, and springs) are represented as the main water sources for Mpigi town council. Kiyanja swamp contributes a significant portion of the surface water supply, while the groundwater sources serve as additional water sources to meet the town's needs.
Are there any problems with the water system that we should be aware of?	Losses hotspots are on an exponential rise and repairing the old infrastructure of the water pipes is most viable solution.
Are there any identified areas of concern or potential vulnerabilities within the water flow system that are highlighted in the diagram?	The diagram highlights aging infrastructure or areas where the distribution pipelines are prone to leaks. It identifies areas at risk of water scarcity during dry seasons or areas that may experience water quality issues due to specific factors like industrial discharges or upstream contamination.
What are the main factors affecting water quality within the urban water flow system, and how are they represented in the diagram?	The main factors affecting water quality in Mpigi town council's urban water flow system include the quality of the surface water from Kiyanja swamp and the groundwater from wells, boreholes, and springs.
Are there any specific strategies or technologies mentioned in the diagram that can be implemented to improve water conservation and efficiency?	The diagram, within its context, might not explicitly highlight water conservation strategies or technologies. However, discussions around the diagram could address the importance of water conservation practices such as promoting efficient water use at the household level, rainwater

QUESTIONS	ANSWERS TO THE QUESTIONS
	harvesting, and promoting awareness campaigns to reduce water wastage and improve overall water efficiency.
Are there any identified areas of concern or potential vulnerabilities within the water flow system that are highlighted in the diagram?	The diagram highlights potential issues related to water quality, such as the need for treatment processes to address contamination risks from agricultural activities near Kiyanja swamp. It shows potential vulnerabilities related to groundwater depletion or contamination due to improper waste disposal or proximity to pollution sources.
Are there any economic considerations, such as cost implications or financial sustainability, that are addressed in the diagram?	While the diagram itself may not directly address economic considerations, discussions around the diagram could involve considerations of costs and financial sustainability. These discussions might explore the investments required for infrastructure development and maintenance, operational costs of the treatment plant, and potential funding mechanisms to ensure the long-term financial sustainability of the water flow system in Mpigi Town Council.
Can you provide insights into any ongoing or proposed initiatives aimed at optimizing the urban water flow system and their potential benefits?	Proposed initiatives for optimizing the urban water flow system could include efforts to improve water treatment processes at the treatment plant, enhancing water quality monitoring systems, or exploring opportunities for groundwater recharge. These initiatives would aim to ensure a reliable and sustainable water supply, improve water quality, and enhance overall system efficiency.

In conclusion, the stakeholder consultation highlighted important concerns related to equitable water access, financial sustainability, and aging infrastructure. The responses provided insights into the representation of different water sources, concerns about the water system, areas of vulnerability, factors affecting water quality, and potential initiatives for system optimization. These findings can inform decision-making and planning processes to address the stakeholders' concerns and improve the urban water flow system in Mpigi Town Council.

The stakeholder consultation demonstrated that the diagram effectively conveyed key information about the urban water flow system in Mpigi Town Council. The stakeholders found the diagram to be clear and intuitive, allowing them to easily understand the different water sources, infrastructure concerns, and factors impacting water quality.

The stakeholders warmly welcomed the idea and expressed gratitude towards the project. They actively participated in the consultation, providing valuable input and raising relevant questions and concerns. This positive reception indicates that the stakeholders recognized the importance of addressing issues related to equitable water access, financial sustainability, and aging infrastructure within the water system.

The diagram facilitated meaningful discussions and enabled stakeholders to gain a comprehensive understanding of the current water situation in Mpigi town council. It effectively communicated the contributions of different water sources, potential vulnerabilities, and the need for infrastructure improvements. The stakeholders' engagement and promises of support further indicate their commitment to the project and their willingness to collaborate for the betterment of the community's water services.

Overall, the stakeholders' warm welcome and positive response to the diagram highlight its effectiveness as a visual tool for conveying information and engaging stakeholders. The clear and intuitive nature of the diagram fostered a productive consultation, encouraging stakeholders to actively contribute and provide valuable insights.

4.3.4 Assessment of the Impact of Pit Latrines to Ground Water Quality

After the development of the flow diagram, there was a need to assess the impact of pit latrines on groundwater quality as it was observed from the diagram that the flows from pit-latrines to groundwater were of problematic quality. The results are shown in Table 4-14

Table 4-14: Laboratory results from groundwater analysis

Sampling Point	*E. coli* (cfu/100ml)	Ammonia (mg/L)	Nitrates (mg/L)	Chlorides (mg/L)	Electrical Conductivity (µS/cm)	Dissolved Oxygen	pH	Turbidity (NTU)
Lwanga Ward D	370	0.04	9.40	10.60	773.50	7.20	7.765	6.62
Mawonve Ward B	970	0.01	226.10	121.20	843.20	5.38	6.455	1.13
Mayembe lower Ward D	95	0.01	23.50	12.10	1123.80	7.19	7.021	0.92
Ssebinyansi Spring Ward A	1	0.01	16.00	13.50	1015.30	7.20	7.006	0.72
Prison Centre Ward D	2	0.01	18.70	7.10	1077.00	7.21	6.845	10.30
Nalugidde Spring Ward A	65	0.01	83.00	15.89	96.75	6.71	7.988	3.22
St. Bruno Shallow Well Ward A	113	0.78	4.54	27.90	111.23	6.68	6.789	11.89
Kakopo Spring Ward B	793	0.02	1.23	339.79	105.23	7.71	7.211	0.32
Waggumbulizi Borehole Ward B	70	3.2	139.27	92.67	1208.50	6.49	6.890	19.67
Mpigi Modern Shallow Well Ward D	10	2.1	11.78	62.31	1173.76	6.32	7.921	6.23
St. Kizito Borehole Ward D	23	0.03	22.56	100.23	1225.67	7.89	8.100	5.22
Kamiyati Spring Ward B	531	0.07	135.67	19.67	943.33	4.22	7.243	5.43
Byangwe Spring Ward B	247	0.01	99.23	210.78	500.00	7.61	6.211	11.34
EAST AFRICAN STANDARD (EAS)	0	<0.5	45	<250	2500	-	6.5-8.5	<5

4.3.4.1 OBSERVATIONS

***E. coli* (cfu/100ml):** The *E. coli* levels vary across the sampling points, with some points exceeding the East African Standard (EAS) limit of 0 cfu/100ml. For example, Mawonve Ward B and Kakopo Spring Ward B have *E. coli* levels of 970 cfu/100ml and 793 cfu/100ml, respectively.

The ammonia levels are generally within acceptable limits, except for Waggumbulizi Borehole Ward B, which has a significantly higher level of 3.2 mg/L, exceeding the EAS limit of <0.5 mg/L. Nitrates concentration exceeds the EAS limit of 45 mg/L at several sampling points, including Mawonve Ward B (226.10 mg/L), Kakopo Spring Ward B (135.67 mg/L), and Byangwe Spring Ward B (99.23 mg/L). Chloride levels are relatively high in Kakopo Spring Ward B, with a concentration of 339.79 mg/L, surpassing the EAS limit of <250 mg/L.

Electrical conductivity values are generally within acceptable ranges, although Byangwe Spring Ward B has a higher value of 500 µS/cm. Dissolved oxygen levels are within acceptable ranges at all sampling points, indicating sufficient oxygen availability in the water. pH values fall within the acceptable range of 6.5-8.5 for all sampling points, indicating neutral to slightly alkaline conditions. Turbidity levels are generally within acceptable limits, except for Waggumbulizi Borehole Ward B, which exhibits a higher turbidity of 19.67 NTU.

Table 4-15 shows the lateral distance of sampling points from the nearest pit latrine. The distances were measured using an RTK machine whose origin was set at the water point. The distances were then hence forth measured from the groundwater point to the source and the value recorded.

Table 4-15: Pit latrine in close proximity with groundwater source

SAMPLING POINT	NEAREST PIT LATRINE DISTANCE (m)
Lwanga Ward D	15
Mawonve Ward B	38
Mayembe lower Ward D	43
Ssebinyansi Spring Ward A	27
Prison Centre Ward D	11
Nalugidde Spring Ward A	13
St. Bruno Shallow Well Ward A	4
Kakopo Spring Ward B	6
Waggumbulizi Borehole Ward B	19
Mpigi Modern Shallow Well Ward D	11
St. Kizito Borehole Ward D	14
Kamiyati Spring Ward B	26
Byangwe Spring Ward B	8

Proximity to Pit Latrines:

The distances range from 4 meters to 43 meters, representing the lateral distance of each sampling point from the nearest pit latrine. The closer the distance to a pit latrine, the higher the potential for contamination of the water source by pathogens and pollutants present in the pit latrine.

Variations in Distance:

The distances vary across the sampling points, indicating different levels of proximity to pit latrines. St. Bruno Shallow Well Ward A has the shortest distance of 4 meters, suggesting a high potential for contamination from the nearby pit latrine. Mayembe Lower Ward D has the longest distance of 43 meters, indicating a relatively lower risk of contamination compared to other sampling points.

Risk Assessment:

Sampling points with shorter distances to pit latrines, such as St. Bruno Shallow Well Ward A and Kakopo Spring Ward B, face a higher risk of potential contamination from pathogens, including bacteria and viruses, present in the pit latrines.

Sampling points with longer distances, such as Mayembe Lower Ward D and Byangwe Spring Ward B, have a relatively lower risk of contamination, but it is still important to consider other potential pollution sources.

4.3.4.2 PARAMETER ANALYSIS

Results from the lab were a starting point to derive deductions. The eight measured parameters are hence forth discussed further;

pH

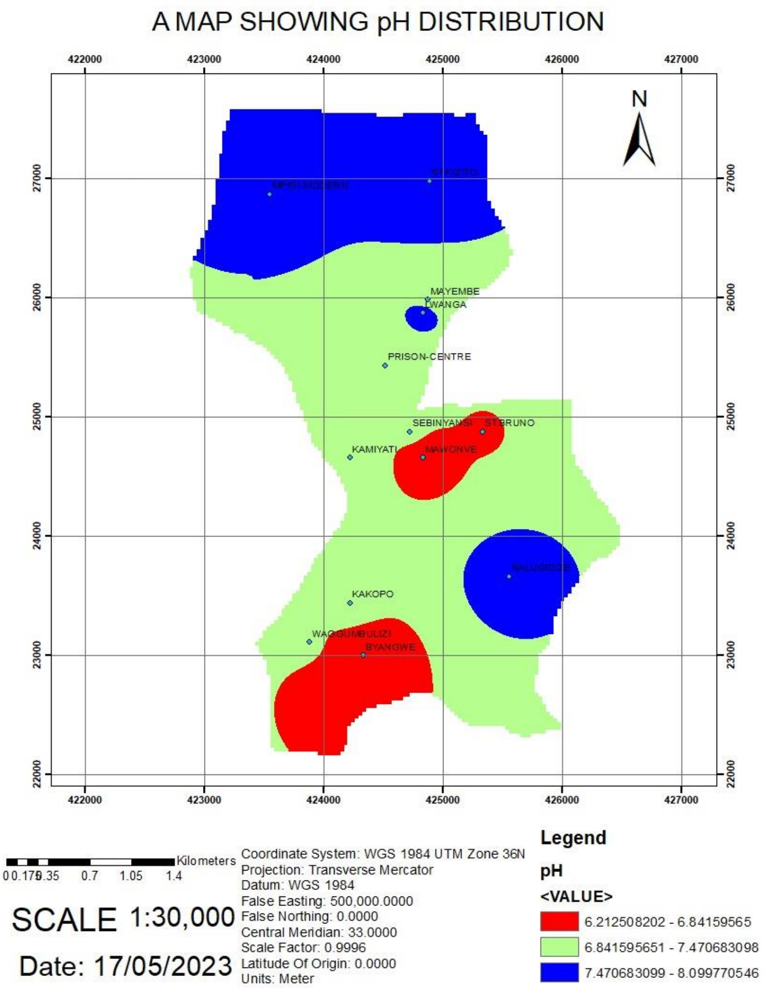


Figure 4-4: Spatial variation of pH for Wards A, B and D

The spatial variation in Figure 4-4 shows that none of the sampling points had a pH greater than that stated in the East African Standards. Considering all samples, Mawonve Ward B and Byangwe Spring Ward B had pH levels unacceptable for drinking water. Pit latrine infiltration may contribute to slight pH changes due to the release of organic acids, but the impact is likely minimal. Other causes to pH variations could be:

Dissolved Minerals: The presence of certain minerals, such as carbonates, bicarbonates, sulfates, and hydroxides, can affect pH levels in groundwater. These minerals can dissolve in water and release ions that can either increase (alkaline) or decrease (acidic) pH.

Rock and Soil Composition: The geological characteristics of the aquifer and surrounding rock and soil can influence pH. Some rocks, like limestone, contain minerals that can increase pH through a process called carbonate buffering. On the other hand, acidic rocks, such as granite, can release acids into the groundwater, lowering its pH.

Organic Matter: The decomposition of organic matter, such as decaying plant material or animal waste, can release organic acids into the groundwater, resulting in lower pH levels.

Acid Rain: Acid rain, caused by air pollution containing sulfur dioxide and nitrogen oxides, can infiltrate into the groundwater, leading to decreased pH levels.

Anthropogenic Activities: Human activities, such as industrial discharges, mining operations, and improper waste disposal, can introduce chemicals and pollutants into groundwater, leading to changes in pH. Industrial processes may release acidic or alkaline substances that can affect the surrounding groundwater.

Groundwater Contamination: Contamination from sources like leaking septic systems, or chemical spills can introduce substances that alter the pH of groundwater. For example, leakage from a nearby pit latrine can introduce acidic or alkaline substances, impacting the pH levels.

4.3.4.3 Turbidity

Turbidity levels less than 5NTU were majorly found in samples at Mawonve, Mayembe lower, Ssebinyansi spring, Nalugidde, Kakopo spring. The spatial variation in Figure 4-5 shows the sampling points Lwanga, Prison Centre, St. Bruno Shallow Well, Waggumbulizi Borehole, Mpigi Modern Shallow Well, St. Kizito Borehole, Kamiyati Spring, Byangwe Spring were unacceptable in drinking water. Waggumbulizi Borehole had a reddish-brown color emanating from rusting borehole casing pipes.

Possible causes of turbidity include

- Sediment Erosion: Natural processes like erosion of soil and rocks can lead to sediment runoff into water bodies, including groundwater. Rainfall, surface water flow, and groundwater movement can transport sediments and introduce them into the aquifer, causing turbidity.
- Construction Activities: Construction sites, land development, and excavation projects can disturb the soil, leading to sediment runoff and turbidity in nearby groundwater. The erosion of construction materials and the movement of heavy machinery can contribute to suspended particles in the water.
- Agricultural Practices: Intensive agricultural activities, such as tilling, irrigation, and the use of fertilizers and pesticides, can result in sediment and chemical runoff. Excessive soil erosion due to improper land management practices can increase turbidity in groundwater.
- Land Disturbance: Any human activities that disrupt the natural vegetation cover, such as deforestation, mining, or road construction, can contribute to sediment runoff and turbidity in groundwater. Bare soil surfaces are more prone to erosion and sediment transport.
- Industrial Discharges: Improper disposal or accidental release of industrial wastes, chemicals, and pollutants can contaminate groundwater and cause turbidity. Industrial activities that generate suspended particles, such as mining, processing, and manufacturing, can directly introduce turbidity-causing substances.

- Septic Systems and Sewage Contamination: Failing or poorly maintained septic systems, sewage leaks, or wastewater discharges can introduce organic matter and suspended solids into groundwater, leading to increased turbidity.

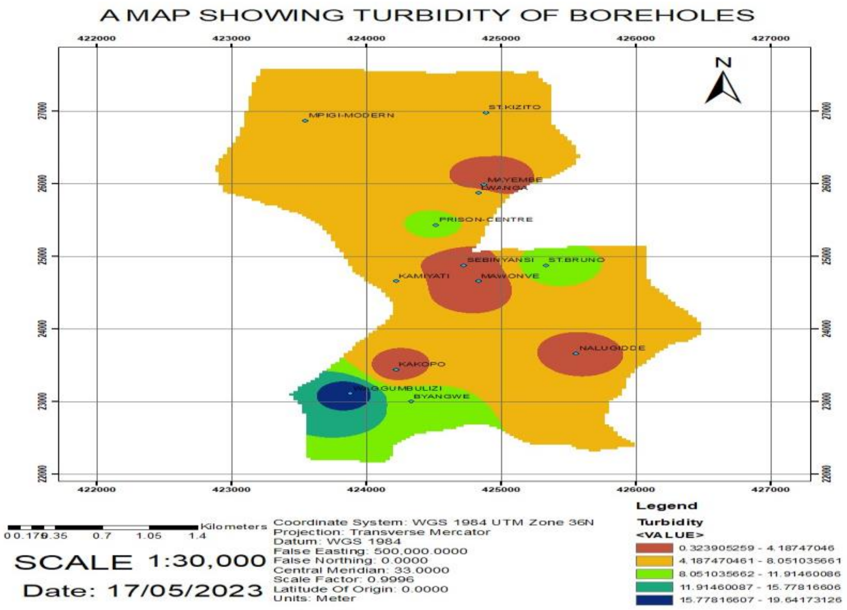


Figure 4-5: Spatial variation of turbidity in Wards A, B and D

4.3.4.4 Dissolved oxygen

Dissolved oxygen (DO) is an important parameter in assessing water quality as it directly affects the aquatic ecosystem and the organisms living within it. Higher dissolved oxygen levels indicate better water quality and a higher capacity to support aquatic life. Lower dissolved oxygen levels can be indicative of pollution, organic matter decomposition, or reduced oxygen transfer from the atmosphere to the water.

The lowest dissolved oxygen level of 4.22 mg/L (Kamiyati Spring, Ward B) may indicate reduced oxygen availability and potential degradation of the water quality.

The highest dissolved oxygen level of 7.21 mg/L (Prison Centre, Ward D) suggests better oxygenation and potentially healthier water conditions.

The EAS do not provide a specific value for Dissolved Oxygen. Spatial variation for Dissolved Oxygen is portrayed in Figure 4-6. The presence of organic material reduces levels of Dissolved Oxygen in water (WHO 2011).

Possible causes of lower Dissolved Oxygen in groundwater could include

- High Organic Matter Content: Elevated levels of organic matter, such as decaying plant material or organic waste, can consume oxygen as it decomposes, leading to lower dissolved oxygen levels.
- Nutrient Pollution: Excessive nutrient inputs, particularly nitrogen and phosphorus from agricultural runoff or wastewater discharges, can cause algal blooms. When these algae die and decompose, it depletes the dissolved oxygen in the water.
- Limited Surface Interaction: Groundwater that has limited contact with the surface, such as confined aquifers or deep wells, may have lower oxygen levels due to reduced interaction with the atmosphere.

- Microbial Respiration: Microorganisms naturally present in groundwater consume oxygen during respiration, which can lead to decreased dissolved oxygen concentrations.
- High Water Temperature: Warmer water has reduced oxygen solubility, resulting in lower dissolved oxygen levels. Higher temperatures can occur naturally or be influenced by factors such as climate change or geothermal activity.

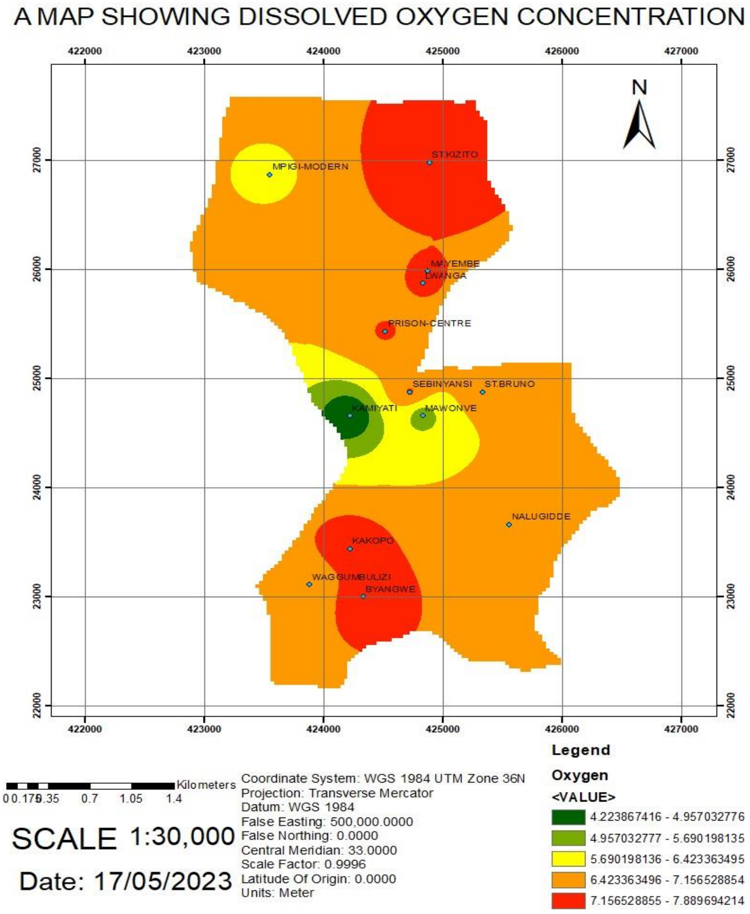


Figure 4-6: Spatial variation of DO in wards A, B and D

4.3.4.5 Chlorides

The spatial distribution of the chlorides is displayed in Figure 4-7. Kakopo Spring in Ward B with 339.79 mg/L was above the stated standard. Also, the lateral distance of the nearest pit latrine was 6m which is a starting point for “could-be” contamination. It should be noted that chlorides concentration levels in excess give rise to detectable taste in water.

Other possible causes of Chlorides could be

- Natural Sources: Chlorides can occur naturally in groundwater due to geological formations rich in chloride-bearing minerals. Certain areas may naturally have higher concentrations of chlorides in the groundwater.
- Agricultural Practices: Excessive use of fertilizers and manures in agricultural practices can result in chloride contamination. Fertilizers containing chloride compounds, such as potassium chloride, can contribute to elevated chloride levels in groundwater if applied in excess or not managed properly.

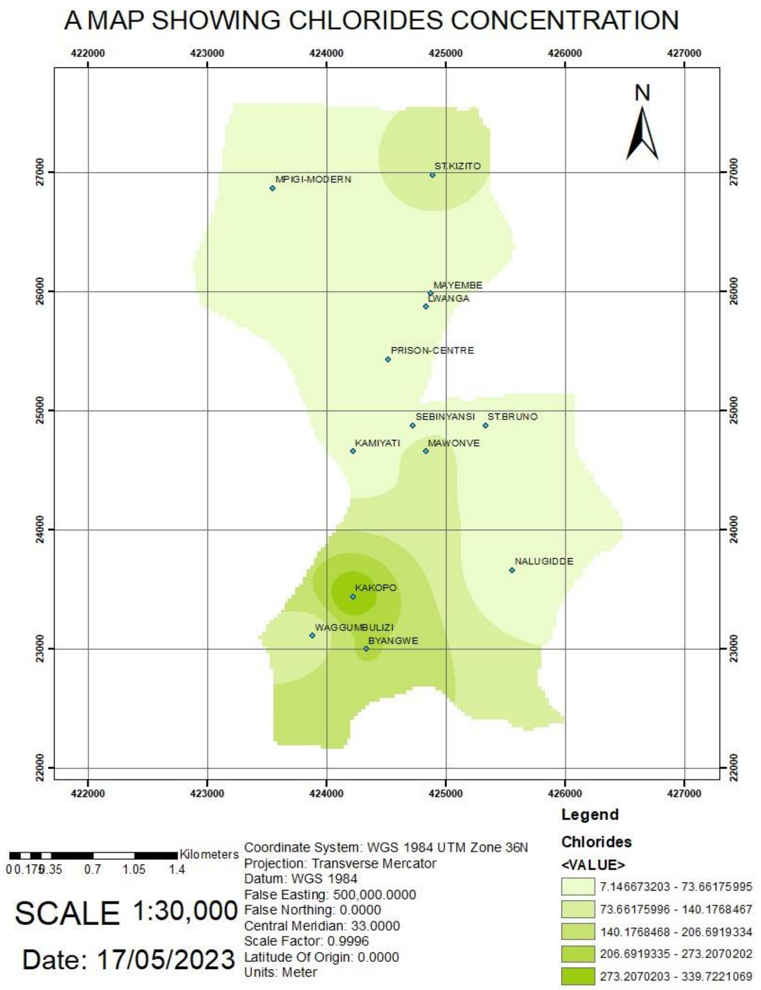


Figure 4-7: Spatial variation of chlorides in Wards A, B and D

4.3.4.6 Nitrates

Lwanga Ward D, Mayembe lower Ward D, Ssebinyansi Spring Ward A, Prison Centre Ward D, St. Bruno Shallow Well Ward A, Kakopo Spring Ward B, Mpigi Modern Shallow Well Ward D, St. Kizito Borehole Ward D were the only samples that ware safe for drinking.

Relating the high nitrate concentrations to the distance of the nearest pit latrines results into

Mawonve Ward B: The nearest pit latrine distance is 38 meters.

Nalugidde Spring Ward A: The nearest pit latrine distance is 13 meters.

Kamiyati Spring Ward B: The nearest pit latrine distance is 26 meters.

Byangwe Spring Ward B: The nearest pit latrine distance is 8 meters.

From the available data, it appears that there is no clear correlation between the distance of the nearest pit latrines and the nitrate concentrations above the EAS standard. The distances vary, and there is no consistent trend indicating that proximity to pit latrines alone is the dominant factor contributing to elevated nitrate levels. Other factors, such as agricultural activities, land use, and hydrogeological conditions, may also play significant roles in nitrate contamination of groundwater. Therefore, a more comprehensive analysis considering these additional factors is necessary to understand the specific causes of nitrate pollution in the identified groundwater sources.

It should be noted that infants younger than 6 months old are susceptible to nitrate poisoning which can cause blue baby syndrome. shows the spatial variation of nitrates within the chosen boundary.

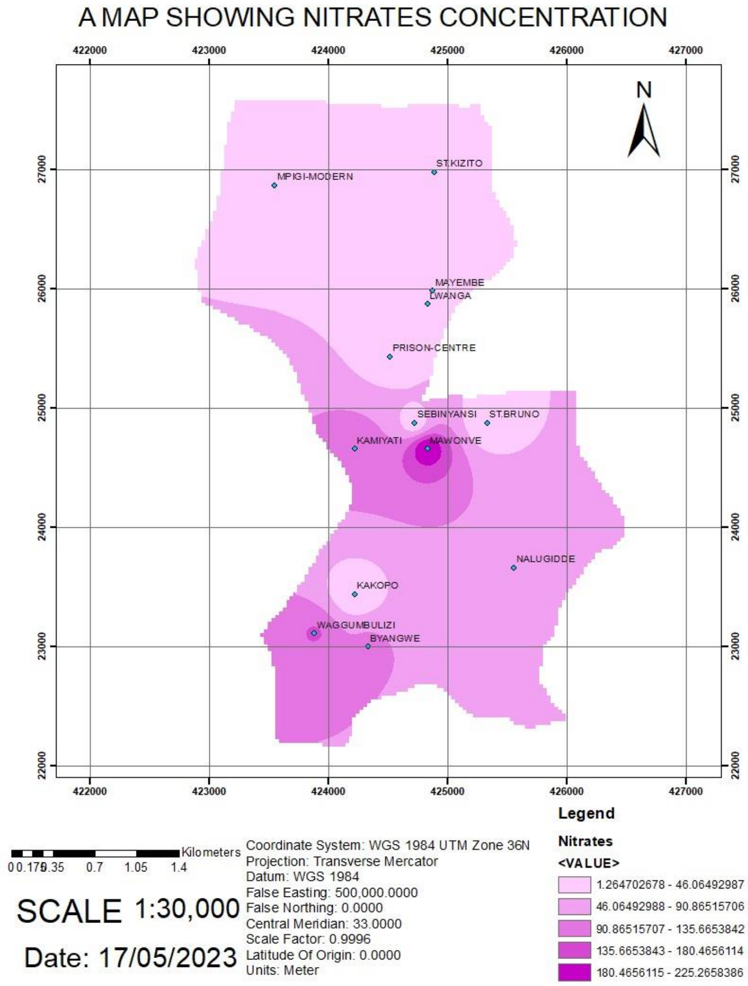


Figure 4-8: Spatial variation of nitrates in Wards A, Band D

4.3.4.7 Electrical conductivity

Based on the EAS (2014) drinking guidelines, all the samples have acceptable values in natural drinking water. The electrical conductivity values vary across the different sampling points, ranging from 96.75 µS/cm to 1225.67 µS/cm.

Waggumbulizi Borehole Ward B has the highest electrical conductivity value of 1208.50 µS/cm, indicating a relatively high concentration of dissolved ions in the water.

Ssebinyansi Spring Ward A has the lowest electrical conductivity value of 96.75 µS/cm, suggesting a lower concentration of dissolved ions compared to other sampling points.

The presence of dissolved ions in groundwater can be influenced by various factors, including natural geological processes, human activities such as agricultural practices, industrial activities, and contamination from nearby sources.

High electrical conductivity values can be an indicator of potential contamination or natural geological conditions that contribute to the leaching of minerals into the groundwater.

It is important to note that electrical conductivity alone does not provide information about specific contaminants but rather indicates the overall concentration of dissolved ions in the water. The spatial variation for Electrical Conductivity is portrayed in Figure 4-9.

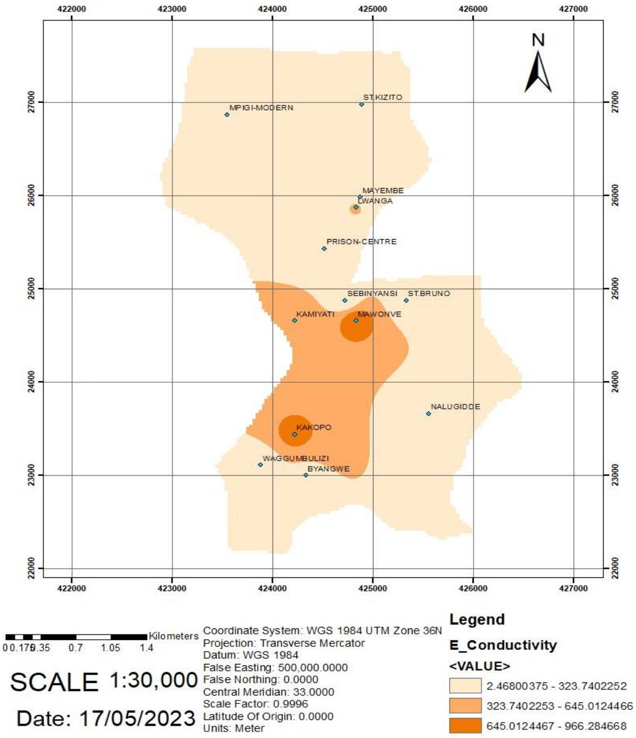


Figure 4-9: Spatial variation of Electrical conductivity in Wards A, B and D

4.3.4.8 Ammonia

Point values of ammonia for Waggumbulizi Borehole Ward B, St. Bruno Shallow Well Ward A and Mpigi Modern Shallow Well Ward D exceeded the EAS (2014) guideline for a maximum value of 0.5 mg/L. The spatial distribution for ammonia is shown in Figure 4-10. The relatively short distance of 11m and 14m of the nearest pit latrine for Mpigi Modern Shallow Well Ward D and Waggumbulizi Borehole Ward B respectively might account for the high concentration levels for ammonia at the water points. Most of the other sampling points have relatively low ammonia concentrations, ranging from 0.01 mg/L to 0.07 mg/L.

The presence of elevated ammonia levels in Waggumbulizi Borehole Ward B, St. Bruno Shallow Well Ward A and Mpigi Modern Shallow Well Ward D may be attributed to nearby agricultural activities or improper disposal of wastewater.

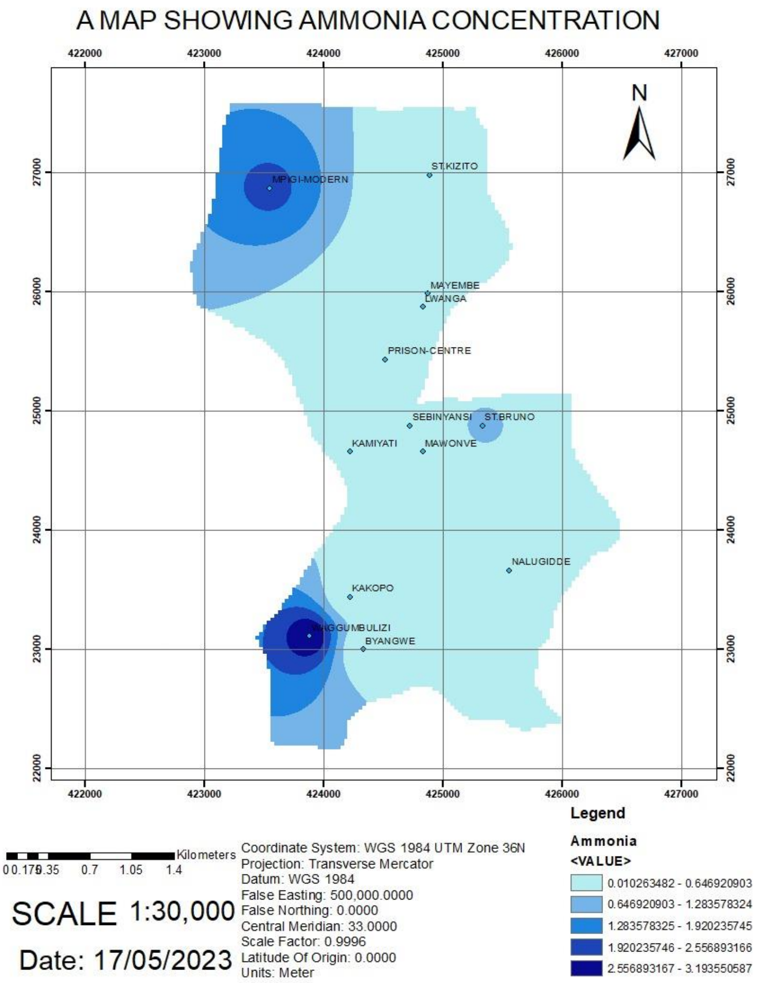


Figure 4-10: Spatial variartion of Ammonia in Wards A, B and D

4.3.4.9 *E. coli*

All the sampling points show *E. coli* concentrations above the EAS standard of 0 cfu/100ml, indicating fecal contamination in the groundwater. The extent of contamination varies across the sampling points, with higher concentrations observed in Mawonve Ward B, Kakopo Spring Ward B, Kamiyati Spring Ward B, and Lwanga Ward D.

The presence of *E. coli* suggests the potential presence of harmful pathogens that can cause waterborne diseases. The elevated *E. coli* levels can be attributed to inadequate sanitation practices, improper waste management, contaminated surface runoff, or other sources of fecal contamination. The color schemes were assigned to reflect the different levels in the spatial distribution of *E. coli* in Mpigi Town Council as shown in Figure 4-11.

All the groundwater points have a high risk to water contamination by pathogenic organisms.

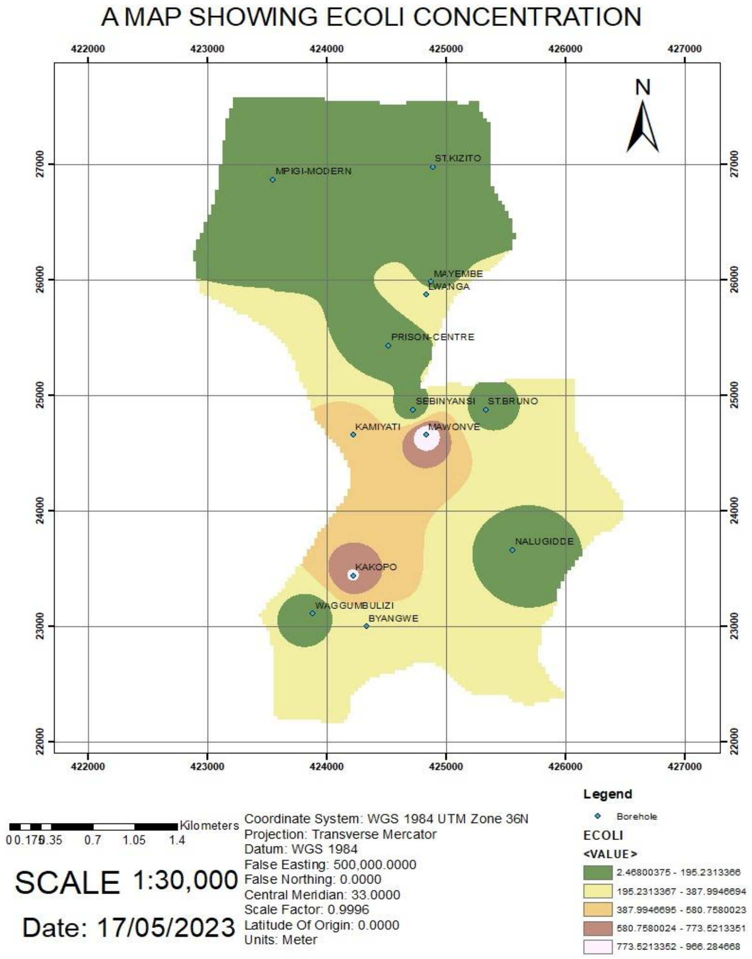


Figure 4-11: Spatial variation of E. coli in Wards A, B and D

It was generally observed that Waggumbulizi Borehole Ward B and Byangwe Spring Ward B were not safe for drinking since they had 4 out of eight parameters not meeting the EAS (2014) guidelines. Mawonve Ward B, St. Bruno Shallow Well Ward A, Mpigi Modern Shallow Well Ward D, Byangwe Spring Ward B had 3 out of the eight parameters that were not within the guidelines. The lateral distance of the water points from the nearest pit latrine is telling of the poor quality at these wells.

Mayembe lower Ward D and Ssebinyansi Spring Ward A had the best water quality with only one parameter out of the eight that was unacceptable in drinking water. *E. coli* contamination was found in all the thirteen water samples. 5 of the 13 water points were contaminated with nitrates at levels that were unacceptable in drinking water according to EAS guidelines. The results suggest a risk to groundwater contamination by pathogenic organisms due to elevated *E. coli* count in the water samples.

4.3.4.10 Statistical Analysis

Determination of key parameters

The data collected in Mpigi was tested for suitability for PCA through the correlation matrix and Bartlett's test of sphericity and results of the tests are shown in Table 4-16.

Table 4-16: Sampling adequacy using KMO and Bartlett's test

KMO measure of sampling adequacy	**0.651**	
Bartletts test of sphericity	*Approx. chi-square*	133.845
	df	28
	p-value	0.002

From the table above, the data was considered suitable to be used in the PCA because the KMO value of 0.651 was greater than 0.6 (the set threshold for sampling adequacy). The KMO measure suggests that the sample is moderately adequate for conducting factor analysis. However, it is not very high, indicating that there might be room for improvement in the sampling strategy.

The Bartlett's test of sphericity yields a significant p-value of 0.002, indicating that the correlation matrix is significantly different from the identity matrix. This suggests that the variables included in the analysis are interrelated and suitable for further factor analysis. Also, since Bartlett's test of sphericity value of 0.002 was less than 0.05. The data set is indeed suitable for the Principal Component Analysis.

Table 4-17: Correlation coefficients of groundwater parameters

	E. coli	**Ammonia**	**Nitrates**	**Chlorides**	**Electrical Conductivity**	**Dissolved Oxygen**	**pH**	**Turbidity**
E. coli	1.0000	-0.3019	0.5092	0.5410	-0.2057	-0.0854	-0.3008	-0.3786
Ammonia	-0.3019	1.0000	0.1242	-0.0305	0.1147	-0.1563	0.0433	0.6728
Nitrates	0.5092	0.1242	1.0000	0.0791	0.0987	-0.1535	-0.4187	0.1268
Chlorides	0.2410	-0.0305	0.0791	1.0000	-0.2746	0.2062	-0.2490	-0.0860
Electrical Conductivity	-0.2057	0.1147	0.0987	-0.2746	1.0000	-0.1315	0.0971	0.1269
Dissolved Oxygen	-0.0854	-0.1563	-0.1535	0.2062	-0.1315	1.0000	0.1092	0.0005
pH	-0.3008	0.0433	-0.4187	-0.2490	0.0971	0.1092	1.0000	-0.2542
Turbidity	-0.3786	0.6728	0.1268	-0.0860	0.1269	0.0005	-0.2542	1.0000

To determine the suitability of the data for Principal Component Analysis (PCA), we need to assess the correlation matrix. Based on the correlation coefficients provided in Table 4-17, we can analyze the data for PCA suitability:

Correlation Strength: PCA assumes that variables are linearly related. Looking at the correlation coefficients, we can see that some variables have moderate to strong correlations with each other. For example, there is a moderate positive correlation between Nitrates and *E. coli* (0.5092) and a moderate negative correlation between pH and Nitrates (-0.4187). These correlations indicate potential relationships that can be captured by PCA.

Correlation Significance: PCA works best when variables are significantly correlated. In Table 4-17, most of the correlation coefficients are non-zero, indicating significant correlations between variables.

Principle component analysis (PCA)

PCA's aim is to extract a smaller number of principal components that can explain most of the variability in the original data.

Table 4-18: Principal component matrix for three components

	Comp1	Comp2	Comp3
E. coli	0.3781	0.3858	-0.2667
Ammonia	-0.0710	0.0414	0.5999
Nitrates	0.0873	0.6067	0.1016
Chlorine	0.6452	-0.1087	0.0588
Electrical Conductivity	-0.4511	0.1498	0.1498
Dissolved Oxygen	0.2348	-0.6286	0.0571
pH	-0.4055	-0.2259	-0.2527
Turbidity	**0.0709**	**-0.0305**	**0.6824**

PCA result as shown in Table 4-18 shows that of the eight components, only three were extracted based on the assumption that components with an eigenvalue of less than 1 are eliminated as shown within the scree plot of Figure 4-12. The extracted three components were rotated according to the varimax rotation in order to make interpretation easier. This is displayed in Table 4-19.

Table 4-19: Rotated component matrix, eigen values, total and cumulative variance

	Comp1	**Comp2**	**Comp3**
E. coli	0.3781		
Ammonia			0.5999
Nitrates		0.6067	
Chlorine	0.6452		
Electrical conductivity	-0.4511		
Dissolved Oxygen		-0.6286	
pH	-0.4055		
Turbidity			0.6824
Eigenvalue	2.38875	2.11525	1.45629
Total Variance (%)	29.86	26.44	18.20
Cumulative Variance (%)	**29.86**	**56.30**	**74.50**

Based on the component loadings, variables that were extracted were categorized based on their designed components as follows;

Component 1: *E. coli*, Chlorides, Electrical conductivity and pH
Component 2: Nitrates and Dissolved Oxygen
Component 3: Ammonia, Turbidity
Components 1, 2, and 3 explained 29.86%, 26.44%, and 18.20% of the variance, respectively. The three extracted components when added account for 74.50% (that is their cumulative variance) of the total variance of the observed variable.

The total variance of the components refers to the amount of variability in the original dataset that is explained by the extracted principal components. Therefore, the key parameters in groundwater contamination were *E. coli*, Chlorides, Electrical conductivity and pH that accounted for 29.86% of the total variance as shown in Table 4-20.

Table 4-20: Stata output for component load sorting

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.38875	.273501	0.2986	0.2986
Comp2	2.11525	.658962	0.2644	0.5630
Comp3	1.45629	.664457	0.1820	0.7450
Comp4	.791828	.0841937	0.0990	0.8440
Comp5	.707635	.441936	0.0885	0.9325
Comp6	.265699	.0857851	0.0332	0.9657
Comp7	.179914	.0852701	0.0225	0.9882
Comp8	.0946436	.	0.0118	1.0000

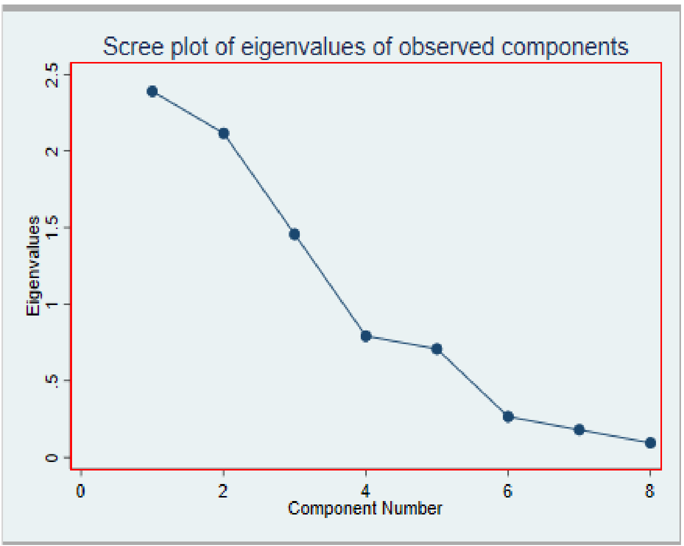


Figure 4-12: Scree plot for eigen values of the observed components

Impact of pit-latrine density on ground water quality

The results in Table 4-21 show the cumulative number of pit latrines in each radius for the groundwater sampling points. It can be observed that the highest pit latrine density in the 15m, 30m, 50m and 100m radius was 2,7,14 and 51 respectively. The increase in density from 15m to 30m radius is not significant from the data shown. Mpigi Modern Shallow well in Ward D had the highest pit latrine density of 51 pit latrines in 100m radius.

Table 4-21: Pit-latrine density around the samples groundwater sources

NUMBER OF PIT LATRINES				
Sampling point	**15 m radius**	**30m radius**	**50m radius**	**100m radius**
Lwanga Ward D	1	1	3	18
Mawonve Ward B	0	5	6	15
Mayembe lower Ward D	0	4	7	37
Ssebinyansi Spring Ward A	0	7	9	29
Prison Centre Ward D	2	4	11	34
Nalugidde Spring Ward A	2	3	9	30
St. Bruno Shallow Well Ward A	1	3	10	44
Kakopo Spring Ward B	1	5	13	31
Waggumbulizi Borehole Ward B	0	2	8	39
Mpigi Modern Shallow Well Ward D	2	5	14	51
St.Kizito Borehole Ward D	1	4	9	36
Kamiyati Spring Ward B	0	2	7	32
Byangwe Spring Ward B	1	0	5	25

The pit latrine density was correlated with groundwater levels of pH, turbidity, Dissolved Oxygen, chlorides, nitrates, EC, ammonia, and TTC in **Error! Reference source not found.**.

Table 4-22: Relationships of groundwater parameters and pit-latrine densities

	E. coli	Ammonia	Nitrates	Chlorides	Electrical Conductivity	Dissolved Oxygen	pH	Turbidity
Density 15	-0.4284	-0.1155	-0.2572	-0.3673	0.2214	0.0591	0.1847	-0.3010
	0.1441	0.7072	0.3962	0.2170	0.4673	0.8479	0.5458	0.3175
Density 30	0.3095	-0.0843	-0.2180	-0.0102	0.1841	0.0625	0.1281	-0.5887
	0.9755	0.7842	0.4743	0.9736	0.5471	0.8392	0.6766	0.0343
Density 50	-0.2172	0.2855	-0.4311	0.2099	-0.0780	0.1333	0.2658	-0.0843
	0.4760	0.3444	0.1414	0.4912	0.8001	0.6641	0.3802	0.7843
Density 100	0.6078	0.5797	0.7474	-0.1600	-0.5731	0.0469	0.6766	0.5202
	0.0275	0.0378	0.0253	0.6015	0.0416	0.8791	0.0102	0.0262

Strong positive linear correlation: Ammonia, pH, Turbidity, Nitrates, *E. coli*

Strong negative linear correlation. EC

No correlation. Chlorides, Dissolved Oxygen.

The results show that an increase in the number of pit latrines from 15 m to 100 m radius from the groundwater point showed a strong positive linear correlation with levels of Ammonia, pH, Turbidity, Nitrates, *E. coli* while Electrical conductivity had an inverse relationship. Chlorides, Dissolved Oxygen showed no relationship with increasing pit latrine density. The results showed that there was a strong association of **Ammonia, pH, Turbidity, Nitrates, *E. coli*** levels to high pit latrine density that suggested groundwater contamination by pit latrines.

4.4 QUALITATIVE ANALYSIS OF FECAL SLUDGE MANAGEMENT IN MPIGI TOWN COUNCIL

The results are explained basing on the sanitation value chain of containment, emptying, transportation, treatment, recycling and disposal of fecal sludge.

4.4.1.1 Containment

Along this sanitation node, all the residents use on-site sanitation facilities in terms of pit-latrines and Ventilated Pit-latrines. There were only 30 households that used septic tanks. There was no sewered sanitation as the area has no developed sewer line. Pit latrines are the most commonly used because they are cheap to construct and easy to maintain. Most of the latrines were clean as most of the households and commercial areas cleaned their toilets everyday either by scrubbing with soap and water or by smoking with 12 households cleaning their latrines once a week. Flush toilets are very few within the area and they are common in the high-income neighborhoods of Mpambire and Ward B. Within communal residences like hostels, the rate of sharing among pit latrines was alarming. One of the respondents added;

"We share the latrine with 10 other rooms. Sometimes it is disgusting when a mature adult leaves the toilet the way my neighbors do."

There was some open defecation practiced by some of the residents especially those in semi-urban areas whose latrines had filled-up as well as the children who were left to defecate in the open compounds of their homes. Basing on the structure of the latrines, there were only 30 households and 12 commercial areas that had lined pits while the rest were unlined shallow pits contributing to the high groundwater contamination within the area as shown in the groundwater risk assessment in 4.3.4. In some households, once their pit got filled, it would be abandoned due to high emptying costs charged by NWSC and another pit dug usually 30 ft. deep without any lining done to the pit walls. However, the frequency of pits filling at a faster rate is low due to a slowly growing population. Eco- sans are still used on a small scale with only 3 households in Ward D using this type. Basing on the consultations had with the health inspector, the coverage of different sanitation technologies based on the population in Mpigi Town Council is shown in Table 4-23 below.

Table 4-23: Coverage of different sanitation technologies in MTC

Sanitation Technology	Coverage (%)
Pit latrines	80
Ventilated Improved Pit-latrines	5
Flush Toilets	10
Eco-sans	5

Comparing this to Bwaise slum in Kampala, there is a similar situation of vast use of pit-latrines for the many locals which are in a poor hygienic state characterized by many flies and foul smell.

4.4.1.2 Emptying

Once the pits became full, they were emptied with a cesspool emptier which is the only emptier within the town council provided by the government parastatal of NWSC. There is however a low demand for the service due the high cost involved in emptying thus being a loss on the side of the water utility. The need for emptying services can be made through placing a phone call to the NWSC toll free line.

The demand is as low as three or four customers a month. The emptiers are provided with good quality equipment like gloves, goggles, masks and overalls. Prior to emptying, chemicals were applied so as to reduce on the bad smell while executing the tasks and this task is done normally done in the night to avoid air pollution in terms of a bad smell. The emptiers also face stigma by the local residents due to the nature of the job as it involves getting into contact with sludge that is smelly and nasty.

However, in Kampala City, there are 85 vacuum trucks owned by private individuals who engaged in the business of fecal sludge emptying. The government through KCCA has 12 vacuum trucks which also engage in the same business of which six of those trucks are used for surveillance and maintenance of the sewerage network. They are hired by for hospitals, markets, schools, community and shared toilet facilities operated by KCCA, private households and the commercial sector. There is a high demand for emptying services in the city especially in the high-income residential areas.

4.4.1.3 Transportation

After collecting of the sludge at the point of generation, it is transported on the cesspool truck to Buwama Wastewater Treatment Plant which is situated 25km away from the town. The charge per emptying trip is usually between UGX 300,000 – UGX 400,000 depending on the volume of sludge available. The cesspool is still in a good condition hence the effects of spillage are not a problem of concern. The cost of emptying by KCCA cesspools charging 65000 UGX per trip for the commercial sector or households in Kampala City.

4.4.1.4 Disposal, treatment and recycling

The fecal sludge is then deposited in Buwama wastewater treatment plant where it is treated through stabilization ponds. These ponds are anaerobic in nature where only settleable solids are removed by sedimentation process. After staying in the ponds for five days, the supernatant is conveyed through pipes to a pool of gravel stones for removal of fine particulates that may not have been removed during sedimentation and thereafter left to infiltrate into the soil.

In the aspect of recycling, outside the plant premises is a CBS pewosa workshop that engages in the making of briquettes that uses the dried sludge as their raw-material. These briquettes are sold at a unit price of UGX 2000 per briquette thus profit generating for the youth participating in it. In a month, if the sales are high, a total of UGX. 600,000 can be earned. They are source of energy used for making fire. The founder of the workshop told us;

"I wish the struggling youth knew how much money one can generate in a month instead of suffering with those white-collar jobs."

Agriculturalists are also great buyers of the dried fecal sludge as it acts as manure for its growing crops. However, there is underutilization of the plant due to the low-demand and this is evidenced by the thick growing weeds and scrubs within the stabilization ponds.

4.4.1.5 Discussion

This study presets an in-depth understanding of the fecal sludge management practices within densely populated low-income settlements within Mpigi Town Council. The on-site sanitation facilities in form of pit-latrines are widely used within the area because they are cheap to construct and easy to maintain. The pit latrines are not shared by private households but by commercial, "*emizigo*" and hostels. The rate of the pits filling up is so low due to the low numbers of people and the pits dug are too deep up to 30 ft. and this may take those 20 years to fill. It was also noted that the entire town council had no developed sewer line for transportation of wastewater and excreta to the treatment plant hence the need to design a sewer system in the future. However, open defection was being done by the young children due to negligence by parents. The community members are more welcoming to the idea of construction of flush toilets but are limited by the high costs involved.

NWSC is the only government entity involved in the emptying and transportation of sludge through a cesspool emptier to the treatment plant in Buwama. This due to the high investment costs involved in the business yet the rate of return is low due to less demand of this service by the local population. There were also challenges that were evidenced along this sanitation value path like the negative perception about management of sludge in the area. The costs for the cesspool were too high and this cost was derived on the basis of distance, number of emptiers per trip.

As part of the opportunities presented along the recycling node is the manufacture of briquettes which emphasizes the need of an assessment of the emissions released by the burning of these briquettes to ensure they are not hazardous to human health and if such emissions can be reduced. The results also show the increased need for stakeholder involvement, the locals, the private sector and relevant authorities so as to achieve sustainable sanitation. There is also underutilization of the treatment plant in Buwama and it is also abandoned with no care and maintenance activities and this calls for more funding and facilitation by the government of Uganda. Subsidization of the cesspool emptier needs to be done so as to increase the waste loads onto the plant to increase its efficiency.

This study was only done using qualitative methods and was limited to low income and densely populated areas within Mpigi Town Council.

4.5 SFD FOR MPIGI TOWN COUNCIL

After conducting a qualitative analysis on the shit flow diagrams, valuable insights into the current state of sanitation and waste management systems have been gained. The analysis has provided a comprehensive understanding of the flow of human excreta throughout the urban environment, highlighting key areas of concern and potential improvements. By examining the various stages of collection, transport, treatment, and disposal of fecal matter, we have identified bottlenecks, inefficiencies, and potential health risks.

These findings will serve as a foundation for developing targeted interventions and strategies to enhance sanitation infrastructure, optimize resource allocation, and ultimately improve public health and environmental sustainability. The qualitative analysis of the shit flow diagrams has proven to be an indispensable tool in assessing the existing sanitation system and guiding evidence-based decision-making for a more effective and efficient management of human waste.

4.5.1 Assumptions for developing the SFD

- Comprehensive coverage of the town's sanitation and waste management system.
- Availability of sufficient data on sanitation facilities, their locations, operational status, and management arrangements.
- Clearly defined boundaries and scale for the town under consideration.
- Assumed pathways for the flow of fecal sludge and wastewater.

- 100% proportion of the contents of each type of onsite container are emptied periodically where onsite containers are connected to soak pits, to water bodies, open ground or have no outlet.

4.5.2 Diagrammatic Representation of Fecal Sludge Management within Mpigi Town Council

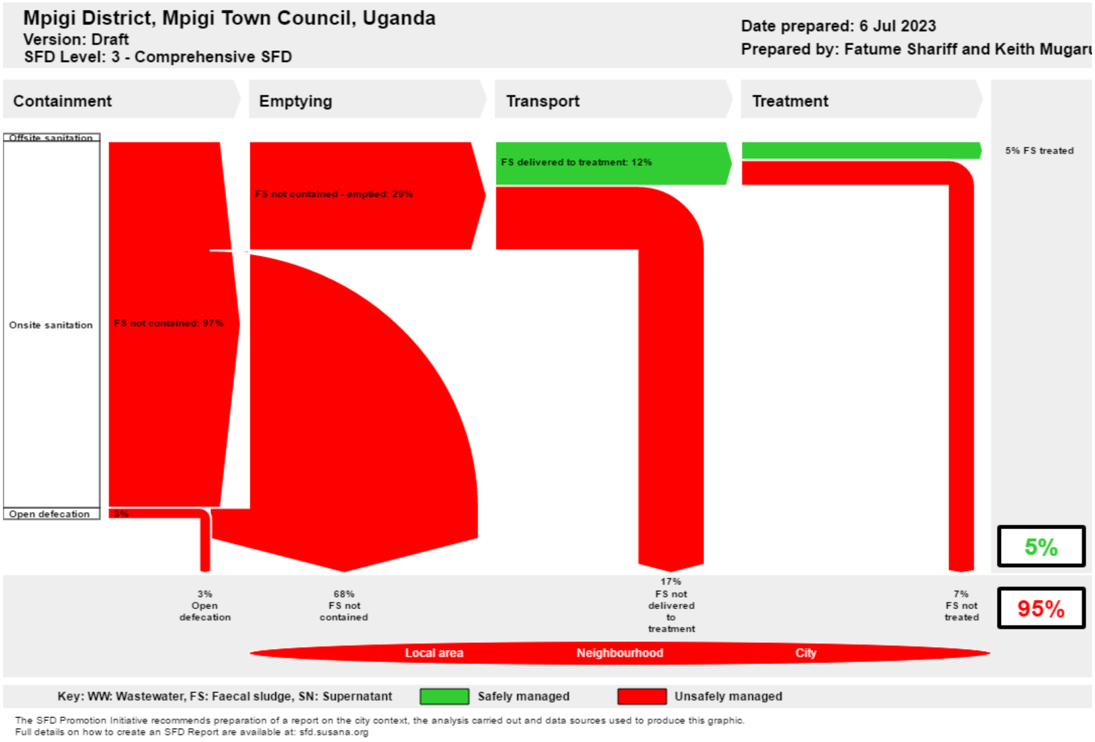


Figure 4-13: Shit Flow Diagram for Mpigi Town Council

4.5.3 Discussion

Based on the developed SFD shown in Figure 4-13, it is evident that the town council faces significant challenges in achieving safely managed sanitation. With only 5% of the sanitation systems classified as safely managed, the majority, 95%, falls under the category of unsafely managed sanitation. This indicates a pressing need for urgent interventions and improvements in the town's sanitation infrastructure and practices.

The safely managed sanitation is due to the few households that use cesspool emptiers which deliver fecal sludge to the treatment placed were by it is treated and safely disposed. It is also because of the manufacture of briquettes which are source of energy in terms of fuel especially in rural households. This represents recycling of fecal sludge within MTC.

The unsafely managed sanitation is due to the use of pits for defecation which are later abandoned by either covering with vegetation or just with soil. It also due to the open defecation still being practiced by a certain portion of the population which increases the exposure to fecal pathogens in the open environment which pose a significant threat to the outbreak of diseases like cholera, diarrhea and dysentery. There is also a less demand for the cesspool emptiers hence most of the fecal sludge is not treated within MTC. There are also many unlined pits which is a source of contamination to groundwater sources in terms of infiltration of the supernatant from the pit-latrines to the water sources.

In comparison with(SFD for Kampala City, 2016.), 54% of the sanitation is safely managed while 46% is unsafely managed. Basing on the SFD report for Kampala City of 2016, there was less than 1% of the population practicing open defecation while most of the households were connected to sewer systems and this justifies why safely managed sanitation in Kampala is greater than that for MTC. The unsafely managed sanitation is also due to the fact that cesspool emptying services are not usually used due to the high costs involved for those not connected to sewer systems.

CHAPTER 5 CONCLUSIONS, RECOMMENDATIONS AND CHALLENGES

5.1 CONCLUSIONS

The system risk assessment showed that biological, chemical and physical contamination risk factors were identified that have a negative impact on the quality of drinking water and cause a hazard of exposure to water borne diseases or chemical contamination. In more detail, on the basis of visual inspection and the results of the sanitary observation questionnaire, the following components/steps of water supply system were identified as the most probable causes of contamination of potable water: **Water treatment points, head works, reservoirs, main pipes and distribution network.**

The groundwater assessment results showed that an increase in the number of pit latrines from 15 m to 100 m radius from the groundwater point showed a strong positive linear correlation with levels of Ammonia, pH, Turbidity, Nitrates, *E. coli* while EC had an inverse relationship. Chlorides, Dissolved Oxygen showed no relationship with increasing pit latrine density. The results also showed that there was a strong association of **Ammonia, pH, Turbidity, Nitrates, *E. coli*** levels to high pit latrine density that suggested groundwater contamination by unlined pit-latrines whose flow contours were in the direction of the water sources downstream.

In the year of 2022, the rate at which the water bodies are replenished is greater than the system abstraction which creates a water surplus. Aquifers fill with water which results in increased surface runoff, higher discharge and higher levels within the Kiyanja Swamp. This means there is a positive water balance. The management practices of civilians within this system boundary are suitable and in conformity with the concept of sustainability.

From the qualitative analysis, the effective management of fecal sludge continues to pose significant challenges in areas where open defecation practices persist together with the abandonment of open pits when they are fully used up. There are negative attitudes the locals have about using pit-emptiers.

It was noted that the majority key stakeholders fell in the category high influence and high interest for the uWFD for Mpigi Town Council. This means that if the diagram is to be used a key visualization tool in the execution the urban water projects, it would be a very successful analytical approach thus should be incorporated in the feasibility stage of urban water projects to identify challenges within urban flows.

5.2 RECOMMENDATIONS

Risk assessment studies for groundwater should be done in the wet season so as to obtain a clear representation of the contributing polluting parameters to the groundwater sources. There is a need to design a sewer system so as to ensure sustainable sanitation as well as encourage the construction of flush toilets. More studies should be conducted in more small towns with rising and promising prospects of urban developments.

The diagram developed for the town council can be used in the planning of future water projects within the area. Fencing of the Kiyanja water intake should be done so as to reduce anthropogenic activities which would result into further contamination. There is a need for sensitization campaigns to encourage the use of this cesspool emptiers within the locality.

Record keeping needs to be emphasized at both the district and town council level to ensure data accuracy.

More water supply projects should be advocated for within the town council like construction of new boreholes to meet the desired water use quantity.

Efforts should also focus on engaging stakeholders, including the local government, water and sanitation authorities especially NWSC, public health agencies, community representatives, and development partners, to foster collaboration, resource mobilization, and knowledge sharing. By implementing evidence-based interventions informed by the shit flow diagram, it is possible to make significant progress in improving sanitation conditions, safeguarding public health, and protecting the environment in the town.

5.3 CHALLENGES

There was inadequate record keeping which made acquisition of necessary required information difficult. Some of the industrial firms were rigid on releasing information regarding their discharges. The highly undeveloped terrain made some areas inaccessible for the acquisition of pit-latrine and groundwater sources.

During the household surveys, the residents were fearful of giving out their household water consumption figures.

APPENDIX

Appendix One

Sanitary Inspection Form (Draft: 1 May 2020) **DRINKING-WATER**

Dug well with a hand pump

I. GENERAL INFORMATION

A. Well location and specification
(Record information on the well location and specification. Add "N/A" where information is not applicable.)

Village/town	Community	District	Province	State

Additional location information: (If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.)						
Year of well construction	**Well depth** (and units)	**Approximate number of households served by this water supply:** (Circle one of the options below.)				
		1-10	11-50	51-100	101-500	500+
Is the well located in a flood zone?	Circle one of the options below		If **Yes**, details (e.g. typical flood frequency, duration, severity):			
	Unknown	No	Yes			

B. System functionality
(Circle **Yes** or **No** to indicate whether water is currently available from the well. If **No**, provide details (e.g. faulty or missing component, no/limited water available etc.) and skip to Section II. Record key remedial actions in Section III that are needed to ensure the well can provide water.)

Is water currently available from the well?		If **No**, details (and skip to Section II):
Yes	No	

C. Weather conditions during the 48 hours prior to inspection
(Indicate the predominant temperature and precipitation conditions during the 48 hours prior to inspection by placing a circle around the options below. Where conditions have been changeable, more than one option may be circled. Additional information may be recorded in Section III.)

Temperature	<0° Celsius	0-15° Celsius	15-30° Celsius	>30° Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

D. Water sample information
(Use the table below to record details of any water sample taken during the inspection. Include information for any parameters tested. Add "N/A" where information is not applicable. Additional parameters may be recorded in Section III.)

Sample taken?		**Sampling location**				**Sample no. /code**		**Other sample information**			
No	Yes										
Parameter tested		*E. coli*	**OR**	Thermotolerant (faecal) coliforms		Additional parameter		Additional parameter		Additional parameter	
Result and units		RESULT	UNITS	RESULT	UNITS	RESULT	UNITS	RESULT	UNITS	RESULT	UNITS

E. Water treatment prior to abstraction/collection
(Answer the question by ticking (✓) the appropriate box and providing further information, where applicable.)

❑ No treatment applied at the well

❑ Chlorine applied directly to the well. If so, describe (e.g. chlorine dose, frequency):

❑ Other. Describe (e.g. method, frequency):

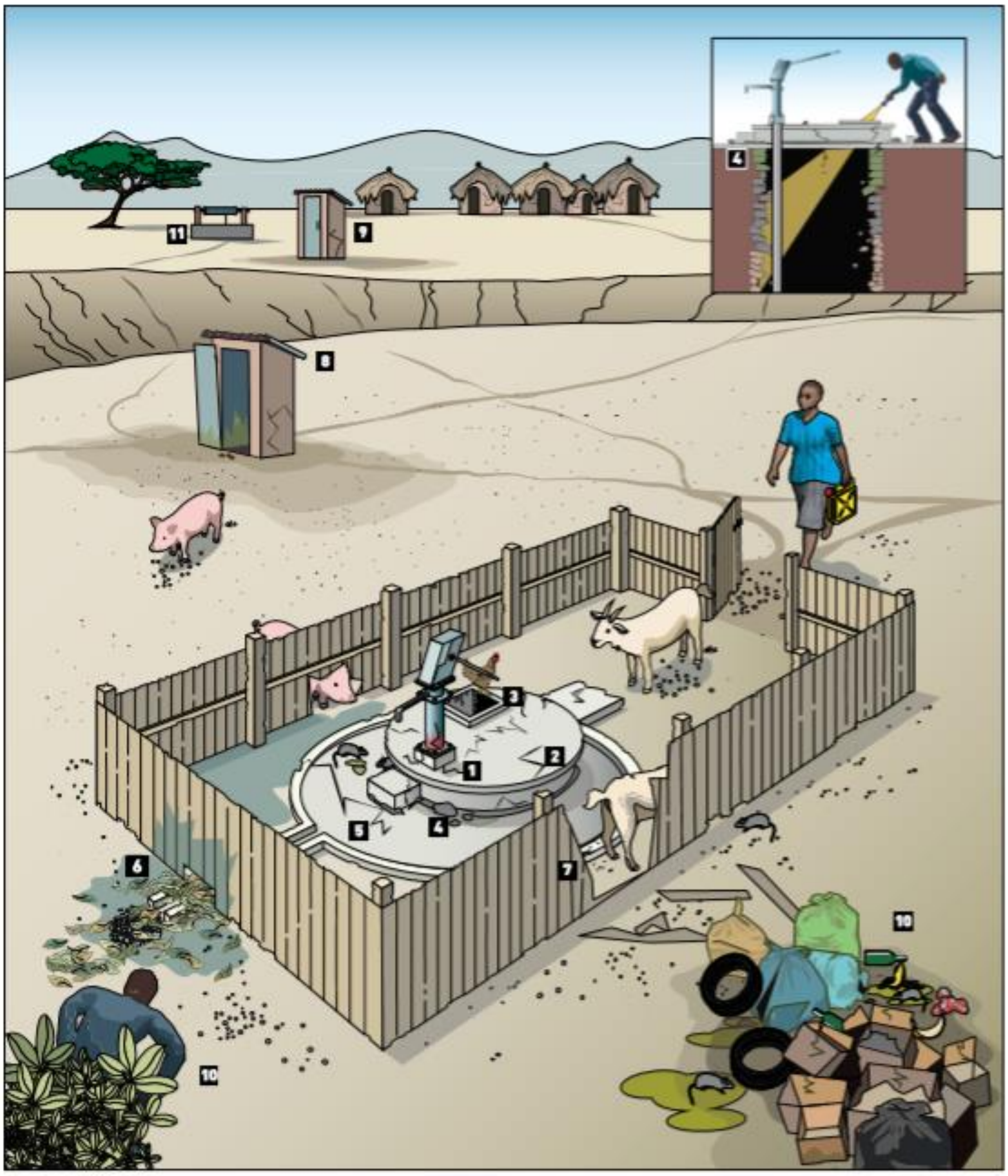
Notes:

1. If there are more dug well sources in your community, or if other water sources are used by the community (e.g. springs, boreholes), carry out individual sanitary inspections for these sources as well using the relevant sanitary inspection forms.
2. If users store water in the household, also carry out sanitary inspections using the form "Household practices".

II. SANITARY INSPECTION

IMPORTANT: Read the following notes before undertaking the sanitary inspection

1. Answer the questions by ticking [✓] the appropriate box. For guidance, refer to the numbered risk factors in the illustration below, which are linked to each question on the next page. Note: these are typical risk factors; consider what additional risk factors may be relevant in your local context. Refer also to the *Technical Fact Sheet* for information on the individual components of the dug well.
2. If there is no risk present, or a question does not apply to the well being inspected, tick the **NO** box.
3. If a risk is present, tick the **YES** box. For important situations that require attention, record the actions to be taken in the column provided. These notes can be used to develop a detailed improvement plan, outlining what will be done, by whom, by when and what resources are required. For guidance, refer to the *Management Advice Sheet*. Where possible, corrective actions should focus on addressing the most serious risks first. Consider low/no cost improvements that can be made immediately.



Sanitary inspection questions		NO	YES (risk)	What action is needed?
1	**Is the pump damaged or loose at the point of attachment to the cover slab so that contaminants could enter the well?** A damaged or severely corroded pump, or a loose pump that is not securely attached to the cover slab, may allow contaminants to enter the well (e.g. contaminated surface water).	❑	❑	
2	**Is the cover slab absent or inadequate to prevent contaminants entering the well?** The absence of a cover slab, or the presence of a poorly maintained cover slab (e.g. damaged, eroded or with deep cracks), may allow contaminants to enter the well.	❑	❑	
3	**If there is an inspection port, is the lid missing or inadequate to prevent contaminants from entering the well?** A missing, unsealed or unlocked inspection port lid provides a potential route of entry for contaminants to the well (e.g. via contaminated surface water, animals or vandalism).	❑	❑	
4	**Are there any visible deficiencies at any point in the well wall?** Any inadequately sealed points (e.g. gaps, deep cracks, faults) in the aboveground (i.e. headwall) or belowground well wall may result in contaminants entering the well. (Note – if there is no inspection port and a belowground visual inspection of the well is not possible, record this in Section III.)	❑	❑	
5	**Is the apron around the well absent or inadequate to prevent contaminants from entering the well?** A missing apron, or any gaps, deep cracks or faults in an existing apron may allow contaminants to enter the well. For adequate protection, the apron should be at least 1 meter[a] wide all around the headwall, sloping down towards a collar to catch and divert water to a drainage channel.	❑	❑	
6	**Is the drainage inadequate, which may result in stagnant water in the well area?** An absent, damaged or blocked drainage channel, and/or the absence of a downward slope for water to drain away from the well, could result in ponding and stagnated water contaminating the well area.	❑	❑	
7	**Is the fencing or barrier around the well absent or inadequate to prevent animals entering the well area?** If the fencing or barrier around the well is absent, broken or poorly constructed, animals could damage or contaminate the well area.	❑	❑	
8	**Is there sanitation infrastructure within 15 meters[a] of the well?** Sanitation infrastructure (e.g. a latrine pit, septic tank or sewer line) close to groundwater supplies may affect water quality (e.g. by seepage or overflow and subsequent infiltration). You may need to visually check structures to see if they are sanitation-related, in addition to asking residents.	❑	❑	
9	**Is there sanitation infrastructure on higher ground within 30 meters[a] of the well?** Groundwater may flow towards the well from the direction of the sanitation infrastructure. Pollution on higher ground poses a risk, especially in the wet season, as faecal material and other pollutants may flow into the well.	❑	❑	
10	**Can signs of other sources of pollution be seen within 15 meters[a] of the well (e.g. animals, rubbish, human settlement, open defecation, fuel storage)?** Animal or human faeces on the ground close to the well constitute a serious risk to water quality. Presence of other waste (e.g. household, agricultural, industrial etc.) also constitutes a risk to water quality.	❑	❑	
11	**Is there any point of entry to the aquifer that is unprotected within 100 meters[a] of the well?** Any point of entry to the aquifer that is unprotected (e.g. uncapped/open well or borehole) is a direct pathway for contaminants to enter the well.	❑	❑	
	Total number of risks identified:	....	**/11**	

a. General guidance only. Depends on local factors including soil type and permeability, depth of the water table and the volume and concentration of contaminants. Refer to Guidelines for drinking-water quality, 2nd edition: Volume 3 - Surveillance and control of community supplies (WHO, 1997) for guidance on determining minimum safe distances for potentially contaminating activities.

III. ADDITIONAL DETAILS — remarks, observations, recommendations

Submit photographs with the sanitary inspection form as required.

IV. INSPECTION DETAILS

Name of inspector: ....

Organization of inspector: ....

Designation/title of inspector: ....

Signature: .... Date: ....

Name of water supply representative: ....

Signature (if available): .... Date: ....

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World Health Organization

Spring source

I. GENERAL INFORMATION

A. Spring location and specification

[Record information on the spring location and specification. Add "N/A" where information is not applicable.]

Village/town	Community	District	Province	State

Additional location information: [If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.]	

Year of spring construction	**Approximate number of households served by this water supply:** [Circle one of the options below.]				
	1-10	11-50	51-100	101-500	500+

Is the spring located in a flood zone?	Circle one of the options below			If **Yes**, details (e.g. typical flood frequency, duration, severity):
	Unknown	No	Yes	

B. System functionality

[Circle **Yes** or **No** to indicate whether water is currently available from the spring. If **No**, provide details (e.g. faulty or missing component, no/limited water available etc.) and skip to Section II. Record key remedial actions in Section III that are needed to ensure the spring can provide water.]

Is water currently available from the spring?		If **No**, details (and skip to Section II):
Yes	No	

C. Weather conditions during the 48 hours prior to inspection

[Indicate the predominant temperature and precipitation conditions during the 48 hours prior to inspection by placing a circle around the options below. Where conditions have been changeable, more than one option may be circled. Additional information may be recorded in Section III.]

Temperature	<0º Celsius	0-15º Celsius	15-30º Celsius	>30º Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

D. Water sample information

[Use the table below to record details of any water sample taken during the inspection. Include information for any parameters tested. Add "N/A" where information is not applicable. Additional parameters may be recorded in Section III.]

Sample taken?		**Sampling location**				**Sample no. /code**		**Other sample information**			
No	Yes										
Parameter tested		*E. coli*	**OR**	Thermotolerant (faecal) coliforms		Additional parameter		Additional parameter		Additional parameter	
Result and units		RESULT	UNITS	RESULT	UNITS	RESULT	UNITS	RESULT	UNITS	RESULT	UNITS

E. Water treatment prior to abstraction/collection

[Answer the question by ticking (✓) the appropriate box and providing further information, where applicable.]

❑ No treatment applied at the spring

❑ Chlorine applied directly to the spring. If so, describe (e.g. chlorine dose, frequency):

____

❑ Other. Describe (e.g. method, frequency):

____

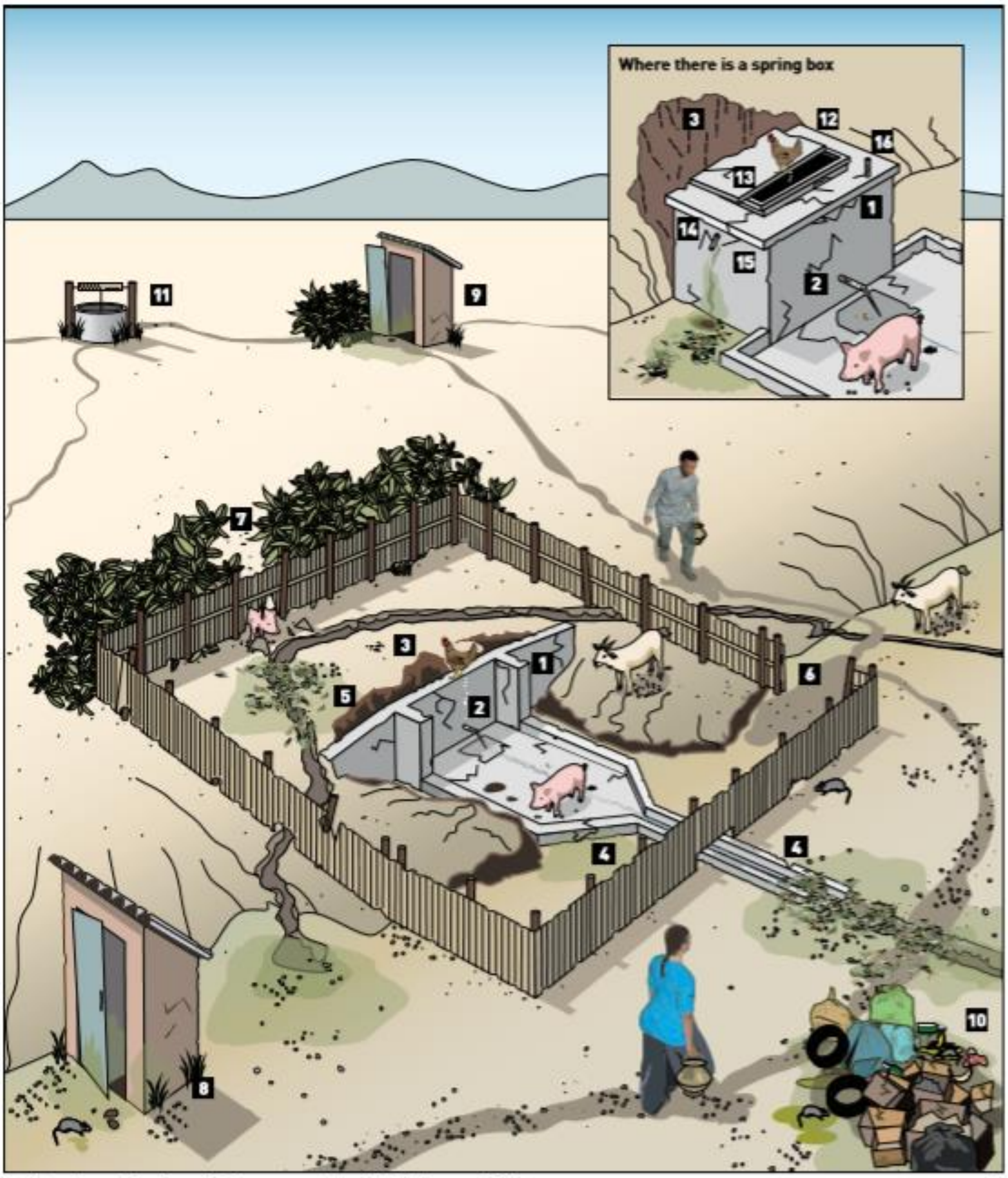
Notes:

1. If there are more spring sources in your community, or if other water sources are used by the community (e.g. wells, boreholes), carry out individual sanitary inspections for these sources as well using the relevant sanitary inspection forms.
2. If users store water in the household, also carry out sanitary inspections using the form "Household practices".

II. SANITARY INSPECTION

IMPORTANT: Read the following notes before undertaking the sanitary inspection

1. Answer the questions by ticking (✓) the appropriate box. For guidance, refer to the numbered risk factors in the illustration below, which are linked to each question on the next page. Note: these are typical risk factors; consider what additional risk factors may be relevant in your local context. Refer also to the *Technical Fact Sheet* for information on the individual components of the spring.
2. If there is no risk present, or a question does not apply to the spring being inspected, tick the **NO** box.
3. If a risk is present, tick the **YES** box. For important situations that require attention, record the actions to be taken in the column provided. These notes can be used to develop a detailed improvement plan, outlining what will be done, by whom, by when and what resources are required. For guidance, refer to the *Management Advice Sheet*. Where possible, corrective actions should focus on addressing the most serious risks first. Consider low/no cost improvements that can be made immediately.



Sanitary inspection questions		NO	YES (risk)	What action is needed?
Answer the following questions 1-11 for all types of spring structures				
1	**Is a protective wall or spring box structure missing or inadequate to prevent contaminants entering the spring?** The absence of a protective structure, or the presence of a poorly maintained one (e.g. damaged, eroded or with deep cracks) may allow contaminants to enter the spring.	❑	❑	
2	**Is the outlet pipe unclean or inadequately positioned to prevent contaminants entering the spring?** An unclean and/or poorly maintained outlet pipe may introduce contaminants into the spring water. If the outlet pipe is positioned too close to the ground, there is a risk of contaminants entering the spring via backflow of surface water or entry of vermin.	❑	❑	
3	**Is the backfill area eroded or prone to erosion due to the absence of vegetation?** If the backfill area becomes eroded (e.g. due to the absence of vegetation), it may act as a direct pathway for contaminants to enter the shallower groundwater as it approaches the spring structure.	❑	❑	
4	**Is the drainage inadequate, which may result in stagnant water in the spring area?** A missing, damaged or blocked drainage channel, and/or the absence of a downward slope for water to drain away from the spring structure, could result in ponding and stagnant water contaminating the spring area.	❑	❑	
5	**Is a storm water diversion ditch above the spring missing or inadequate to prevent contaminants entering the spring?** If the diversion ditch is missing or inadequate (e.g. blocked or lacks sufficient capacity to divert heavy surface water flows), contaminated surface water may enter the spring area.	❑	❑	
6	**Is the fencing or barrier around the spring missing or inadequate to prevent animals entering the spring area?** If the fencing or barrier around the spring is missing, broken, or poorly constructed (e.g. with wide gaps), animals could enter and damage or contaminate the spring area.	❑	❑	
7	**Is the fencing or barrier upstream of the spring missing or inadequate to prevent contaminants entering the spring?[a]** If the fencing or barrier upstream of the spring is missing, broken, or poorly constructed (e.g. with wide gaps), animals could enter and contaminate the shallower groundwater as it approaches the spring structure. Contaminating activities such as agriculture or open defecation could also be practiced in this area without the protection of a fence or barrier.	❑	❑	
8	**Is there sanitation infrastructure within 15 meters[b] of the spring?** Sanitation infrastructure (e.g. a latrine pit, septic tank or sewer line) close to groundwater supplies may affect water quality (e.g. by seepage or overflow and subsequent infiltration). You may need to visually check structures to see if they are sanitation-related, in addition to asking residents.	❑	❑	
9	**Is there sanitation infrastructure on higher ground within 30 meters[b] of the spring?** Groundwater may flow towards the spring from the direction of the sanitation infrastructure. Pollution on higher ground poses a risk, especially in the wet season, as faecal material and other pollutants may flow into the spring.	❑	❑	
10	**Can signs of other sources of pollution be seen within 15 meters[b] of the spring (e.g. animals, rubbish, human settlement, open defecation, fuel storage)?** Animal or human faeces on the ground close to the spring constitute a serious risk to water quality. Presence of other waste (e.g. household, agricultural, industrial etc.) also constitute a risk to water quality.	❑	❑	
11	**Is there any point of entry to the groundwater that is unprotected within 100 meters[b] of the spring?** Any point of entry to the groundwater aquifer that is unprotected (e.g. uncapped/open well or borehole) is a direct pathway for contaminants to enter the spring.	❑	❑	

 ... continued on next page

	Sanitary inspection questions	NO	YES (risk)	What action is needed?
	Where there is a spring box, also answer the following additional questions			
12	**Are there any visible signs of contaminants inside the spring box (e.g. animals and/or their waste, sediment accumulation)?** The presence of animals or their wastes constitute a serious risk to water quality. Sediments may contain microbial pathogens and other contaminants (such as metals) that can be resuspended and impact the safety or acceptability of the spring water. (Note – if there is no inspection port, and an internal visual inspection of the spring box is not possible, record this in Section III.)	❑	❑	
13	**If there is an inspection port, is the lid missing or inadequate to prevent contaminants entering the spring?** A missing, unsealed or unlocked inspection port lid provides a potential route of entry for contaminants to the spring (e.g. via contaminated surface water, animals or vandalism). Such openings may also allow light to enter the spring box, which can result in algal growth within.	❑	❑	
14	**Is the overflow pipe inadequately designed to prevent contaminants entering the spring?** If water from the overflow pipe falls from a height and erodes the ground beneath the pipe, the spring box structure may be undermined, providing a route of entry for contaminants into the shallower groundwater.	❑	❑	
15	**Is the overflow pipe inadequately covered to prevent contaminants entering the spring?** If the overflow pipe is not covered with a screen (e.g. with a mesh or gauze), contaminants may enter the spring box (e.g. vermin).	❑	❑	
16	**If there are air vents, are they inadequately designed or covered to prevent contaminants entering the spring box?** If air vents are angled upwards, and/or are not covered with a screen, contaminants may enter the spring box.	❑	❑	

Total number of risks identified

Where there is no spring box: .... **/11**

OR

Where there is a spring box: .... **/16**

a. Adequate fencing or barrier implies that the upstream area is closed off to where the groundwater is at least 2 meters deep or 30 meters away from the eye of the spring. (General guidance only; refer to note b.)

b. General guidance only. Depends on local factors including soil type and permeability, depth of the water table and the volume and concentration of contaminants. Refer to *Guidelines for drinking-water quality, 2nd edition: Volume 3 - Surveillance and control of community supplies* (WHO, 1997) for guidance on determining minimum safe distances for potentially contaminating activities.

III. ADDITIONAL DETAILS — remarks, observations, recommendations

Submit photographs with the sanitary inspection form as required.

IV. INSPECTION DETAILS

Name of inspector: ....

Organization of inspector: ....

Designation/title of inspector: ....

Signature: .... Date: ....

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Signature (if available): .... Date: ....

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World Health Organization

Appendix Two

HOUSEHOLD INTERIEW QUESTIONS

1. What sanitation technology is used i.e., on-site or off-site?
2. If it is on-site or off-site, what type is it?
3. Why is that sanitation technology preferred?
4. How regularly is the sanitation facility cleaned and what cleaning methods are used?
5. What is the current state of the sanitation facility?
6. Would you prefer any other option of a sanitation facility than the one you're using currently?
7. Has the sanitation facility ever filled before and if so, how was it emptied or dealt with?
8. Do you experience cases of open defecation in your community?
9. Would you like your community leaders to engage in fecal sludge management and if so, what can they do to improve the current state of fecal sludge management?

Appendix three

TOPIC	PRIMARY QUESTION	SECONDARY QUESTION	TERTIARY QUESTION	OTHER QUESTION
Trade-offs for households from increased investment in FSM services	Where people pay more for emptying services? How does this affect other financial needs of their household?	Are some financial needs more affected than others?	If so, which?	
Improved service provision	Say there is a service to empty pit latrines in this area. It would be legal, professional, and affordable. How willing would you be to buy this service?	What features/benefits of this service would be most important to you?	Would you recommend these services to a friend?	
Seasonal changes in FSM	Is there any difference in how you or your community manage your toilet waste at different times of the year?	If yes, what are the differences?	How is the price calculated?	
Rain induced challenges to FSM	Do you or community face any challenges with managing toilet waste when it rains?	If yes, how do people in your community typically respond to this situation?	Does it work?	Would there be a better approach?

Table 1: Inquiry grid for focus group discussions (cont.)

TOPIC	PRIMARY QUESTION	SECONDARY QUESTION	TERTIARY QUESTION	OTHER QUESTION
Role of different stakeholders in improving FSM	Are there any community rules or regulations that affect how you manage the waste from your toilet?	If yes, what are they?		
	What do you think the City authorities could do to improve the management of toilet waste in your area?			
	Could others be involved in improving the management of toilet waste in your area?	Who do you suggest and what could they do?		
	What do you think households could do to improve the management of faecal sludge in your area?			
Current payment for FSM services	Have you ever paid for services to deal with a full, smelly or dirty latrine?	How did you feel after they complete the service?	Would you recommend these services to a friend?	
	What are the types of emptying options used by households in your community?	How much does this typically cost?	How is the price calculated?	

Table 1: Inquiry grid for focus group discussions (cont.)

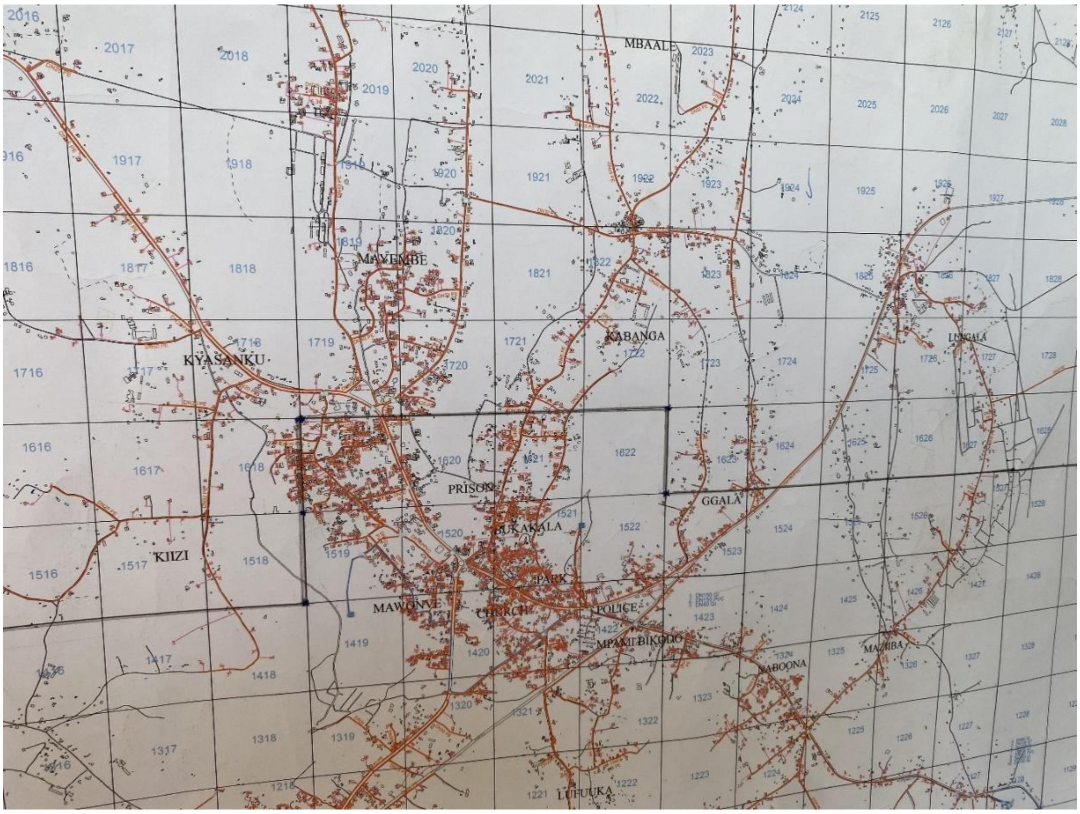
TOPIC	PRIMARY QUESTION	SECONDARY QUESTION	TERTIARY QUESTION	OTHER QUESTION
Range of technical options available	Can you tell me about the type of toilet facility that you commonly use?	Why do you use this type of toilet?	Where does your toilet waste go?	
	Is this the same type that is commonly used on your community?	If no, what is the most common type?		
	Are the different types of toilet facilities used differently by women and men, or other groups of people, in this area?	Can you explain what these differences are?	When and why are they occurring?	
	How long does it take for your pit or septic tank to get full?	What did you do (or plan to do) about the full pit or septic tank?	What was your experience when it was emptied?	Are there any other reasons that would cause you to clean out your latrine?
What people consider to be appropriate services and how this influences demand	What do you consider are the best services to manage toilet waste from your household?	Who do you think should be responsible for providing this service?	If emptying services improved, do you think people would be prepared to pay more for them? Please explain.	
What motivates communities or households to demand and use more appropriate emptying services	What motivates people to demand and use the best toilet facility emptying services?	What percent of the community do you feel are motivated to use these emptying services?		

Table 1: Inquiry grid for focus group discussions

TOPIC	PRIMARY QUESTION	SECONDARY QUESTION	TERTIARY QUESTION	OTHER QUESTION
Extent to which risk free and functioning services are provided: containment, emptying, transport	Can families in this community find suitable toilet facility emptying services, when they want to have their pit or septic tank emptied?	Do these emptying services introduce any risks?	If so, what are those risks, when and where do they occur?	
	Are you aware of any recent improvements made to pit/septic tank emptying services in this community?	If so, what has happened?	What difference has this made to the services you see provided?	If not, are any improvements planned?
	If there is a challenge with waste from your toilet, who do you call?	Why?	Can you describe the typical challenges that occur in your community?	
Awareness and support through existing policies and regulations	Do you know of any policies or regulations on managing waste from your toilet?	How have different government agencies or administrations responded to toilet waste management?	If no, how have you been managing waste from your toilet without any support from the government?	
Electoral returns to FSM investments	Do politicians mention issues of sanitation/sludge handling during their campaigns?	Why do you think they do or don't?	Does it affect people's voting decisions if they do?	Or if the currently don't, would it if they did in the future?

Table 1: Inquiry grid for focus group discussions (cont.)

Appendix Four



An interview session with Mr. Paul Ssebinyansi the CEO of Mpigi Fish Farm

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