Synne Høyås and Jehan Kanaganathan

A Case Study of Community-Driven Water Supply System Development in Rural Tanzania

Master's thesis in Civil and Environmental Engineering
Supervisor: Sveinung Sægrov
Co-supervisor: Marius Møller Rokstad
June 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

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Norwegian University of Science and Technology
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Department of Civil and Environmental Engineering

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Science and Technology

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Date	Reference
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Master thesis

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Post control of water supply schemes to villages in Tanzania

Problem Statement

From 2015 to 2019 Norwegian Church Aid constructed more than 30 water yards bases on solar-powered electric pumps for villages in Mbulu and Singida counties, Tanzania, funded by the Norwegian Television Action of 2014. This was followed by 6 additional projects in the same regions in 2020 and 2021, funded by private sponsors. The installations were to a large extent successful, but a brief status report form the local human aid organisation 4CCP in 2022 reveals the need for a follow-up program on technical and societal issues. The aim of this master is to explore the current situation more in depth and suggest further actions.

In previous years five independent master thesis have been conducted that analyse various aspects of the water technical performance and the social, environment and economic impact of this water supply. The current candidates have conducted a preparatory project work during autumn 2022.

The focus of this thesis should be a further analysis of the operational and socio-economic status with a focus on criteria for a successful management, extension of the water infrastructure, water quality and remote monitoring of water yards. The findings by information collection at local villages and other sources should be compared with literature found through the exploration of literature. Furthermore, potential challenges and opportunities, suggestions from previous master theses and conversations with 4CCP should be addressed.

During the previous project work, a list of prioritized tasks was presented by 4CCP. The tasks included were:

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- Extension of infrastructure: Explore the possibility and design of connecting the water system in Dang'aida village to nearby sub-villages.
- Conduct water quality measurements with a focus on fluoride and bacterial contamination.
- Collect data on community water needs.
- Collect data on the performance of the water systems and CBWSOs (village water committee).
- Explore possibilities of increasing the water quantity from the solar-powered water systems.
- Explore a potential suitable remote monitoring solution for the water systems.

The ultimate goal of this master thesis, based on these tasks, the aforementioned theory relating to the study area and the research opportunities found through previous master theses, is to conduct a case study exploring community-driven development in rural Tanzanian settings.

Assistance

Professor Sveinung Sægrov and associate professor Marius Møller Rokstad will be supervisors for this task, assisted by Manfred Arlt, Norwegian Church Aid, Rebecca Martinsen, Engineers without borders, Eliminata Awet and Ahadi Mollel from 4CCP,

Presentation and delivery

The project report is to be delivered electronically via Inspera according to applicable rules.

Deadline 11. June 2023

Abstract

Reliable access to water is at the foundation of a healthy and prosperous life. Still, only 45.45% of the Tanzanian rural population had basic access to water in 2020. To address this issue, Tanzania along with many other Sub-Saharan African nations, has implemented a community-driven management strategy for rural water supply.

This master thesis investigates which conditions contributed to the community-driven development of groundwater supply systems in rural Tanzania and how such a development could be facilitated. The examined conditions were based on sustainability indicators that were analysed through the use of Qualitative Comparative Analysis (QCA) using fuzzy set scoring. The analysis was based on interview data and field observations from a solar-powered water well project constructed by Norwegian Church Aid (NCA) from 2015 to 2021. The issue was further investigated by designing an expansion of the water system in the village of Dang'aida, measuring and reviewing the water quality in several water wells and evaluating the use of remote monitoring in the management of rural water systems.

The most robust pathway leading to the development of a water point is identified by the QCA to consist of user acceptability, financial durability, storage and supply reliability and the absence of an alternative water source. User acceptability is a necessary condition. The designed expansion of the water system in Dang'aida can provide sufficient water to all the planned locations. It is therefore likely to positively affect these conditions, provided the well has the required capacity for increased use. Expanding the system therefore has the potential to trigger a self-reinforcing cycle of community-driven development.

The water quality measurements reveal that several of the boreholes have water with high levels of nitrate and E. coli. This is likely caused by agricultural runoff and human and animal activities close to the water borehole. It is therefore recommended by this study that a management plan of the areas around the borehole is made by the districts and applied by the communities.

The implemented remote monitoring systems were, despite data quality problems, proof of concept for a low-cost and user-friendly remote monitoring system. Remote monitoring can make the District Engineers' follow-up support of the CBWSOs more efficient and be an essential part of ensuring reliable water access to rural Tanzania. However, under the current management regime, it is deemed as too big an investment to be prioritised, both in relation to finances and technical resources.

The result of this thesis provides a set of conditions that can encourage community-driven development of rural water supply systems, as well as an example of how such a development can be designed. It also offers a comprehensive review of the system's water quality and a proof of concept for a remote monitoring system that can be used to enhance the cooperation between the community and the district level.

Sammendrag

Tilgang til rent vann er fundamentalt for et godt og langt liv. Likevel hadde bare 45,45 % av den tanzaniske befolkningen grunnleggende tilgang til rent vann i 2020. For å effektivisere utvilkingen har Tanzania, i likhet med flere andre nasjoner i regionen, implementert en desentraliseringsstrategi hvor lokalsamfunnene forvalter drikkevannsforsyningen sin selv.

Denne masteroppgaven undersøker hvilke egenskaper som bidrar til at lokalsamfunn utvikler drikkavannsforsyningen sin i rurale Tanzania og hvordan slik utvikling kan støttes opp under. Egenskapene som ble undersøkt var basert på bærekraftsindikatorer og ble analysert gjennom en kvalitativ sammenlignende analyse (KSA) ved bruk av ikke-binær poenggivning. Analysen var basert på intervjudata og feltobservasjoner fra et solcelledrevet vannbrønnprosjekt i området rundt Haydom i Tanzania konstruert av NCA fra 2015 til 2021. Problemstillingen ble ytterligere undersøkt ved å designe en utvidelse av vannsystemet i landsbyen Dang'aida, evaluere vannkvaliten i drikkevannskildene i området samt en test og vurdering av fjernovervåking i forvaltningen av rurale vannsystemer.

Den mest robuste veien til utvikling av et vannpunkt som ble identifisert gjennom KSA bestod av egenskapene brukeraksept, økonomisk bærekraft, lagrings- og forsyningspålitelighet samt fraværet av en alternativ vannkilde. Brukeraksept viste seg å være en nødvendig egenskap for at en landsby skulle utvikle vannsystemet sitt. Videre greide den planlagte utvidelsen av vannsystemet i Dang'aida å forsyne tilstrekkelig vann til alle de planlagte stedene. Det vil derfor trolig påvirke disse egenskapene positivt, forutsatt at brønnen har den nødvendige kapasiteten for økt bruk. En utvikling av drikkevannsforskyningen har derfor potensial til å utløse en selvforsterkende syklus av lokaldrevet utvikling.

Vannkvalitetsmålingene avdekket at flere av borehullene har vann med høye nivåer av nitrat og E. coli. Dette er sannsynligvis forårsaket av landbruksavrenning og menneske- og dyreaktivitet nær vannbrønnene. Det anbefales derfor av denne studien at en forvaltningsplan for områdene rundt borehullet lages av distriktene og implementeres av lokalsamfunnene.

Fjernovervåkingssystemene var, til tross for datakvalitetsproblemer, proof of concept for et rimelig og brukervennlig fjernovervåkingssystem. Fjernovervåking kan gjøre distriktsingeniørenes oppfølging av drikkevannskildene mer effektiv og være en viktig del av å sikre pålitelig vanntilgang til rurale Tanzania. Under dagens forvaltningsregime vurderes det imidlertid som en for stor investering til å bli prioritert, både i forhold til økonomiske og tekniske ressurser.

Resultatet av denne oppgaven gir et sett med egenskaper som kan fasilitere lokaldrevet utvikling av rurale vannforsyningssystemer, samt et eksempel på hvordan en slik utvikling kan designes. Den tilbyr også en omfattende gjennomgang av systemenes vannkvalitet og er et proof of concept for et fjernovervåkingssystem som kan brukes til å styrke samarbeidet mellom lokalsamfunnet og distriktsnivå.

Preface

This thesis is the product of extensive research and collaborative efforts, made possible by the support and contributions of many individuals and organisations. It was conducted at the Department of Civil and Environmental Engineering at the Norwegian University of Science and Technology during the spring of 2023. First and foremost, we would like to express our wholehearted thanks to all the individuals in the Haydom area in Tanzania, who shared their time and experiences with us during the data collection phase of this research. We extend our sincerest gratitude to all those we interviewed, including community members, students and CBWSO members, whose contributions were used as the basis of this study.

We are grateful to 4CCP and their exceptional staff for their unwavering support throughout this journey. In particular, we would like to extend our heartfelt thanks to James Mmbando and Ahadi Mollel. Their kindness, humour, translation services, and cultural guidance were invaluable assets, enabling us to have a fun and successful fieldwork. Additionally, we express our gratitude to Eliminata Awet for her excellent organisation of the interviews and to our kind drivers Jakobo and Isaiah for always getting us there, regardless of the driving conditions.

The support provided by Engineers Without Borders, Norway played a vital role in the realisation of this thesis. We are especially grateful to Rebecca Martinsen who guided us from the first week in the field to the day we delivered. We would also like to thank Francisco Chavez, our project manager from Engineers Without Boarders, who helped organise the field trip.

We would like to thank our supervisors, Sveinung Sægrov and Marius Møller Rokstad, for their mentorship and support throughout the research process. Their insights and feedback, as well as their compassion, were a necessity in shaping the quality and direction of this thesis. Special appreciation goes to Marina Fernandez-Delgado Juarez, who provided invaluable assistance with test kits and sample methods. Marina's expertise greatly enhanced the accuracy and reliability of our data.

We extend our gratitude to our sponsors, Norsk Vannforening, SINTEF, and IUG, for their financial support, which made this research possible. Their commitment to academic pursuits and their belief in the significance of this project is deeply appreciated.

Last but certainly not least, we want to express our thanks to our friends, fellow students, roommates, family, and partners for their unwavering love and support. Among them, we want to extend a special acknowledgement to Nora Cornelia Benningstad, whose advice has been invaluable in finishing our research.

This thesis would not have been possible without the efforts of all these individuals and organisations. Their contributions have enhanced our understanding of the field of water and environmental engineering. We are immensely grateful for their involvement and extend our heartfelt appreciation to everyone who has played a part in this journey.

Synne Høyås

Jehan Kanaganathan

Trondheim, 9th of June 2023

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List of abbreviations

AC	Alternating current
CBWSO	Comunity Based Water Supply Organisation
CDD	Comunity-Driven development
DC	Direct current
HDI	Human development index
EWB	Engineers without borders
JMP	Joint Monitoring Program
NCA	Norwegian Church Aid
RUWASA	Rural water supply and sanitation agency
RWSS	Rural water supply systems
SSA	Sub-Saharan Africa
QCA	Qualitative Comparative Analyses
4CCP	Four corner culture project

Chapter 1

Introduction

1.1 Water - A life-changing resource

Water is essential to all human life, and reliable access to a water source is a necessity in order to live a healthy and prosperous life. Therefore, in 2010, the UN defined access to water as a human right [UN, nd]. Countless studies have shown how access to water drastically improves other aspects of human life. In 2012, WHO found that for every dollar invested in improved drinking water, there is an average global return that is double that [Hulton, 2012]. The health benefits of having an improved water system are many, including reductions in cases of malnutrition and waterborne diseases. These benefits are experienced especially by poor children and disadvantaged communities [Hulton, 2012].

Although the importance of access to water is universally accepted and the efforts trying to ensure global and local water access are many, the challenges surrounding this are still numerous. In 2020, 1.2 billion people lacked basic water access [UN, 2022b], which is defined by having a water collection time of no more than 30 minutes and the source being located less than 1000 m away [WHO, 2022]. The problem of water access is particularly significant in Tanzania, which has one of the world's lowest proportions of the population with access to basic drinking water [JMP, 2020]. In 2020, only 60.73% of the population in Tanzania had basic access to water, with conditions in rural Tanzania being even worse, with only a 45.45% coverage [JMP, 2020].

Tanzania is ranked among the countries in the world that are least developed, with a human development index (HDI) of only 0.549 in 2021 [UN, 2022a]. This is despite significant improvements in the country's conditions over the last 30 years. Between 2000 and 2021, Tanzania's HDI has increased by over 40% from 0.390 to 0.549, indicating a positive development trend [UN, 2022a]. Tanzania also experienced substantial economic growth, with GNP per capita increasing by approximately 182 % in the same period [WB, nd]. Access to efficiently managed drinking water in adequate quantities is a prerequisite for achieving higher living conditions and for lowering poverty, with water being a foundation for socio-economic development [Tantoh and Simatele, 2016]. Water is also critical for other aspects such as sustainable development and environmental protection [Tantoh and Simatele, 2016].

To meet the challenges mentioned above, Tanzania is one of many sub-Saharan African countries that has adopted a community-driven development strategy for the development and management of rural water supply [Tantoh and Simatele, 2016]. The conventional top-down government-led strategies have often been ineffective in meeting the water demands of the users, which has given rise to arguments for communities to act as initiators and decision-makers, with the governments and NGOs acting as facilitators [Tantoh and Simatele, 2016].

1.2 Case description

In this thesis, we study a water distribution project funded by aid from NRKs telethon in Norway in 2014 and other private donors, built by the Norwegian Church Aid (NCA) from 2015 to 2021. The project constructed 36 solar-powered water wells in villages in the districts of Mbulu, Mkalama and Hanang in the area around Haydom town in rural Tanzania. The construction was successful, but reports from the local aid organisation Four Corners Cultural Program (4CCP) and earlier master's theses completed by students at NTNU, indicate the need for further investigation into the development of the water points and current social and technical concerns.

Figure 1.1: The location of Haydom in Tanzania [GISGeography, nd]

The NCA have since the beginning collaborated closely with 4CCP, and when NCA gave the water points to the villages after construction, 4CCP took over the responsibility of supporting, training and inspiring the CBWSOs [Personal communication, James Mmbando and Ahadi Mollel, 26th of February 2023].

4CCP is primarily an NGO that through community empowerment and cultural programs, works to enhance the lives of the people around Haydom in Mbulu, Makalama and Hanang district. In Haydom the four main ethnolinguistic groups of the African continent meet in one place with different life-styles, languages, economic activities and social-related factors [4CCP, nd]. 4CCP focuses on building understanding between the communities and celebrating the different cultures.

This deep-rooted understanding and respect for and from the communities in the area were one of the reasons NCA chose 4CCP as their local partner organisation when they wished to build water wells in the area. 4CCP was involved in ensuring local ownership and community participation before, during and after construction and also helped communicate the local's needs and wishes in terms of the location and organisation of the water wells [Personal communication, James Mmbando and Ahadi Mollel, 26th of February 2023]. Due to the ongoing local involvement of 4CCP in the study area today, they have high accountability and responsibility towards the communities. Having 4CCP as a local partner organisation is therefore essential to ensure local content in the project.

The collaboration between 4CCP, NCA and the villages in the study area has resulted in five previous master thesis projects at NTNU, exploring different aspects of the water situation in the region. In 2018, Martinsen [2018] studied the water situation in the area and evaluated the factors affecting the sustainability of the water supply. A pilot project for remote monitoring of the water systems was also launched in collaboration with NCA [Martinsen, 2018].

In 2019, Misund and Møller [2019] studied the conditions for groundwater abstraction in the area, water quantity and quality, failure frequency of the hand pumps in the area, the function of the CBWSO's and the willingness to pay for water [Misund and Møller, 2019]. Røer [2020] continued with water quality assessments and the implementation of remote monitoring, as well as evaluating the performance of solar-powered pumping systems and exploring the advantages of multiple-use water services and willingness to pay for this [Røer, 2020].

Asklund [2020] also assessed the water quality and the performance of solar-powered pumping systems. Research into the pumping systems' effect on the groundwater level as well as the management practices used was also conducted [Asklund, 2020]. Finally, Evang and Bakken [2021] continued the work of Misund and Møller [2019] with regard to CBWSO performance and the work of Asklund [2020] with regard to the groundwater level. Potential adsorption methods for fluoride removal in rural Tanzania were also investigated [Evang and Bakken, 2021]. These master theses, along with a literature review [Høyås and Kanaganathan, 2022] conducted as part of a project work at NTNU in the fall of 2022, form the basis for the research in this study.

In order to fully understand the scope of this master thesis and the reasoning behind the research questions, some important topics need to be clarified. This includes the general water situation in rural Tanzania as well as the socioeconomic characteristics, the definition of sustainability in terms of water systems and development, a description of solar-powered water pumping systems, the organisational structure of water distribution and development in rural Tanzania and an introduction to community-driven development.

1.2.1 The study area

Tanzania has several large freshwater reservoirs with the most famous being Lake Victoria, but due to a lack of infrastructure and dispersed settlement, this water is not accessible in all parts of the country. In rural areas, much of the water access comes from wells that tap into groundwater sources [Yekom, 2019]. The Hanang, Mbulu, and Mkalama districts are in the mid-northern region of Tanzania within the Internal Drainage water catchment. This catchment is among the driest in the country and has limited water resources available [Yekom, 2019]. The groundwater resources in this region are primarily composed of shallow aquifers with a recharge rate of less than 100mm/year. Shallow aquifers have a water table that typically starts from 2 to 3 meters below ground. Beneath these aquifers, there is impermeable bedrock or saline aquifers. This results in a limited potential for water withdrawal [Yekom, 2019].

There is significant variation in precipitation levels throughout the year in Tanzania, with a distinct dry season and rainy season. This fluctuation leads to a considerable difference in soil water content in the Internal Drainage catchment, with a mean of 15 % during the dry season and 62 % during the rainy season [Yekom, 2019]. This variation impacts the water requirements of agriculture and the recharge of groundwater. As a result, there is an increased demand for water during the dry season, but the groundwater table is lower, and the water is less accessible [SNV-Tanzania, 2010].

1.2.2 Socioeconomic characteristics

Tanzania has had substantial economic growth and a decline in poverty over the past decade due to its strategic location, rich resources, socio-political stability, and economic reforms [WB, 2019]. However, a third of the country's rural population lived below the nation's basic needs poverty line and Tanzania is still considered one of the lowest developed countries in the world according to the Human Development Index. Poverty has not declined at the same rate as the population has grown in the last decade, leading to an increase in the number of people in poverty. This is due to many working in slow-growing industries, such as farming. The decline in poverty is also low compared to the economic growth of Tanzania. A disproportionate amount of the poor live in rural areas. Poor households typically have many children and low access to education, which leads to reinforcing poverty for future generations. Inequality and vulnerability are sustained by low educational mobility and gender inequality [WB, 2019].

1.2.3 Sustainability

In the context of this master thesis, sustainability, and thereby sustainable water systems and sustainable development, refers to the ability to ensure universal and equitable access to safe water through improved water systems without compromising the ability of future generations to do the same [UN, 1987]. This definition combines the general definition of sustainability proposed by the UN [1987] in 1987 with the UN's [2022c] Sustainable Development Goal (SDG) 6, which was made to combat the water- and sanitation-related issues of today. SDG 6 also focuses on reducing water pollution, implementing integrated water resource management and strengthening the participation of local communities in the development and management of improved water systems [UN, 2022c]. These objectives are at the centre of the case study conducted during this master thesis project.

1.2.4 Solar-powered groundwater well

The water supply systems in this project are based on solar-powered groundwater wells constructed by NCA. Their main features are illustrated in Figure 1.2 and are solar panels, a borehole that extends below the water table, a submersed pump and water tanks. The use of solar power limits the well's operation to the day, but it also reduces operating costs and logistics compared to diesel-driven pumps because no extra fuel is required [WB, 2018].

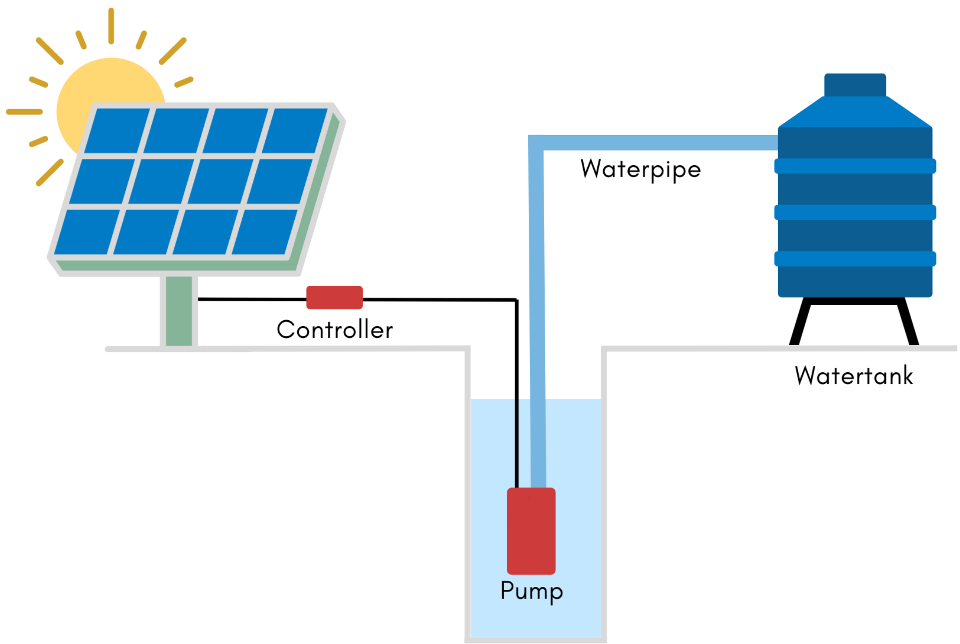


Figure 1.2: Solar powered groundwater system

Groundwater is a suitable water supply source for rural areas in Tanzania. Groundwater responds slowly to changes in precipitation and therefore works as a buffer from the impact of droughts. This makes groundwater available in the dry season when surface water is not easily accessible [MacDonald and Davies, 2000]. Groundwater is also a suitable source for water supply because it is naturally protected from microbiological contamination and pollution [Ødegaard, 2014]. Solar-powered groundwater wells are also extra suitable for these areas because the solar radiation is high, especially during periods when other water sources can be hard to find [Sweyaa et al., 2021].

1.2.5 Organisational structure of water distribution development and management in rural Tanzania

The following section is based on the information stated by The Rural Water Supply and Sanitation Agency (RUWASA), which was established in 2019 through the Water Supply and Sanitation Act No.5 [RUWASA, nd]. RUWASA is responsible for various functions related to rural water supply and sanitation services. These include planning, designing, constructing, and supervising rural water supply projects, conducting groundwater surveys, promoting and sensitising rural communities on sanitation and hygiene education and practices, providing technical and financial support to community organisations for maintenance of rural water systems, facilitating the engagement of the private sector in the provision of rural water supply and sanitation services, and regulating and registering the performance of community organisations [RUWASA, nd].

The highest level in the RUWASA organisation is directly below the Tanzanian Minister of Water. The organisation's lower levels are decentralised with a regional office in each region that supports the district office in each district in that region.[RUWASA, nd]

The RUWASA Regional Offices will have the responsibility of supervising the execution of water projects and ensuring the availability of water and sanitation facilities. Additionally, the Manager will offer technical support to the districts in the region [RUWASA, nd].

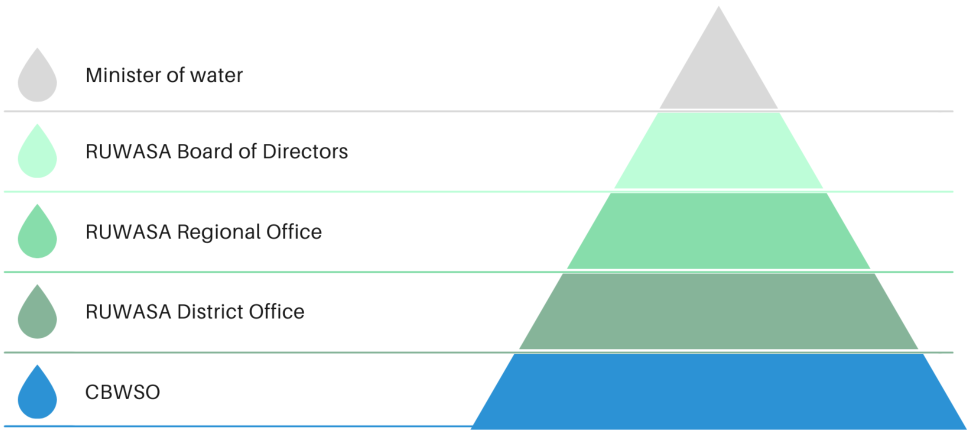


Figure 1.3: Illustration of the organisation of rural water supply management in Tanzania

The District Offices of RUWASA will primarily focus on implementing water and sanitation projects in the villages within the district. It is also responsible for enhancing the capacity of the Community-Based Water Supply organisations (CBWSOs) to ensure that their service delivery is sustainable [RUWASA, nd].

The CBWSO is a fully independent entity that is democratically chosen by the community members. The CBWSOs have the responsibility of managing, operating, and maintaining water projects [RUWASA, nd]. This includes ensuring they have the financial capacity to conduct repairs and expansions. They are expected to collect the necessary found through revenues from selling the water. They can ask the district engineer to help with funding for big repairs, but that can take several years to get, depending on the District office's economy. The district office will prioritise repairs of water points that are well managed by the CBWSO [Personal communication, Representatives from the District Engineer office, 21st February 2023]. CBWSOs serve as the primary source of sustainable water and sanitation services in rural regions [RUWASA, nd].

In this thesis, the focus is primarily on the CBWSOs and their ability to develop and sustain a water point, but the RUWASA district office as an important supporter of the CBWSO is also part of the scope.

1.2.6 Community-driven development in rural Tanzania

Community-driven development (CDD) is part of a people-centric development strategy that is especially successful at creating a development that benefits the poor [Wong and Guggenheim, 2018]. CDD is an approach that focuses on giving communities control over resources and planning strategies. This has over the past decade been implemented across a broad spectrum of sectors and become a key strategy for governments as well as aid agencies. [Wong and Guggenheim, 2018]. It is argued that the involvement of local communities in decision-making most often results in a greater sense of community commitment and participation, and that this participation makes it more likely that the projects deliver services that are needed by the community.[Tantoh and Simatele, 2016] In this case study CBWSOs are seen as organisations designed to carry out community-driven development.

1.3 The project

The work conducted in this master thesis project consists of several stages, including project work at NTNU [Høyås and Kanaganathan, 2022] and planning of the fieldwork in the fall of 2022, fieldwork in the area around Haydom, Tanzania in February of 2023 and the analysis of the gathered data in the spring/summer of 2023.

1.3.1 Problem description

The focus of this thesis was found through the exploration of the literature on potential challenges and opportunities, suggestions from previous master theses and conversations with 4CCP. Although suggestions for future work mentioned in the previous master theses gave invaluable insight into the ongoing challenges in the study area, conversations with 4CCP ultimately conveyed the immediate wants and needs of the communities in the region. During these conversations, a list of prioritised tasks with regard to the solar-powered water systems, the CBWSO's and the water system users were presented by 4CCP. The tasks included are listed below in 4CCPs prioritised order:

- Look into the possibility and design of connecting the water system in Dang'aida village to nearby sub-villages.
- Conduct water quality measurements with a focus on fluoride and bacterial contamination.
- Collect data on community water needs.
- Collect data on the performance of the water systems and CBWSOs.
- Look into possibilities of increasing the water quantity from solar-powered water systems.
- Look into a suitable remote monitoring solution for the water systems.

The goal of this master thesis, based on these tasks, the aforementioned theory relating to the study area and the research opportunities found through previous master theses, is to conduct a case study exploring community-driven development in rural Tanzanian settings. Firstly, the tasks of collecting data on community needs and CBWSO performance is addressed by conducting interviews and subsequent analysis of the interview data with regards to community-driven development. Secondly, a design of the water system expansion in the village of Dang'aida to the sub-villages nearby is suggested within the confines of community-driven development. Thirdly, an assessment of the water quality in the study area and its effect on future developments is also conducted, as it is one of the most important aspects of a water supply system. Finally, two remote monitoring systems are installed, and their potential is explored in order to further investigate potential opportunities for remote monitoring in the management of RWSS. The task of possibly increasing the water quantity from the solar-powered pumps was deemed too demanding in terms of time and funding and is not assessed in this study.

1.3.2 Research questions

Based on the objectives mentioned above, this thesis will try to answer the main research question:

Which conditions contribute to community-driven water system development in rural Tanzania and how can such a development be facilitated?

with the help of these sub-questions:

- *How can an expansion of the water system in the village of Dang'aida be designed, and how can this design be used in the future development of water systems in rural Tanzania?*
- *What do the water quality tests tell us about the water situation in the project area, and how can this knowledge contribute to ensuring a sustainable water supply in the future?*
- *How can remote monitoring data from solar-powered water boreholes be used to improve the management of these systems, and what are the challenges associated with implementing such monitoring mechanisms in rural Tanzania?*

1.3.3 Project structure

This master thesis is structured based on the research questions presented above. After the initial introduction (chapter 1), case description and research questions, the theory and methodology are presented. The theory and methodology chapter (2) start by presenting the theoretical framework needed to answer the main research question, as well as the methodology used to analyse the collected interview data. This is followed by the theory and methodology relevant to each of the sub-questions, which includes, the development of local infrastructure, water quality measurements and remote monitoring, in that order.

In the next chapter (3), the results are presented and discussed. The results that concern the main research questions, which consist of the analysis of the interview data, are presented first. It is followed by the results from the design of the water system expansion in Dang'aida, the water quality measurement results and the results from the remote monitoring of the water systems. Included in all parts are short discussions of the results.

In chapter 4, a final discussion, connecting all parts to community-driven development and the main research question, are presented. The master thesis is completed with a conclusion, followed by a section on future work, which highlights areas of interest that was not covered in this study.

Chapter 2

Theory and Methodology

This chapter outlines the methodology and theory applied during the planning and execution of our data collection during the performed fieldwork and later the analysis of this data. Firstly, some background information about CDD and Solar powered water wells will be presented. Then the method used for data gathering and the subsequent fuzzy set Qualitative Comparative Analysis (QCA) using said data will be described. Thereafter, the design choices and methods used to design an extension in the village Dang'Aida, connecting two sub-villages to the water well will be outlined before the assessment of the water quality and the theory behind the water test will be presented. Finally, the design and installation of the remote sensing system will be reviewed.

Overall, this chapter provides a comprehensive account of the methods and theories employed in our research and highlights the importance of using multiple methodologies to gather and analyse data on complex issues such as water access and quality in rural communities.

2.1 Community driven development

CDD has proven to be an effective tactic that when compared to traditional tactics, use less funds and less time in order to build basic development infrastructure [Wong and Guggenheim, 2018]. CDD has also been found to be popular in the communities since it centres around giving them agency in the decision-making that affects their life [Wong and Guggenheim, 2018], and has been recognised as one of the development approaches that are most successful in preserving, modifying, and enhancing the traditional resource management system [Tantoh and Simatele, 2016]. This is based on communities being more equipped to handle and address any issues and challenges in terms of development, if helped in their efforts [Tantoh and Simatele, 2016, p. 180].

Wong and Guggenheim [2018] argued that communities are the best judges of how to enhance their lives and livelihoods because they have the most knowledge about local conditions. Additionally, communities will have the greatest incentives to use funds appropriately as well as the best position to monitor their use.

Whether or not the community level as the institution with primary responsibility for development and management has the required level of capacity and resources, the literature on the subject disagrees. [Wong and Guggenheim, 2018, Lockwood et al., 2003] The cooperation among stakeholders seems to be essential and according to Bowen [2005, p. 86], the extent to which stakeholders are able and willing to address issues, take part in economic activities and manage and maintain social relationships, determines the sustainability of development programmes [Bowen, 2005, p. 86].

2.2 Fieldwork

The fieldwork was conducted in and around Haydom, Tanzania from the 5th of February 2023 to the 3th of Mars 2023. The planning started in cooperation with the local partner 4CCP in September 2022 and lasted up to and during the field trip. During the fieldwork, the primary objectives were to:

- Conduct water quality measurements at locations significant to the study (see water quality parameters in section 2.7).
- Conduct interviews with CBWSOs, users, and students.
- Observe and assess the state of the solar-powered water boreholes.
- Install remote monitoring systems at two villages.
- Conduct interviews to gather background information from 4CCP and district engineers.
- Gather the information necessary to design the expansion of the water system in the village of Dang'aida.

As a result, 17 villages were visited and their water systems were assessed, 93 interviews were conducted divided between CBWSOs, users and students, 28 water points were sampled and tested in terms of water quality, and two remote monitoring systems were installed in the villages Basonyagwe and Endagaw Chini. Two interviews with district engineers and one interview with 4CCP staff were also conducted and multiple visits to the village of Dang'aida resulted in the gathering of the necessary information.

The field trip was funded by Engineers Without Borders (EWB) Norway via their Master with Meaning-program, and with scholarships from Norsk vannforening and SINTEF. EWB Norway also provided us with security briefing and training before departure and a mentor, Rebecca Martinsen, that accompanied us during the first week of the field trip and that supervised our work up to the completion of this master's thesis. 4CCP contributed with transportation and a driver, organisation of interviews and two team members, James Mmbando and Ahadi Mollel, who acted as local guides, interviewers and translators.

During the fieldwork, we lived in the guest house in Haydom Lutheran Hospital and travelled by car to nearby villages each day. When arriving at the villages we typically went to the village office, greeted the village officials and signed the guest book before we went to the water point. At the water point, we took water samples and took videos and pictures to capture our observations about the state of the water well and the area around it. Thereafter we conducted interviews with the CBWSOs with Mmbodo as a translator while Mollel interviewed the users or the other way around. Sometimes, when relevant, we also went to the schools in the area and conducted interviews with the students. When we got home we conducted the water quality tests and categorised the data collected that day. Throughout our field trip, we adhered to a strict schedule to ensure that we visited all the planned water sources within the designated time frame.

2.3 Literature review

To answer the research question, a comprehensive understanding of the relevant methods, the case area and the past, current and future water situation in Tanzania is needed. Thus, a theoretical literature review was conducted in this study. The review examined publications to identify theories and findings that provide relevant knowledge and to evaluate whether they relate to one another. This was continuously done to discover relevant knowledge in every phase of the work, from the project work at NTNU [Høyås and Kanaganathan, 2022], to the planning of the fieldwork and to the discussion of the results.

Relevant publications were primarily identified using a combination of keywords such as "community-driven development", "rural drinking water quality", "remote monitoring", "solar-powered water systems", and "QCA water systems" in Google Scholar and Scopus. Recommendations from supervisors and others who had previously worked on related projects led to finding additional publications and reports on useful topics.

Additionally, new theories and relevant information were found using the references of a relevant publication. This enhanced the likelihood of the sources being connected through the relevant topics. Academic books, technical reports and web pages were also used to gather information. Most of the relevant theory was gathered from WHO, World Bank, UN and area-specific literature. The master theses of Martinsen [2018], Misund and Møller [2019], Røer [2020], Asklund [2020] and Evang and Bakken [2021] were used to find both case-specific knowledge and new relevant literature.

The publications used were selected based on multiple assessments. Firstly, the title, publication year, publisher and number of citations were assessed. Furthermore, the articles were considered based on whether they were peer-reviewed. The previous master theses used were not peer-reviewed and were therefore interpreted them with caution. Finally, the relevance of articles was assessed by reading the abstract and the conclusion, before information was gathered.

2.4 Solar-powered groundwater well

The most common type of solar pump used for rural water supply systems (RWSS) is an alternate current (AC) pump driven by solar panels. The solar panels produce direct current (DC) electricity, which is then fed through an inverter [Aliyua et al., 2018]. The solar-powered pumping systems in this study use this technology and are built using a motor, solar cells, an AC/DC inverter, and a pump from Dayliff. The submersible pumps used are Dayliff DS, DSP, and DSD multistage centrifugal pumps. These pumps were chosen because they are reasonably priced and have a floating-type impeller that gives strong sand handling characteristics [Røer, 2020, p .14].

The pump uses multi-staged spinning impellers to add energy to the water and must be fully submerged to work. The motor is sealed and connected to the pump body [Davis and Shirtliff, nd]. The motors used in the pumps are liquid-cooled and are 2-pole asynchronous squirrel-cage motors made of stainless steel [Røer, 2020, p. 14]. The DSD, DSP, and DS pumps' maximum immersion depths in the research area are 150 metres, 200 metres, and 250 metres, respectively. The pumps' motor speeds are 2900 rpm for the DSP and DS and 2850 rpm for the DSD. To avoid contamination, a sealed wellhead plate is put in place on top of the borehole [Davis and Shirtliff, nd]. The pumps are listed to run on a frequency of 50Hz. The exact power consumption is calculated by reading the power per stage according to

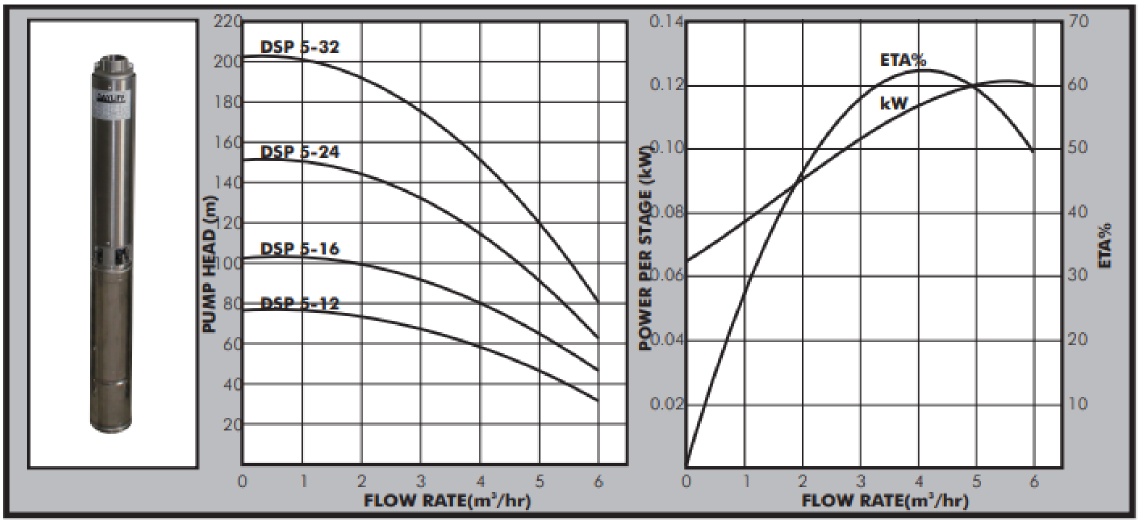


Figure 2.1: The pumping curves of different models of pumps to the left and the kW-curve per stage to the right. [Dayliff, nd]

the discharge of the provided kW-curve given by the manufacturer (Figure 2.9) [Paul Uwe Thomsen, Personal communication, 15. May 2023]. The stage is the number of impellers and is given in the name of the pump. For example, a DSP 5-16 pump would have 16 stages. The power per stage is the same across the different versions of the same pump shown in Figure 2.9 [Paul Uwe Thomsen, Personal communication, 15th May 2023]. The pump curve is another important characteristic of a pump. It shows the pumping head in relation to discharge and is important when calculating the operating point to find the system's pump rate [Ødegaard, 2014].

Pump test

A pump test is used to determine well performance and hydraulic parameters by measuring discharge and drawdown [Brattli, 2018, p.75]. A cone of depression forms around the borehole during pumping as the groundwater stored in the aquifer flows to the borehole as illustrated in Figure 2.2. The cone of depression will gradually get bigger while pumping, until equilibrium is found [Brattli, 2018, p.76]. The step test method is one type of pump test and is based on the well being pumped with a series of successively increasing pumping rates while the drawdown is measured [Gjengedal et al., 2023]. Each rate is kept constant for each stage, and it is normal to have at least three stages which are spread over the pump's lower and upper capacity range. The duration of each stage is typically 30-120 minutes but can be reduced if the well achieves a stable water level [Gjengedal et al., 2023].

2.4.1 Performance of solar-powered groundwater well

The World Bank [2018] lists several variables that affect the performance of a solar-powered water well. The key parameters are the seasonal change in solar radiation, the contingency in radiation, and the seasonal change in the pumping head. Additionally, seasonal variations in user habits and water demand are significant in the case area, with demand for economic activities like livestock and irrigation as a driving force for this variation [Yekom, 2019].

Irradiation has a significant impact on water output [WB, 2018]. Therefore, the radiation change is important. While the daily variation is large, with a peak radiance at noon, the seasonal variation

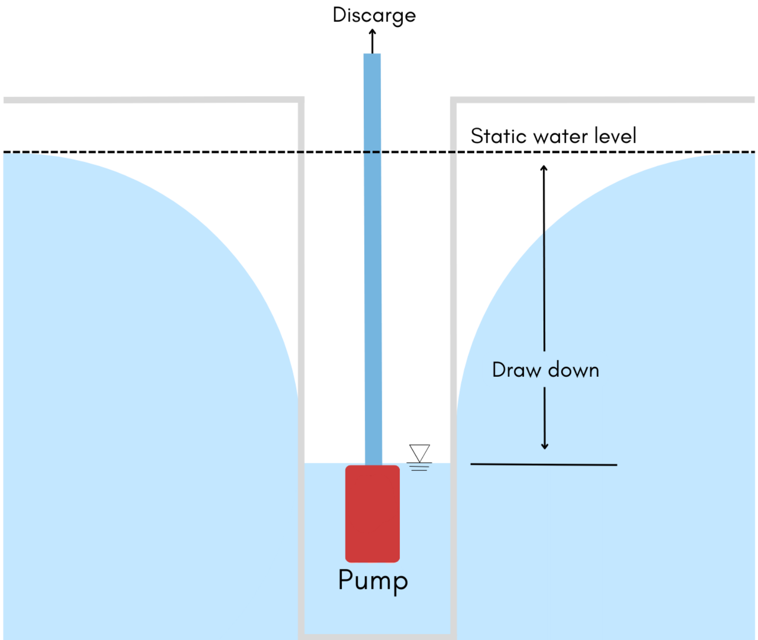


Figure 2.2: Depression cone during pumping.

in radiation is small close to the equator. This implies that the pumping system's water output will fluctuate throughout the day, reaching a peak at noon. Furthermore, dirt on the solar panels can drastically reduce their efficiency and cleaning the panels should be done regularly [WB, 2018].

Temperature is another factor that influences the efficiency of the solar panels, and consequently the performance of the system [WB, 2018]. The solar panels are less efficient the higher the temperature. Therefore it is beneficial to counteract this, for example by installing solar panels in a windy place [WB, 2018].

The consistency of the radiation is also important. Therefore, the amount and consistency of cloud coverage are important[WB, 2018]. Variable power is particularly damaging to the performance of AC pumps under stop-start solar conditions. This is because they require a minimum power condition to start and take a long time to reach the required rotations per minute once threshold levels are reached. So while two days might have the same amount of cumulative radiation, no sun in the morning, followed by a clear afternoon is likely to yield a far higher water output than at an on-and-off cloudy day [WB, 2018].

The pumping head directly relates to the water output. As a result, the performance of the water well will be impacted by seasonal changes in water level. The total head consists of several factors, as shown in Figure 2.3, but the head due to lifting height is often dominant. Total head is the total amount of energy required to lift the water column under the given terms and is often given in meter water column (m wc) or just meter. In addition to the energy needed to lift the water, there is energy loss due to friction and minor losses due to changes in the pipes, such as valves or bends.

2.4.2 Calculating the systems operating point

In this thesis, the operating point in Basonyagwe will be calculated to compare the pump power measurements collected by the remote monitoring system with the theoretical pump power needed and thus assess the performance of the pump. The following section will describe the calculations as well

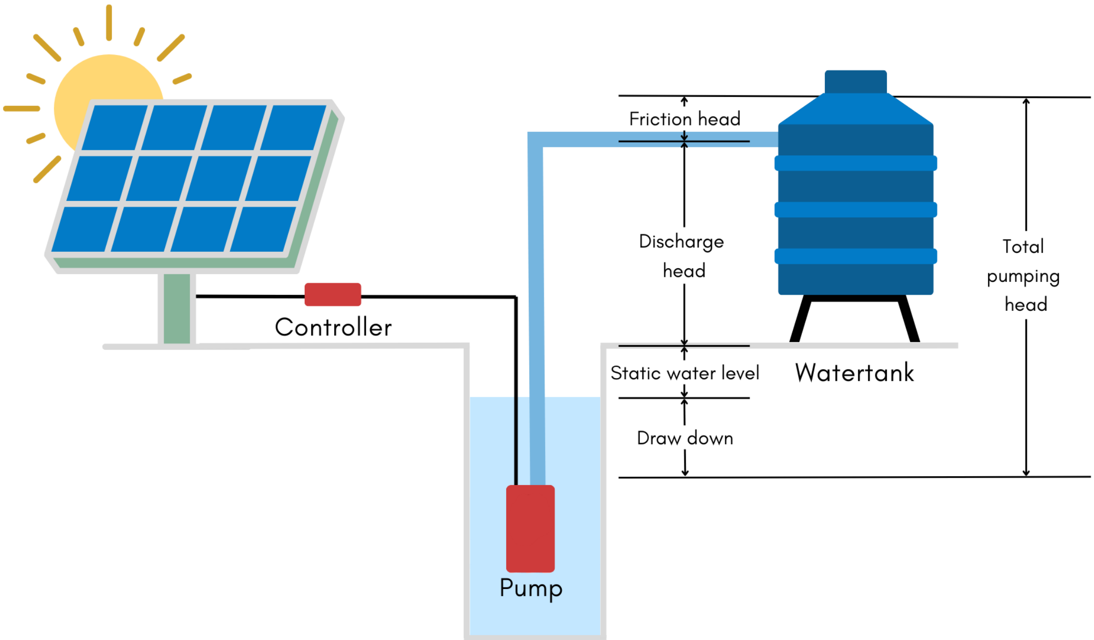


Figure 2.3: The different factors of total pumping head.

as describe important aspects that affect the pump rate in a groundwater well. The operating point is the intersection of the pump curve and the system curve and describes the pump rate of the system. The manufacturer gives the pump curve, and the system curve is calculated.

The system curve represents the relationship between the total head (or total energy) required by the system and the flow rate through the system. The total energy required by the system consists of drawdown, static water level, friction head and minor losses.

The static water level is measured as the water table when it is not affected by stress from for example pumping [Brattli, 2018, p.75-77]. The drawdown is, in an open aquifer, a lowering of the groundwater over a period of time, [Brattli, 2018, p.93-103] and can be measured during a pump test. The energy loss consists of friction loss (h_f) and minor losses (h_s). The friction loss is calculated using the Darcy-Weisbach equation (2.1) [Ødegaard, 2014, p. 67].

$$h_f = f * \frac{L}{D} * \frac{v^2}{2g} \tag{2.1}$$

where:
h_f = friction loss in pipe (m)
f = friction coefficient, 0.1 in PE-pipes
L = length of pipe (m)
D = internal diameter of pipe (m)
g = gravitation, 9.81 (m/s^2)
v^2 = velocity in pipe (m/s)

The friction factor is calculated as shown in Equation 2.2. The Reynolds number is calculated according to Equation 2.3.

$$f = \frac{0.25}{(\log(\frac{k}{3.7*D} + \frac{5.74}{R_e}))^2} \tag{2.2}$$

where:
R_e = Reynolds number
k = roughness, 0.1 in PE-pipes [Ødegaard, 2014, p. 67]
D = diameter of pipe (mm)

$$R_e = \frac{vD}{\nu} \tag{2.3}$$

where:
v = velocity (m/s)
ν = kinematic viscosity of water, 9.121*10 $^{-7}$
D = diameter of pipe (mm)

The minor loss is calculated using Equation 2.4. The values are listed in Table 3.13

$$h_s = k_s * \frac{v^2}{2g} \tag{2.4}$$

where:
h_s = minor losses in pipe (m)
k_s = singular coefficient
g = gravitation, 9.81 (m/s^2)
v^2 = velocity in pipe (m/s)

The velocity is calculated using Darcy's law. It states that flow equals velocity times area ($Q = VA$) [Ødegaard, 2014, p. 68]. The velocity head is calculated for each flow using Equation 2.5 that is derived from Darcy's law assuming circular pipe.

$$v = \frac{Q}{\frac{\pi D^2}{4}} \tag{2.5}$$

As mentioned above, to find the operating point the characteristic system curve is plotted with the pump curve and the operation point is where the two curves intersect. The flow of the operating point can be used to find the required pump power by using the pumps' characteristic kW-curve as illustrated in Figure 2.4. In that example, if the pump has an operation point with an output of 2 m^3/h, that implies that the pump would require approximately 1.38 kW to run with sufficient power.

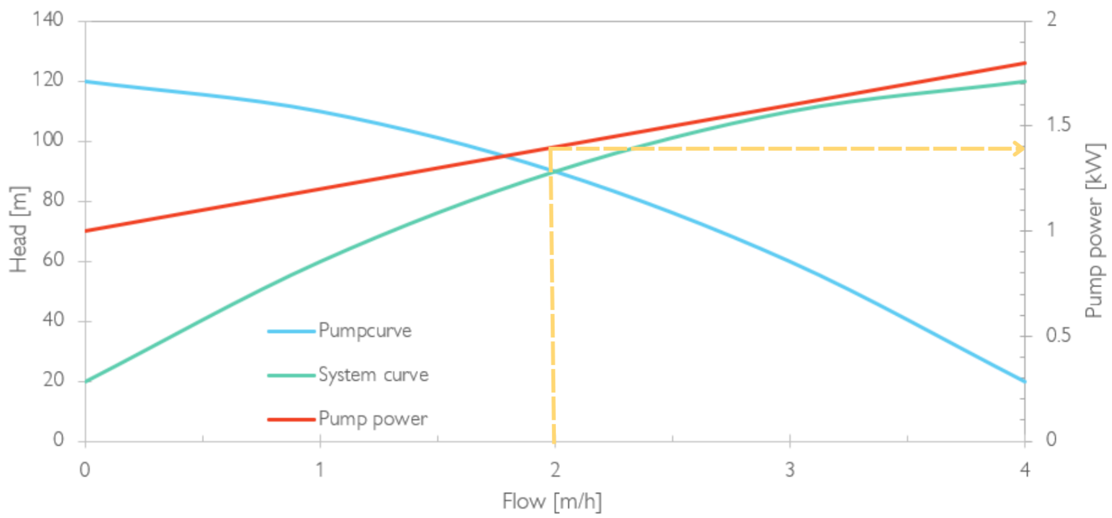


Figure 2.4: How to find the needed pump power for an operation point.

2.5 Questionnaire

The data gathering was decided to do through the use of questionnaires and observation. Questionnaires are a helpful tool when conducting multiple interviews and gathering data on how similar systems are different in terms of use and organisation [Tjora, 2021].

2.5.1 Development of the questionnaires

Developing a comprehensive and effective questionnaire requires a structured and collaborative approach, including incorporating feedback from various sources [Tjora, 2021, p.127-190]. In this project, a methodical and iterative process was followed that involved working closely with key stakeholders to create a questionnaire that met the research objectives, was understandable across language barriers and covered all necessary aspects. The first step was to determine the purpose and scope of the questionnaire, based on the research objectives. Three questionnaires were made, one for the users (Appendix C), one for the CBWSOs (Appendix B) and at a later stage, one for the students (Appendix D). These groups were chosen because of their different perspectives on the management and operation of the water well and because they have regular interaction with the water point.

The development of the questionnaires started during the project work assignment conducted in the fall of 2022 at NTNU [Høyås and Kanaganathan, 2022]. These questionnaires aimed to collect data on the sustainability and resilience of the water systems that were built as a part of the NCAs telethon campaign in 2014.

The questionnaires were then sent to Manfred Arlt over email for feedback in September 2022. Arlt works with the NCA and has followed this project since the construction of the wells. He has also worked on several similar projects. Arlt reviewed the questionnaire and provided extensive feedback on the questions' relevance, clarity, and structure. He recommended that the questions should be based on sustainability indicators [Personal communication, Manfred Arlt, 29th September 2022]. The indicators chosen are described in 2.5.3. Arlt also recommended a platform that is widely used in similar surveys called Kobo Toolbox. Kobo Toolbox is an open-access platform that makes you create questions and gather them in cooperation with other users. The surveys can be filled out on any device and do not need a continuous internet connection. This was perfect for our use and made us flexible in the field [KoboToolbox, nd].

After making the questionnaires in Kobo Toolbox, they were shared with James Mmbando and Ahadi Mollel from 4CCP, who then gave their feedback. They have conducted similar research in the past and know the project and the villagers. Their feedback was more case-specific and they provided suggestions for other relevant questions and aspects, as well as insights into phrasing that they meant would make the questions clearer for the subject. The goal was to test the questionnaires before the fieldwork, but due to lack of time, it was not possible. During the first days in the field, with the help and suggestions from Mmbando and Mollel, the questionnaires were edited. For example, a health question was added and the phrasing of some questions was changed.

There was a need for more background information about the system in which the CBWSOs operated and what kind of government support they had. Therefore interviews with 4CCP and representatives from the district engineer office were conducted. This interview was conducted toward the end of the fieldwork and was based on questions that had been raised during the work after talking to the CBWSOs and to clarify some of the observations. James Mmbando and Ahadi Mollel as representatives from 4CCP and one representative from each of the Mkalama and Hanang district offices were interviewed. The information gathered is not used as data but is a part of the study's understanding of the system in which the CBWSOs operate, of the District Engineer and 4CCP as stakeholders and follow-up support institutions.

2.5.2 Conducting the interviews

Data collection

The data collection was done by interviewing users, CBWSOs and students. It was decided to conduct the interviews with the CBWSOs and the students in a group since they represented the institution they were a part of, and not themselves. Collecting data from multiple individuals simultaneously can be advantageous and effective. The interaction between the participants can inspire each other and provide an opportunity to uncover additional perspectives [Tjora, 2021, p. 138]. The user interviews were done individually because they represented only themselves and because some of the questions could be seen as embarrassing or personal. The data gathered is often of higher quality if the interviewee is comfortable and in a familiar setting [Tjora, 2021, p.135-137]. The interviews of the CBWSOs and the users were conducted near the water point, often in some shade nearby. The students were interviewed at their school.

The methodology for gathering interview data was decided together with Mmbando and Mollel. They contacted the communities in advance and arranged meetings at the village water well or the village office. Once there, work was divided between interviewing CBWSO members collectively and community members individually. It was intended that questions would be asked in English and that 4CCP staff would translate the questions and answers from English to Swahili and from Swahili to English, respectively. It became apparent after the first interview session that the previously chosen procedure would be time-consuming and that revisions needed to be made. CBWSO members would be questioned by us in a group with a 4CCP translator present, and the remaining community interviews would be conducted solely by 4CCP staff. 61 community members from 14 villages were interviewed, as well as 16 groups of CBWSO members from 16 villages. The discrepancy between the number of villages with CBWSO interviews and community interviews is the result of difficulties with fieldwork planning. In the two instances, community members did not show up for the interviews because of the timing interfering with daily duties.

A total of 15 schools were visited and group interviews were conducted with students at each location. The interview was mostly conducted using translators, but in some of the secondary schools, students were able to answer the questions in English.

Figure 2.5: Group interview of a CBWSO.

Figure 2.5: Group interview of students at a primary school.

District engineer

During the fieldwork, only two interviews with the district managers in Mkalama and Hanang were conducted because of limited time and scheduling issues. The interviews were conducted at the district RUWASA office with 4CCP staff present as translators. According to Tjora [2010, p. 137] the location of the interview can have a large impact on the openness and comfort of the subject. This location was therefore not only chosen due to practical considerations but it was also assumed that the subject would feel more relaxed in an interview situation at their own place of work. It was also useful because they could fetch relevant information or maps from their files when needed. The translator would translate questions and answers when needed. During the interview, follow-up questions were used in order to gain more information when relevant. The follow-up questions were not pre-planned but registered as they were asked.

4CCP

This interview was conducted as a conversation with some talking points and open questions that were prepared beforehand, and notes were taken during the conversation. The interview was held in their headquarters.

2.5.3 Indicators

To decide which indicators to base our questions on, we reviewed literature and studies on the assessment of the sustainability of water supply systems in rural areas. This allowed us to identify indicators that were frequently used in relevant literature and definitions of sustainability. The questionnaire includes questions related to nine sustainability indicators, which are defined in the following subsections along with the specific criteria used for each. These indicators are used to assess the village's performance in the following analysis of the interview data. The indicators used in this study were found during the project work conducted at NTNU the fall of 2022 [Høyås and Kanaganathan, 2022].

Access to Water

Access to water is an indicator that measures the distance travelled and collection time used in order to get adequate water for personal and domestic use (UN, 2022). It is an important indicator as access to an improved water source has many benefits such as improved health, education, productivity and leisure time [Sweyaa et al., 2017]. The indicator can be measured using WHOs [2022] definition for basic level access to water, which is having a water source closer than 1000 m from the household with the collection time for a round-trip not being more than 30 minutes.

System function

The system function is an important indicator of the reliability of the system. It is suggested by Schweitzer and Michelic [2012, p. 26] that system function can be assessed by measuring how many hours per week the system has water. An assessment of the downtime length and frequency is also needed, as several brief instances without water might have a smaller impact than one long one [Schweitzer and Mihelcic, 2012, p. 26]. Many factors can contribute to the downtime of a solar-powered water system in rural Tanzania, including repairs, seasonal changes and cloud cover [WB, 2018].

Repair service

Repair service is measured by the time the water system is down, due to repairs [Schweitzer and Mihelcic, 2012, p. 25]. Although similar to system function, this indicator focuses on the time it takes for repairs to get done and how often they happen. Service interruptions exceeding 24 hours can be seen as crisis maintenance, which indicates shortcomings in repair service on the administrative or technical level [Schweitzer and Mihelcic, 2012, p. 26]. Inadequate repair service has been emphasised by several previous reports on this project [Martinsen, 2018, Misund and Møller, 2019, Asklund, 2020], making it an important indicator to include in this study.

Activity level

Activity level is an indicator that is measured by the number of people with an active role in the management of the water system [Schweitzer and Mihelcic, 2012, p. 23]. This is an important indicator as few active members tend to leave the system vulnerable in case of absence. Active members include all individuals with an active day-to-day role in the management of the water system, for example, water sellers and security [Schweitzer and Mihelcic, 2012, p. 23].

Financial durability

Financial durability reflects the community's ability to through selling water, generate enough to cover the cost of everyday activities such as operation and maintenance, and by doing so, ensure access to water [Schweitzer and Mihelcic, 2012, p. 25]. Sufficient income generation should also be able to prepare savings for major repairs and future development of the water infrastructure. Relying on outside funding or community contributions lowers the sustainability of the water system [Schweitzer and Mihelcic, 2012, p. 25].

User acceptability

User acceptability is a measure of the satisfaction the users have with the water service and is composed of their satisfaction towards four aspects: water quality, water quantity, service reliability and willingness to pay for the water [Domínguez et al., 2019, p. 5]. High user acceptability is important in community-driven development as it is more likely that the customers, which in this case are the community members, are willing to contribute with either funds or labour [Bowen, 2005].

Accountability and transparency

Accountability and transparency is a measurement linked to the governance and management of the water service [Andres et al., 2018, p. 2]. It is an important attribute that enables stakeholders to evaluate and, when necessary, contest incorrect claims. Accountability and transparency are essential to ensure that policy and decision-making are informed and investments are made in the right places [Andres et al., 2018, p. 2]. Four characteristics presented by Dominiguez et at. [2019, p. 6] have been modified for the project set to describe this condition: the existence of democratic procedures for choosing the water committee's members. How frequently the water committee meets with users, whether there are systems in place to inform users about committee finances and the distribution of funds, and how the users perceive how the CBWSOs operate and how funds are used [Domínguez et al., 2019, p. 6].

Administration, operation and maintenance

This indicator is used to measure the CBWSOs organisational capacity and focuses on the management and function of the water committee [Domínguez et al., 2019, p. 7]. Initially, interview questions were created and answers were gathered based on this indicator. It was however later realised that the interview data to a large degree reflected the same information as the one gathered from the accountability and transparency indicator. It was therefore decided to merge the data and remove Administration, operation and maintenance from the subsequent interview analysis.

Participation

Participation is measured by the involvement of the community in decision-making processes and the presence of community members at village meetings regarding the water systems [Schweitzer and Mihelcic, 2012, p. 24]. Higher participation tends to enhance the sustainability of the water systems, while prolonged lack of participation usually compromises the water system performance [Schweitzer and Mihelcic, 2012, p. 24]. It is therefore an important indicator to include in the analysis of the interview data as well as in further discussions about community-driven development.

Storage and supply reliability

Quitanaa et al [2020, p. 5] emphasised the importance of storage and supply reliability for the resilience of a water system. A resilient system reduces the risk of losing service and income over a long period. This can lead to more money and capacity towards developing the system. Storage capacity is important for supply reliability as it enables the availability of water during times of increased demand and decreased water supply disruptions [Quitanaa et al., 2020].

2.5.4 Analysing the interview data

To adequately analyse the data collected through fieldwork, a method grounded in social science must be applied. When selecting a method, several factors must be considered to extract the maximum amount of information from the data. The interview data collected in this study consists of both individual interviews with users as well as group interviews with CBWSO members and students. Although this leaves us with a rich and detailed dataset, the number of cases (villages) and interviews within each case is still considered relatively small. In quantitative research, it is common to work with a large number of cases (usually above 50) when conducting comparative analysis [Berg-Schlosser et al., 2009, p. 4]. In contrast, studies with 10-20 cases, such as this one, necessitate a method that combines features from quantitative statistically-based methods that can give numerical answers to the research questions and case-focused qualitative methods that allow for exploration of concepts and user experiences. Qualitative Comparative Analysis (QCA) is a method that meets these criteria [Berg-Schlosser et al., 2009, p. 6] and is, as a result, used in this study in order to systematically compare the different cases and explore the causality behind community-driven development.

Qualitative comparative analysis (QCA)

QCA is a case-based comparative method of analysing qualitative data [Chatterley et al., 2014]. It combines the detailed knowledge about individual cases that is gained through qualitative research with the general information that is gained through the use of statistical methods on large-scale data [Chatterley et al., 2014]. QCA focuses on determining the causal effects between different variables and a predefined outcome, meaning it is used to compare cases and find different pathways that lead to an outcome based on the combination of different variables, or conditions [Berg-Schlosser et al., 2009, p. 6]. One of the most important assumptions of QCA is therefore that different combinations of conditions, i.e., pathways, can lead to the same outcome. This assumption, which is also known as equifinality [Berg-Schlosser et al., 2009, p. 8], is crucial when assessing the causality behind why development does happen in some villages, and not in others.

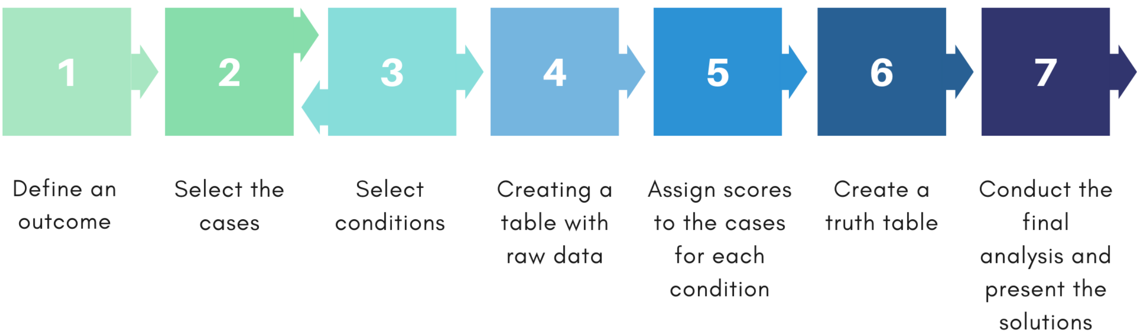


Figure 2.6: Step by step process of QCA. Adaptation of the framework presented by Jordan et al. [2011, p. 1162]

The process of conducting a QCA consists of several stages. The conceptual framework suggested by Jordan et al. [2011] starts with (1) defining an outcome. The outcome for which the analysis is conducted is an integral part of QCA, and must be clearly defined in the early stages of the analysis [Berg-Schlosser and Meur, 2009, p. 20]. This is important in order to both give sufficient answers to the proposed research question (section 1.3.2) and to provide sufficient preparation when starting the next stage of the QCA, (2) selecting the cases [Berg-Schlosser and Meur, 2009, p. 20].

Based on the defined outcome, the cases that share key underlying characteristics that are relevant to this outcome of interest are selected [Berg-Schlosser and Meur, 2009, p. 22]. Furthermore, the group of selected cases should exhibit the full range of potential outcomes, including positives and negatives. When considering the number of cases that should be included, the familiarity it is possible to gain with each case should be the deciding factor, as it is crucial to have in dept knowledge of all the cases in order to perform a successful QCA [Berg-Schlosser and Meur, 2009, p. 22].

The next stage of QCA is (3) the selection of conditions [Jordan et al., 2011]. The conditions are the variables that may influence whether or not the outcome is realised [Berg-Schlosser and Meur, 2009, p. 25]. In the case of any outcome, there is an abundance of different conditions that might be a factor of influence and conditions must therefore be chosen carefully. There are several practices mentioned by Berg-Schlosser and Meur [2009, p. 28] that are helpful when selecting conditions. Firstly, it is important to not select conditions that have a low coefficient of variation in the sample of cases selected [Berg-Schlosser and Meur, 2009]. Chatterley et al. [2014] recommend excluding conditions that have less than 30% variation. These conditions are referred to as constant conditions as they do not change significantly throughout the different cases [Chatterley et al., 2014]. Secondly, the number of conditions included should be low [Berg-Schlosser and Meur, 2009, p. 28]. This is done to keep the complexity of the calculation down, as more conditions lead to exponentially more combinations of conditions to be investigated. Additionally, cases become individualised by having a large number of conditions, as they exhibit unique combinations as explanations for their outcome. For studies analysing 10-40 cases, it is recommended to use 4-7 conditions in the QCA. Finally, each condition should have a clear hypothesis explaining why it is a necessity in connection with the outcome [Berg-Schlosser and Meur, 2009, p. 28]. Stage 2, selection of cases, and stage 3, selection of conditions, are iterative processes that should be repeated until a theoretically sound basis for the QCA is established [Jordan et al., 2011].

After the cases and conditions have been selected, the process continues with (4) creating a table with raw data and (5) assigning scores to the cases based on each condition and the outcome [Jordan et al., 2011]. At this stage, QCA provides three methods of scoring the cases. While two of the methods, crispy-set QCA (csQCA) and multi-value QCA (mvQCA) score the cases rigidly into two [Rihoux and Meur, 2009, p. 33] and three or four [Cronqvist and Berg-Schlosser, 2009, p. 70] categories respectively, the third method, fuzzy-set QCA (fsQCA), provides the possibility for cases to be scored on a degree scale [Ragin, 2009, p. 88]. For the topic of community-driven development of water systems in rural areas, the cases (villages) are more precisely depicted when scored at varying degrees of membership to the conditions of interest. Thus, fsQCA is used in this study to give the cases a score for each condition and the outcome.

Fuzzy-set QCA

A four-value fussy set is applied in this study, where each of the conditions and the outcome are scored either 1, 0.67, 0.33 or 0, where 1 is the presence of a condition and 0 is the absence. Although a finer graded scale could have been used, a four-value scale was deemed to provide a scoring that fits the conditions and the available information about each case. For studies with a large amount of data on each case and lacking similarity in the evidence for each condition across the cases, it is recommended to implement a fussy set scheme [Ragin, 2009, p. 90]. Additionally, a four-value fussy set reduces the complexity of the method and makes it easier to construct scoring criteria for each condition and the outcome [Ragin, 2009, p. 91]. Furthermore, it is important to construct criteria that is based on substantial case knowledge and theory, so that it is clear what justifies the different scores. After the cases have been scored for each condition, the next stage (6) is creating a truth table. This stage is, in this study, done through the application of the fs/QCA 4.0 software [Ragin, 2018].

The fs/QCA software simplifies the analysis by performing the calculations, creating the truth table and conducting the analysis of the necessary conditions when given a calibrated table of scores for outcome and conditions for all the selected cases. The truth table represents a transformation of the raw data into a table with Boolean configurations using the Quine-McCluskey minimisation procedure [McCluskey, 1956]. It consists of all possible combinations of the selected conditions, with both the presence (1) and the absence (0) of each condition in mind [Rihoux and Meur, 2009, p. 39]. Additionally, information regarding how many of the cases that fits into each combination is presented in the table, along with some assessment parameters [Ragin, 2018].

Before creating the truth table, it is advised to conduct a necessary conditions analysis [Ragin, 2009, p. 109]. A necessary condition analysis identifies which of the conditions are necessary in order to achieve the outcome [Ragin, 2018]. This is done using the software, by calculating values for the assessment parameters: consistency and coverage [Ragin, 2018]. Consistency reflects the relationship between the score of a condition or a combination of conditions and the score for the outcome. This is used both in the necessary conditions analysis and the truth table analysis [Jordan et al., 2011]. The coverage assesses to what degree a combination of conditions is reflected in the cases included in the study [Rihoux and Meur, 2009, p. 64]. When determining if a condition is to be labelled as a necessary condition, a consistency score of 0.9 is suggested by fsQCA professionals to be adequate [Jordan et al., 2011]. If a necessary condition is identified, it can be removed from the truth table analysis and be promoted to a "must-have" condition for any pathway to the outcome [Ragin, 2009, p. 110].

In the next step, a cutoff consistency value for when a combination of conditions is regarded as having the presence (1) of the outcome has to be determined in order to analyse the truth table [Ragin, 2009, p. 106]. A consistency value of 0.8 is often proposed by fsQCA professionals [Jordan et al., 2011]. This enables the software to conduct the final analysis (7) and present the solutions. Three types of solutions are presented by the software, along with their respective consistency and coverage values [Ragin, 2018]. In order to fully understand the difference between the solution types, the term "logical remainder" needs to be explained.

A logical remainder is the combination of conditions that did not represent any of the cases in this study, i.e. hypothetical cases [Ragin, 2009, p. 111]. The *complex solution* uses no logical remainders to derive its solution. This often leads to the solution being long and complex, hence the name. The *parsimonious solution* uses all the logical remainders to derive its solution. This is useful when trying to simplify the pathway to the outcome, but since there is no check for the plausibility of the hypothetical cases included, the solutions might not be an accurate representation of the study. The *intermediate solution* uses only plausible logical remainders, which is usually found through the use of theory and substantial case knowledge [Ragin, 2009, p. 111]. The software on the other hand, uses counterfactual analysis to derive the intermediate solution [Ragin, 2018]. In short, the counterfactual analysis states that a solution that contains some of the conditions presented in the complex solution and all the conditions presented in the parsimonious solution must be a valid solution to the truth table analysis. This might produce several "valid" solutions that can be further narrowed down using the theoretical backing in which the conditions were selected on; usually associating the presence of a condition with the outcome and not the absence [Ragin, 2018]. The intermediate solution is therefore referred to as the superior solution and should therefore be used when deriving a result from the analysis [Ragin, 2009, p. 111]. Even though this is also the case in this study, an analysis of the other types of solutions is recommended in order to make simplifications and assumptions regarding the selected conditions, and in order to evaluate whether the solutions make sense [Jordan et al., 2011].

Outcome of interest

The outcome of interest in the fsQCA is directly linked with the main research question of this thesis (ref main research question). It is defined as substantial community-driven development of the water system in the village. The criteria for what warrant a score of 1 is expressed as having expanded the water system infrastructure to include a water tap located in a different area than the water well. Other developments, such as office spaces near the water well, cattle troughs, water taps next to the well and increased storage, or feasible development plans are also taken into account. The criteria for each outcome score is further elaborated in table 2.2.

Selection of cases and data used

Out of the 16 villages visited during the fieldwork for this thesis, 13 were included as cases in the QCA. As suggested in the QCA methodology presented earlier in this section, cases were selected based on shared underlying characteristics that were relevant to the outcome of interest. All the water boreholes assessed in this QCA were built as a part of NCA's telethon campaign in 2014 and are all driven by solar-powered pumps. The villages are also located in similar geographical and socioeconomic settings spread around three neighbouring districts. Out of the three excluded villages, one had undergone major government development to supply several villages. The two others were missing key data from user interviews. Another criterion for selection was that the cases exhibit the full range of potential outcomes, which the remaining 13 cases did.

The data sources for the cases selected include interviews with users, group interviews with students and COSWO, and detailed field observations. The interviews consisted of questions made using sustainability indicators that were found in the literature (see 2.5.3). During group interviews, probing was actively used to gain additional information about relevant topics. In the QCA, all the gathered data are used collectively to form an information base for each case. The in-depth knowledge of each case was obtained by reading and re-reading the interviews and forming an overall view of the situation. Additionally, previous knowledge from master theses conducted in the same study area and information provided by NCA about the water boreholes were used as supplementary information.

Selection of conditions

When selecting which conditions were to be included in the QCA, several evaluations were made. The sustainability indicators used to create the questionnaires were decided to be a valid starting point as the data collected would provide substantial information about said indicators. Additionally, the indicators are grounded in theory and their relevance to the selected outcome can therefore easily be hypothesised. Initially, 15 conditions were created based on the indicators mentioned in section 2.5.3. Using the practices mentioned in the OCA methodology above, two of the conditions were excluded based on having a too-low coefficient of variation, i.e. they were constant conditions. Further evaluation and re-evaluation of the remaining conditions led to the exclusion of eight more. Some of these were excluded based on their lack of relevance to the selected outcome, and others were excluded because of their similarity to the other conditions. The elimination process was done in order to keep the number of conditions included in the QCA low, as suggested in the methodology. Finally, five conditions were included in the analysis: (1) User acceptability, (2) Repair service, (3) Financial durability, (4) Storage and supply reliability, and (5) Absence of an alternative water source. Table 2.1 presents all the conditions that were considered and as well as whether they were included, constant or excluded.

Table 2.1: Causal conditions considered for use in the QCA.

Conditions	Excluded	Constant	Included
User acceptability			X
Activity level		X	
Participation		X	
Repair service			X
System function	X		
Financial durability			X
Willingness to pay	X		
Storage and supply reliability			X
Absence of alternative water source			X
Access to water	X		
Accountability and transparency	X		
Water quality	X		
Follow government guidelines	X		
Yield	X		
Construction year	X		

Scoring of conditions and outcome

Initially, scores using the fuzzy set, 1-0.67-0.33-0, were assigned to all considered cases for each condition as well as the outcome. The criteria for the conditions and the outcome were created with the basis that a score of 1 reflects full presence and a score of 0 reflects full absence. The intermediate scores of 0.67 and 0.33 were given to cases that were neither fully in nor fully out, respectively. The scoring process was initially conducted individually by each student, before a final cooperative scoring procedure was applied. The elimination of conditions and cases was agreed upon in the cooperative stage. In table 2.2, a detailed scoring scheme is presented, including which sources were used as the background for the scores. The final scores for the selected cases and conditions are presented in table 3.1. As this analysis focuses on the interactions between different causal conditions and the outcome and not the performances of the villages, it was decided that village names should be excluded from the scoring table and be replaced by non-descriptive numbers (see table 3.1).

Table 2.2: Criteria scoring scheme for outcome and conditions used in the QCA.

Condition	Criteria coding scheme	Data source
Development (OUTCOME)	**1**: Water system is expanded with at least one tap in a different area. **0.67**: Feasible plans for water system expansion (major development) in the near future is in place. **0.33**: At least two small water system developments have been implemented (office, cattle trough, etc.) or one income-generating development. **0**: One or no small developments have been implemented.	C, U, S, F[a]
User acceptability	**1**: Users are satisfied with all four aspects of the water system[b] **0.67**: Users are satisfied with three aspects of the water system. **0.33**: Users are satisfied with two aspects of the water system. **0**: Users are satisfied with one or less of the aspects of the water system.	U, S
Repair service	**1**: No major repairs have been needed; few small repairs; repair time is two or less days. **0.67**: No major repairs have been needed; many small repairs; repair time is two or less days. **0.33**: Major repairs have been needed; repair time less than three days. **0**: Major repairs have been needed; repair time is more than three days.	C, U, F
Financial durability	**1**: Can cover all expenses with tariff generation; have considerable savings for future repairs and development. **0.67**: Can cover all expenses with tariff generation; have some savings for future repairs **0.33**: Can cover most expenses with tariff generation, but increase in income is needed for savings. **0**: Cannot cover expenses with tariff generation.	C, U, S, F
Storage and supply reliability	**1**: At least 20000 l storage; few and short stops in supply (less than 3 hours); no issues filling the tanks; always water during opening hours. **0.67**: At least 10000 l storage; some short stops in supply; no issues filling the tanks; almost always water during opening hours. **0.33**: At least 10000 l storage; some stops in supply (less than one day); some difficulties filling the tanks; mostly water during opening hours. **0**: Less than 10000 l storage; long stops in supply; not enough water for the community most of the time.	C, U, S, F
Absence of alternative water source	**1**: Few use other water sources and primarily only rainwater during rainy season as the other source. **0.67**: few use other water sources and if so, it is not for domestic use. **0.33**: Some use other water sources; mainly because of price and distance. **0**: Many use other water sources; also for domestic use; mainly because of price and distance.	C, U, S

[a] C: CBWSO; U: User; S: Students; F: Field observation
[b] See section 2.5.3 for the aspects.

2.5.5 Limitations

Barriers likely to affect the interviews

In everyday communication, there is a number of different processes that happen for people to share and receive information [Dahl, 2013]. The Sender first codes their information into a message which is then decoded by the Receiver. The message can be in the form of a sentence, a sound or body language. The coding and decoding are among other things dependent on the references, worldview and perceptions the Sender and Receiver have [Dahl, 2013]. It is also dependent on the barriers that the communication must overcome. The communication process was further complicated by the use of a translator. It added an additional step of coding and decoding the message to the communication process as illustrated in Figure 2.7, and increased the potential for misunderstandings.

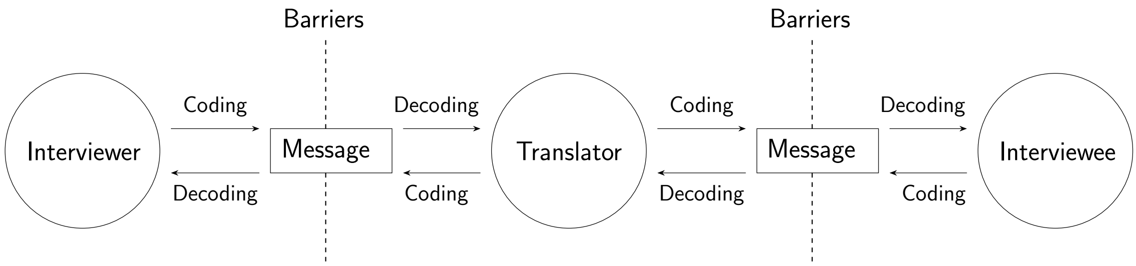
All this has affected the interview situation done in the fieldwork to a great degree. There were several barriers affecting the interview: cultural barriers in the form of different cultural references and backgrounds, language barriers, and differences in roles and knowledge areas.

Prejudgement most likely affected the interviews as well. The preconceived notions about the interviewee's priorities, the state of the system, and how they organised the water well and the community could have had an impact on the questions posed. The interviewee's responses could likewise be influenced by preconceived notions.

When conducting a group interview a limitation can be that one or a few people in the group talks more and in a sense speak for the whole group. It is not certain that this individual inhabits and communicates all the different perspectives in the group. During the student interviews, there was often only one or two persons that did most of the talking. This can lead to a wrongful perception of the group's opinion as a whole.

All of this is likely to have affected the interview data. Attempts to minimise these limitations were made by being aware of the barriers and preconceived notions. In order to counteract misunderstandings, clarification questions were asked as well as restating the interviewees' answers to confirm their statements.

Figure 2.7: The communication process through a translator



QCA

Like any research approach, QCA has several limitations that need to be considered and addressed. When assessing QCA as a method that falls in-between quantitative (statistical) and qualitative (case-based) methods, not only the strengths from each side but also the limitations are adopted. The limitations of a quantitative approach tend to revolve around the lack of in-depth knowledge about the cases and the underlying interactions between cause and effect [Meur et al., 2009, p. 148]. On the other hand, the limitations to qualitative approaches focus on the lack of structure and the use of subjectivity in the research [Meur et al., 2009, p. 148].

The dichotomisation (division into strict groups) of data is also addressed as a limitation of QCA [Meur et al., 2009, p. 149]. This is of most importance when conducting csQCA, and less so with fsQCA. It is regardless relevant in terms of loss of information and bias when scoring cases, as the researchers are forced, in this study, to simplify complex cases into one of four scores [Jordan et al., 2011]. This limitation can be addressed by creating clear condition criteria and using a transparent scoring procedure, although not entirely removed [Meur et al., 2009, p. 149].

Another limitation described by Meur et al. [2009, p. 152] refers to the use of logical remainders (i.e. hypothetical cases). It is argued that the use of logical remainders to derive a solution is speculative, and that the solution becomes unverifiable [Jordan et al., 2011]. QCA researchers counter this by saying the use of logical remainder works as a simplifying assumption, which is already done in most social science research. It is also stated that this limitation can be less of an issue if the intermediate solution is used, where only plausible logical remainders are included in the calculations [Jordan et al., 2011].

Difficulties in selecting conditions and cases are also a limitation of the QCA method. As there could be an unlimited number of factors influencing an outcome, selecting the most influential might prove difficult. This can however be addressed by building substantial knowledge through theory and research, and with that, making informed decisions [Meur et al., 2009, p. 158]. The selected cases will also have a large impact on the outcome and should therefore also be selected based on sufficient in-depth knowledge about each case and their relevance to the outcome. Small changes in the scoring of the cases can cause big differences in the solutions identified and clear and precise criteria for scoring are therefore needed [Meur et al., 2009, p. 158].

The final limitation is the lack of a temporal dimension [Jordan et al., 2011]. The solution pathways identified do not take into account when the conditions are satisfied or if they need to be satisfied in a particular order in order to reach the outcome [Jordan et al., 2011]. This issue has not been addressed in QCA literature or in this study [Meur et al., 2009, p. 161].

2.5.6 Ethical considerations

When travelling to a different continent to speak with locals about their water supply systems, there are many ethical issues to take into account. The ethical considerations that affected the data collection will be listed in this section.

It was important that none of the questions made it possible to identify the subject as the answers were logged digitally. It is the researchers' ethical responsibility to secure the confidentiality of the gathered information [Tjora, 2021, p. 187-190]. This is also implemented by law in Norway via the EUs General Data Protection Regulation [Engen, nd]. There is always a possibility that digital data can be interfered with, hacked or shared with outsiders [Tjora, 2021, p. 187-190]. Therefore unnecessary personal data was not gathered. The interviews were not audio or video-recorded for the same reason. To reduce the likelihood of unauthorised access, the number of individuals with access to the data was also restricted. Additionally, the villages have been made anonymous in the QCA because the analysis requires scoring and simplifying each village's qualities, which is unfortunate if taken out of context.

Prior to each interview, it was important to clarify that no contributions or services would be given or withheld regardless of their cooperation. Regardless of this, there were occasionally expressed expectations or hopes for funds at a later stage in the interview, so this is something that could have been communicated better. This is especially important in an area with such a long history of Norwegian aid projects, as the mere presence of Norwegians may have generated expectations, which when not met could have bred mistrust.

When taking pictures and videos of observations intended to be publicised it was important to request permission from all persons that were pictured. Protecting privacy and reducing the exposure of children was an important consideration [Tjora, 2021, p. 187-190], so no pictures where children could be recognised were saved.

It is advantageous from an ethical standpoint to relay findings, reflections, and concepts to the communities observed [Tjora, 2021, p. 187-190]. In this project, this was done by giving a water quality report to the CBWSOs responsible for each tested water source and sharing the results of this master's thesis with 4CCP.

An important ethical consideration when doing research is to do no harm. In an interview situation, this translates to making the interviews as comfortable and convenient as possible for the interviewees [Tjora, 2021, p.127-190]. Being polite and respecting their time is important. This consideration becomes even more important when interviewing a vulnerable group, [Tjora, 2021, p. 187-190] like children. It was therefore essential to create a safe and comforting environment for the interviews of students and remind them of their option to not answer questions or leave the interview at any time. These interviews were always conducted in groups and, when possible, with a teacher present to maintain their limits and reduce stress.

2.6 Development of local water infrastructure in Dang'aida

Dang'aida village is among the four Villages in Basotu Ward within Hanang District. The village has a solar-powered water well that was built in 2021 by NCA with funding from private donors. The village has approximately 6864 inhabitants projecting the 2012 statistics using the average rural population growth of 21 % [WB, nd]. The village is located north of Lake Basotu, 70 kilometres from the district head office. The village was officially registered in 1979 with 4 sub-villages and is dominated by a pastoralist society [Personal communication, Ahadi Mollel, 26th of February 2023]. The village has already expanded their water supply system with a pipe to the nearby primary school. They plan to expand the water supply system to two sub-villages, Herbosh and Dorowdow.

2.6.1 The current system

The current system consists of a 55 m deep solar-powered groundwater well with two 10000 l storage tanks on a 3 m tall tower 20 m from the borehole. The pump is a 2.2 kW Dayliff DSP8-13 and is situated 50 m below ground. The pump curve is illustrated in Figure 2.8. The expected yield during construction was 8000 l/h. The static water level in the well is 17.29 m with a dynamic water level of 43.67 m below ground level as described by NCA (Appendix H). The borehole pipe as well as all other pipes is PE pipe with a 50 mm dimension.

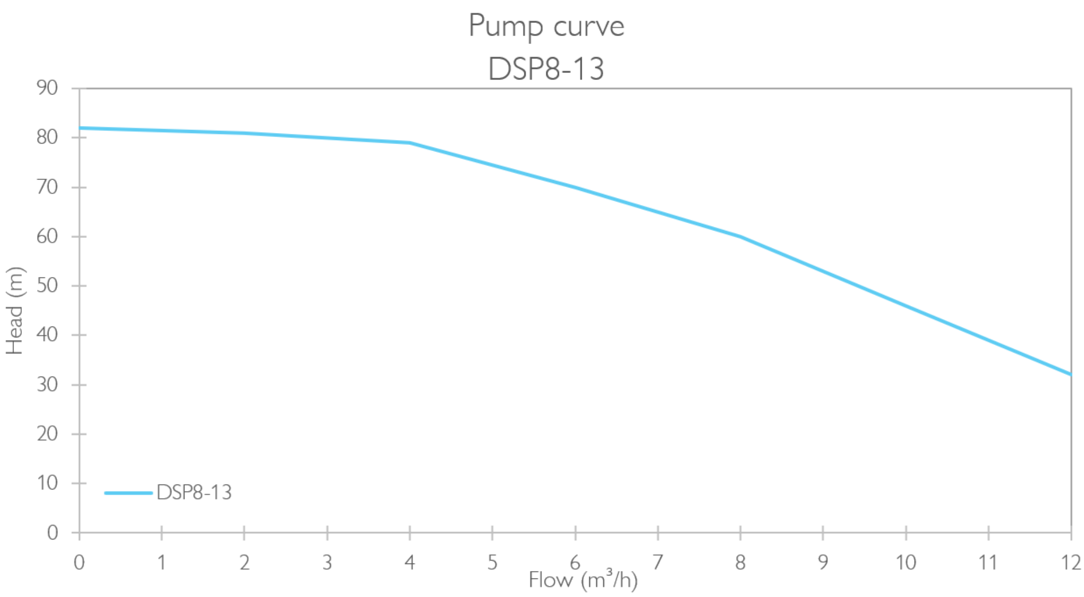


Figure 2.8: Pumpcurve of the pump showing the available head in relation to flow. Numbers from: Davis and Shirtliff (2023)

As mentioned, the community have already expanded the water supply system to the Dang'aida primary school nearby. It is connected with a split connection and a valve in the well. The pipe used is a PE pipe with a dimension of 50 mm. The pipe is laid in a ditch directly from the water well to the school across a field. The ditch was dug by the community through voluntary work. At the school, the pipe is connected to an old concrete rainwater tank that has been fixed by the community [4CCP, 2022]. In this tank, the water from the well is mixed with rainwater gathered from the roofs of the school. From this tank, the water is distributed to taps around the school and to the nearby village centre.

2.6.2 Information gathered during fieldwork

During the fieldwork information concerning the pipes and location of the current system and the topography of the area was gathered. Additionally, the wants and needs of the community in terms of the locations of the new taps were acquired from the village leaders, as well as information about how the previous expansion was done, both in materials and execution. The location in Herbosh was chosen based on its proximity to a primary school, and because it was an approximate centre of the settlement in the sub-village. The location in Dorowdow was chosen because it was the sub-village centre with other institutions nearby such as the village office and shops.

Each of the different locations was visited during the field trip and the location was plotted using Google Maps. This is not an exact plotting method but was deemed precise enough for this use. The locations were manually checked against satellite images of the area. The accuracy was improved by calibrating the position of the phone according to Google's recommendations for Android phones. The distances were later found using the distance measurement in Google Maps from each of the locations to the borehole. The distances are listed in Table 2.3.

During the visit to the different locations, the height difference relative to the ground at the borehole was approximated by analysing the visible topography of the area. The approximations were later checked against maps of the area. The height difference is listed in Table 2.3. The village leaders and the chairman of the CBWSO were asked about relevant features that would complicate the construction such as rivers or areas with bedrock close to the surface. The area is an area characterised by extensive weathering [Yekom, 2019], and this was confirmed by the villagers. There were no large rivers, but it is an area that is characterised by large runoff during the rainy season. These conditions can lead to temporary rivers, which can quickly dig deep ditches in the landscape due to erosion [Ødegaard, 2014]. At the time of the fieldwork, no such rivers were seen or reported and are not a part of the simulation, but this is a vulnerability of the system that should be assessed during the construction phase.

Table 2.3: Height and distance data gathered during fieldwork.

Location	Distance from well	Height difference from well
Dang'aida primary school	1003 m	0
Herbosh	3250 m	+20
Dorowdow	2350 m	+10

2.6.3 Design method

The system was designed using Epanet. Epanet is an open-source software application that can simulate the hydraulic and water quality behaviour of pressurised pipe networks over an extended period [Rossman et al., 2020, p. 1]. Such networks are typically composed of pipes, nodes (pipe junctions), pumps, valves, and storage tanks/reservoirs. During a simulation period consisting of multiple time steps, Epanet monitors the water flow in each pipe, the pressure at each node, and the water level in each tank. Epanet offers a hydraulic analysis engine that provides a range of capabilities. The software calculates friction head loss using the Hazen-Williams, Darcy-Weisbach, or Chezy-Manning formulas [Rossman et al., 2020, p. 1-2]. Darcy-Weisbach was chosen for this simulation as presented in Equation 2.1 with a roughness coefficient of 0.005 as is the standard for new PE pipes in Epanet [Rossman et al., 2020]. Singular losses were calculated in the simulation using Equation 2.4 with a loss coefficient of $k_s = 1$ for exit to tank, $k_s = 1.8$ for t-cross, and $k_s = 0.2$ for open valve [Rossman et al., 2020]. All bends were disregarded as singular losses are often negligible in larger systems [Ødegaard, 2014, p. 74] No demand patterns were included in the simulation, as the performance was measured by the time it took to fill a 10000 l tank at each location.

Design parameters derived from information gathered in the field

The model is created with the ground level of the well chosen as (0,0,100) in coordinates (x,y,z). The water level in the well while pumping in this coordinate system was calculated accordingly:

$$\text{Ground level} - \text{Dynamic water level} = \text{Height of water in coordinatesystem} =$$
$$100 - 43.66 = 56.33$$

The heights at the other locations were calculated in the same way and are presented in Table 2.4.

Table 2.4: Height and distance data used in the simulation.

Location	Distance from well	Height in new coordinate system
Dang'aida primary school	1003 m	100
Herbosh	3250 m	120
Dorowdow	2350 m	110

2.6.4 Optimisation of the design

The method used for the optimisation of the system was a trial-and-error method, based on iteration. The performance was measured by the time it took to fill 10000l tanks at all locations. The different factors that were tested were: the constellation of the system, the diameter of pipes and how the pump performance affected the system. The different variables tried for each factor are listed in Table 2.5

Table 2.5: The variables checked for each factor.

Factors	Variables checked	Reason for choosing these variables
Constillation of system	Pumping to all four locations at once Pumping to three of the locations at once Pumping to two locations at once Pumping to one location at a time	Every possible constellation of the system was checked to find the best performing setup
Diameters of the pipes	50mm 100mm	50mm has been used in the system so far. 100mm results in less friction loss No higher diameters was checked because economy is a strongly limiting factor.
Pump performance	A pump with higher head, DSP8-17 The pump in the well, DSP8-13 A pump with lower head, DSP8-08	The performance of the pump is important for the performance of the system. The pumps were chosen to represent a higher performing pump and a lower-performing pump

The performance of the pump is important for the performance of the system and can change based on a number of factors as disclosed in section 2.4.1. The pump in the groundwater well is a DSP8-13. To examine the effects on the system and yield, the simulation was run with a pump with a higher head (DSP8-17) and one with a lower head (DSP8-08). Figure 2.9 shows the pump curves. Different pumps were chosen to represent a higher-performing pump and a lower-performing pump.

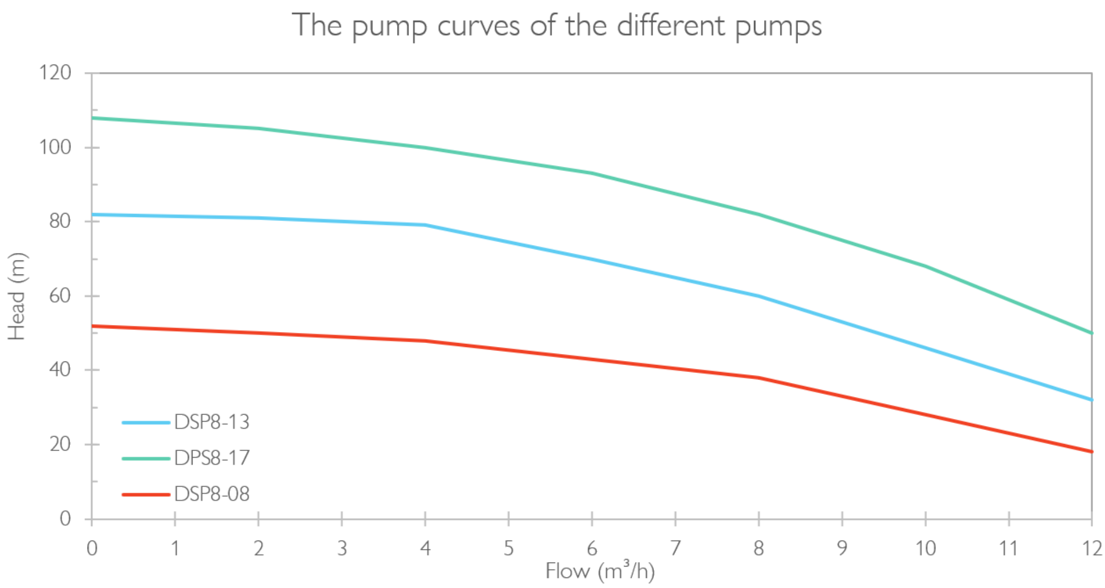


Figure 2.9: Pumpcurve of the three applied pumps.

The results from each iteration of the simulation were compared with each other. The optimal solution was then selected.

Limitations connected with the chosen parameters

It is important to consider the limitations of the simulation used to inform the design. A model is a simplified representation of a complex system or phenomenon [Litvak et al., 2019]. It is created by making assumptions and simplifications that allow us to understand the behaviour of the system in a more manageable way. While models can be incredibly useful for making predictions, guiding decisions, and understanding complex systems, they are never true in the absolute sense [Litvak et al., 2019]. When using the results from the simulation to design the water supply system, it is crucial to be aware of these limitations. Information always gets lost and this is important to keep in mind when using simulation results to inform the final design. In this instance, the simulation provides helpful insights into how various design decisions will impact the system's performance. The results should be used as an indication rather than an exact prediction of the system's behaviour.

Additionally, the simulation does not consider the vulnerability of the system to contamination. This can be expected to increase with the expansion due to more parts and because of the fluctuating pipe pressure [Ødegaard, 2014, p. 262]. The varying pressure in the pipes can cause contaminants to leak into the system, which can be a serious health hazard. This is an important factor to take into account when designing a water supply system, and this vulnerability increases the relevance of treatment options like chlorination [Ødegaard, 2014, p. 262].

The groundwater well is the only improved drinking water supply in the area. If the assumed size of the population is correct that means that the tanks only have the capacity to provide 2.9 l/d per person. To realise the essential levels of health and hygiene, the minimum quantity of safe water required is 20 l/d per person[Reed and Reed, 2013]. NCA design the water supply systems to have storage for 3-5 days of water use for the village population. This can either mean that NCA constructed a far too small water storage for the population, or the village has lost a lot of residents since 2012 and the assumed size of the population is wrong. This led to a big uncertainty related to the boreholes' capacity.

There is also a significant uncertainty connected to the distances. The distances are given in a straight line from the pump to the location, but in reality, the distances may vary due to the terrain or other obstacles. This means that the actual performance of the system may differ from what is predicted by the simulation. The dimensions of the designed system are also uncertain as they were only measured from the outside with a ruler and the measurement was not precise. This uncertainty can lead to inaccuracy of the pump rate to the school and the tower by the well. The standard values in Epanet were used for roughness and minor loss coefficient. There were not done any measurements of flow in any part of the system so no calibration of these coefficients was done.

2.7 Water quality measurements

In this section, the theory behind the water quality parameters that were chosen for the fieldwork and the subsequent study will be presented. The water quality parameters that were chosen to be tested in this study include temperature, conductivity, fluoride, nitrate and nitrite, phosphate, chlorine, iron, pH and E. coli presence. The parameters were chosen because of their importance in drinking water composition in terms of suitability for human consumption, and partly because of the availability of testing kits.

Also included in this section will be the testing methodology for the different water quality parameters. In total 27 water points were tested at 16 different villages. The water samples were mostly collected from taps directly connected to water boreholes. Four of the collection points were taps connected to rainwater tanks, three of them mixed with borehole water and one with only rainwater. Additionally, one of the collection points was a natural spring.

All water samples except the spring sample were collected after letting the water run for 10-15 seconds. The samples were collected in 1 l plastic bottles which were cleaned with the water from the water points before collection. During the first week of the fieldwork, three samples were collected from each water point. This was later reduced to two samples and finally one sample during the last couple of days (Appendix E). This was done to save some of the test kits as new water points emerged as relevant candidates during the fieldwork. Due to a shortage of certain water quality parameter tests, such as phosphate, chlorine, iron and E. coli, it was decided to only conduct two tests. This was also deemed to be sufficient in terms of the validity of the results. Conductivity and temperature were tested at the water points directly after the water samples were collected. The rest of the water quality measurements were conducted at the Haydom Lutheran Hospital guesthouse in the afternoon of the same day, with the exception of the two first locations, where all the tests were conducted on-site.

2.7.1 Conductivity (EC) and Temperature

Conductivity is an important water quality parameter that reflects the water's ability to conduct an electrical current [EPA, 2022a]. The ability to conduct an electrical current depends on the activity of cations and anions in the water and thus reflects the total content of salts and other substances present in the water [FHI, 2021]. Conductivity is also related to salinity, the dissolved salt content. The higher salinity, the higher the conductivity [EPA, 2022a]. In the case of groundwater, conductivity can be used as an indicator of whether there has been a discharge of surface water or other pollution sources into the groundwater [FHI, 2021]. This can be analysed by comparing the measured conductivity to previous values and looking for significant changes, as the conductivity tends to stay relatively stable in one water source [EPA, 2022a]. The temperature of the water sample will also affect the measured conductivity, as warmer water has a higher conductivity [EPA, 2022a].

The conductivity and the temperature were measured using the HANNA Instruments DiST 4 Waterproof EC Tester [HANNA, nd]. The tester (see figure 2.11) measures conductivity in a range from 0.00 - 20.00 mS/cm and measures temperature with a resolution of 0.1°C. The conductivity tester was calibrated with a solution which had a conductivity value of 12.88 mS/cm at 25°C. The calibration was done once before the first test was conducted [HANNA, nd].

The conductivity and temperature measurements were conducted on-site, directly after the collection of each water sample. Depending on the number of available containers, either one, two or three water samples were collected from each water point. In cases where multiple samples were collected, all values were logged and an average of the measured conductivity and temperature was calculated and used for further analysis (Appendix E). The conductivity tester was cleaned with water from the next sample and wiped dry before use. In order to obtain a reliable measurement from the tester, it has to be submerged in the sample until a stable reading is given.

Limitations

The accuracy of the EC measurements is reported to be ±2% of the full scale range, meaning any given reading can be off by as much as 0.4 mS/cm [HANNA, nd]. The temperature reading accuracy is ±0.5°C. The solution provided for the calibration procedure was required to be at 25 °C in order to have an EC value of 12.88 mS/cm [HANNA, nd]. This was not ensured during the calibration, as there was no reasonable method to change the temperature of the solution, had it not been 25 °C. This might also affect the accuracy of the EC and temperature readings. In some cases, only one sample was collected and tested, which prevents verification of the measurements.

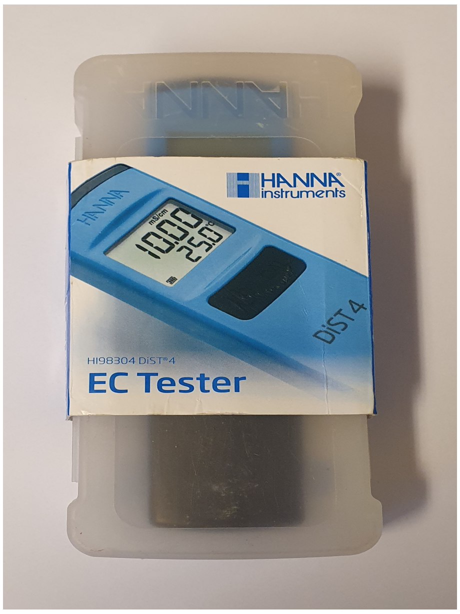


Figure 2.10: EC and temperature tester.

Figure 2.11: EC and temperature test method.

2.7.2 Fluoride

Fluoride is an element that is commonly found in groundwater [Jha et al., 2013] and is therefore an important parameter to include when assessing water quality in areas where high fluoride concentrations have been reported, such as Tanzania [Onipe et al., 2020]. The concentration of fluoride in the groundwater is determined by the rock composition and the geothermal temperatures in the aquifers. Volcanic activity in the Great Rift Valley area in East Africa has resulted in generally high fluoride concentrations in the groundwater [Onipe et al., 2020].

There are several health effects associated with fluoride at different concentration levels [Onipe et al., 2020]. When considering the effects of prolonged exposure to fluoride through drinking water, high concentrations (>1.5 mg/l) are associated with dental fluorosis [Onipe et al., 2020, WHO, 2017]. Dental fluorosis is characterised as changes in tooth enamel caused by the ingestion of fluoride when children are forming their teeth [CDC, 2019]. In severe cases, browning of the teeth and the formation of pits might occur. Additionally, in areas where the concentration of fluoride in the drinking water is 3-6 mg/l, skeletal fluorosis, which causes changes to the bone structure, may occur. In cases with concentrations above 10 mg/l F, crippling skeletal fluorosis may occur [WHO, 2017].

The fluoride (F) content was measured using a Fluoride Test Method: Colorimetric with colour card 0-0.15-0.3-0.5-0.8 mg/l F MQuant. The product brand is Milipore and it is produced by Merck Life Science AS. The testing kit contains two reagents (figure 2.12), F-1 (liquid) and F-2 (powder) and a colour card with a value range from 0-0.8 mg/l F (figure 2.13). The method of testing consists of six steps. Five drops of reagent F-1 are added to a clear container. 4 ml of the water sample is then added to the container and mixed before adding one scoop of reagent F-2 with the micro-spoon included in the test kit. The mixture is then stirred in order to dissolve reagent F-2. After 12 minutes the test sample is ready to be compared to the given colour card and a result can be read.

Most of the fluoride measurements, with the exception of two, were conducted at a later time than the water sample collection time. Since previous fluoride measurements conducted in the area indicated that fluoride levels would exceed the maximum concentration in the test range of 0.8 mg/l [Røer, 2020, Asklund, 2020], all the water samples were initially diluted with a ratio of 1:2. The water used for dilution was bottled drinking water from the brand Kilimanjaro, which when separately tested, measured a fluoride level of 0.15 mg/l using the same method as described above. Some of the water samples were further diluted because of high concentration readings. In order to calculate the fluoride concentration of the collected water samples, the given formula was used:

$$
\begin{aligned}
F_{dw} * 0.15 + F_{tw} * C_a &= C_{osb} \\
C_a &= \frac{C_{obs} - F_{dw} * 0.15}{F_{tw}}
\end{aligned}
\tag{2.6}
$$

where:
F_{dw} = fraction of dilution water
F_{tw} = fraction of water sample
C_a = fluoride content in water sample
C_{obs} = fluoride content in mixture of dilution water and water sample

Limitations

The containers used for the test mixture and the dilution mixture were cleaned with water from the next sample (diluted) and wiped dry before use. This method proved to be efficient, but any residue from earlier tests could affect the next as the testing samples were quite small. The accuracy of the measurements is highly dependent on the ability to compare the colour of the mixture to the colours from the colour card. Although the colour comparison was checked by multiple people, some uncertainty remains in terms of the final measurement values used. In the instruction manual for the test kit, there are given upper limits for foreign substances for which the test method has not yet shown any interference. It is also stated that fluoride concentrations exceeding 5 mg/l, could yield falsely low readings because of reaction products. While conducting the fluoride measurements, it was decided that readings within the colour card range would not need further dilution, which in some cases might have resulted in falsely low measurements.

Another limitation of the fluoride measurements is the use of bottled water. Although the same brand of bottled water was used for the entirety of the testing, the same batch of water was not used. One fluoride content measurement was done on one batch of bottled water before the beginning of testing. Several studies suggest that the fluoride content differs from both the labelled content and from bottle to bottle [Ahiropoulos, 2006, Zohouri et al., 2003]. This implies that there are large uncertainties in the calculations and the subsequent results.

Figure 2.12: Fluoride test components.

Figure 2.13: Fluoride colour scale.

2.7.3 Nitrate and Nitrite

Nitrate (NO_3^-) and nitrite (NO_2^-) are two inorganic compounds that are naturally found in the environment as part of the nitrogen-cycle [EPA, 2022b]. In addition to entering the water sources through natural pathways such as vegetation and bedrock, nitrate and nitrite can also enter water sources through anthropogenic pathways and is therefore an important parameter to include when assessing water quality [WHO, 2017]. Anthropogenic pathways include agricultural activities through fertilisers, for which nitrogen is a common ingredient, animal waste from animal farming and activities close to the water source, and wastewater disposal [WHO, 2017]. In the case of animal and human waste, nitrate and nitrite are formed through the nitrification of ammonia [EPA, 2002]. Since nitrite is produced as an intermediate product in the nitrification process, it is expected to be found in lesser quantities than nitrate [EPA, 2002]. High nitrite concentrations are often the consequence of recent contamination [FHI, 2021].

Elevated nitrate and nitrite levels in drinking water are known to cause methemoglobinemia, a disorder that reduces the blood's ability to transport oxygen around the body [FHI, 2021]. Infant babies who bottle feed are especially at risk because of their high intake of water in relation to body weight and their low acid levels in the stomach, which enables nitrate-reducing bacteria to grow. Additionally, several studies have identified a connection between elevated ingestion of nitrate and nitrite and cancer [FHI, 2021].

The nitrate (NO_3^-) and nitrite (NO_2^-) content was measured using QUANTOFIX Nitrate 100 semi-quantitative test strips (figure 2.14). The method of testing consists of four steps (figure 2.15). The test strips contain two square pads, one for nitrate and one for nitrite, which are submerged in the water sample for 1 second. The strips are then shaken to remove excess water and placed untouched for 60 seconds before it is ready to be compared to the included colour card. The colour card concentration ranges were 0-100 mg/l and 0-50 mg/l for nitrate and nitrite, respectively. In cases with high concentration readings, the water sample was diluted (see method in section from fluoride) in order to conduct a plausibility check of the measurements.

Limitations

Limitations in the methodology of testing nitrate and nitrite are mainly due to the use of test strips. The test strips can only measure values within a certain range, with only seven measurement values. Similarly to the fluoride measurements, the accuracy is highly dependent on the ability to correctly compare the test strip to the colour card, which often proved to be a difficult task. Additionally, the test strips tend to get darker, which indicated a higher concentration. Therefore any deviation from the time in the instructions might result in either a falsely high or a falsely low reading. For samples that are diluted, the same limitations with the use of bottled water mentioned in the fluoride methodology, apply here as well.

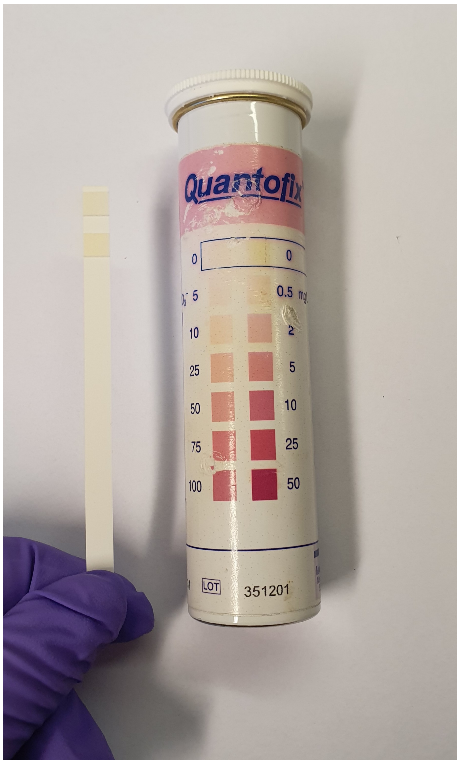


Figure 2.14: Nitrate and Nitrite colour scale.

Figure 2.15: Nitrate and Nitrite test method .

2.7.4 Phosphate

Like nitrate, phosphate (PO_4^{3-}) is an essential nutrient for plants and vegetation to grow [EPA, 2022c]. Its presence in water sources is also often due to agricultural runoff and is therefore important to monitor in an assessment of water quality. Phosphates or more specifically phosphorus are also the limiting nutrient in terms of algae and plant growth in the water. This means that elevated levels can cause excessive growth and eutrophication, which leads to poor water quality for human consumption [EPA, 2022c].

The phosphate (PO_4^{3-}) content was measured using QUANTOFIX Phosphate 10 semi-quantitative test strips (figure 2.16). The method of testing is similar to the one for nitrate except for a submersion time of 2 seconds and no shaking to remove excess water before the strip is placed untouched for 60 seconds (figure 2.17). The strips are then compared to a colour card with a concentration range from 0-10 mg/l PO_4^{3-}.

Limitations

The limitations surrounding test strips mentioned in the nitrate and nitrite limitations are also relevant here. Additionally, the phosphate test strips were particularly difficult to colour compare, especially between the two lowest measurement values, 0 mg/l and 0.5 mg/l.

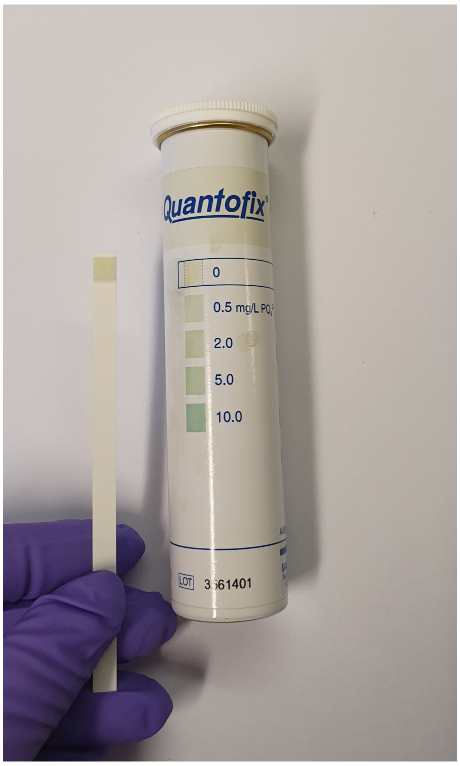


Figure 2.16: Phosphate colour scale.

Figure 2.17: Phosphate test method.

2.7.5 Chlorine

Chlorine (Cl_2) is often added to storage tanks and drinking water distribution systems as a disinfectant against pathogenic microorganisms such as bacteria [WHO, 2017]. For chlorine-treated drinking water systems, it is important to monitor the concentration levels to prevent these pathogenic microorganisms' growth. Too high chlorine levels might cause odour and taste [WHO, 2017].

The chlorine (Cl_2) content was measured using QUANTOFIX Chlorine Sensitive semi-quantitative test strips (figure 2.18). The test strips are submerged in the water sample for 15 seconds before it is directly compared to the colour card (figure 2.19). The colour card consists of six coloured squares that has a concentration range of 0-10 mg/l Cl_2.

Limitations

Limitations surrounding test strips are mentioned in the nitrate and nitrate measurements methodology. The chlorine test strips were, similarly to the phosphate test strips, difficult to read at the lowest concentration values.

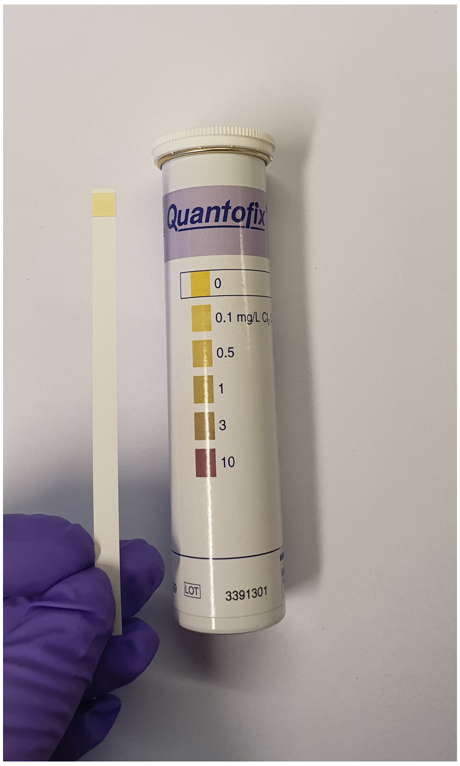


Figure 2.18: Chlorine colour scale.

Figure 2.19: Chlorine test method.

2.7.6 Iron

Iron ($Fe^{2+/3+}$) is one of the metals that are most commonly found in the Earth's crust and is therefore found naturally in most water sources [WHO, 2017]. In groundwater, it is common to find iron levels up to several milligrams per litre [WHO, 2017]. Although there are no health effects from iron for most of the population at the levels found in drinking water [FHI, 2021], there are other concerns associated with high iron concentrations. When in contact with oxygen, iron oxidises and causes piping and laundry to stain [WHO, 2017]. The growth of iron bacteria, which can cause slimy coatings in pipes and fixtures, is also of concern when dealing with high iron levels [WHO, 2017].

The iron ($Fe^{2+/3+}$) content was measured using QUANTOFIX Iron Sensitive 1 semi-quantitative test strips (figure 2.20). The method of testing consists of four steps (figure 2.21). The test strips are submerged in the water sample for 30 seconds before they are shaken one time with the circular pad facing up to remove some of the excess water. The strips are then placed untouched for another 30 seconds before they are ready for comparison with the colour card. The colour card has a concentration range from 0-1.0 mg/l $Fe^{2+/3+}$. A limited number of iron test strips were brought to the fieldwork, and therefore, some of the collected water samples were not tested for iron content. It was also decided early into the fieldwork that only one iron test was to be done for each sample, in order to test as many sites as possible.

Limitations

As well as the test strip limitations mentioned earlier, the limited number of iron test strips brought to the fieldwork caused issues when deciding where to conduct the measurements. This affected the sample size and the ability to verify the results. Additionally, it reduced the possibility to gain an overall view of the study area in terms of iron concentrations and limited the usability of the iron measurement in further discussions.

Figure 2.20: Iron colour scale.

Figure 2.21: Iron test method.

2.7.7 pH

pH is an important water quality parameter that measures the logarithmic value of the concentration of hydrogen ions (H^+) in a water-based solution, which in turn reflects the acidity and basicity of the solution [Britannica, 2023]. pH control is essential in order to prevent the corrosion of pipes, as pH levels below 7 can be corrosive [WHO, 2017]. Additionally, pH levels above 8 decrease the disinfection efficiency when disinfecting using chlorine. Extreme pH levels are usually the cause of external factors such as spills [WHO, 2017] and water with a pH value above 10.5 can cause damage when in contact with the eyes [FHI, 2021].

The pH of the water samples was measured using two different tools. pH-indicator paper pH 1-10 Universal indicator Roll (4.8 mm) from Merck KGaA (figure 2.22) was used for initial testing of the water samples. A second test was conducted for most of the water samples using MN PH-FIX 0-14 test strips (figure 2.23). The method of testing for the pH paper roll consists of submerging a part of the paper until the colour changes. The paper is then compared to a colour wheel with ranges from pH 1-10. The method of testing for the strips consists of submerging the strips until the four attached pads react with the water. The colour change is then compared to a colour card that consists of four colours for each pH value. The pH range for the test strips is from 1-14. Both pH measurement tools can only indicate pH values as integers. The accuracy of the pH measurements is therefore low. It was decided in the preliminary planning of the fieldwork that a more accurate pH sensor was not needed since the goal of the measurements was for the result to function as indicators and as extreme value detectors.

Limitations

Both the pH paper roll and the test trips were limited to integer measurement values, thereby limiting the accuracy of the pH measurements. The pH paper roll also had an upper limit of pH 10, but this was not an issue during the fieldwork, as the second test using the test strips could be performed in cases where the upper limit was reached. Although both pH paper and test strips were considerably easier to colour compare than the other test strips, an uncertainty in readings still might exist.

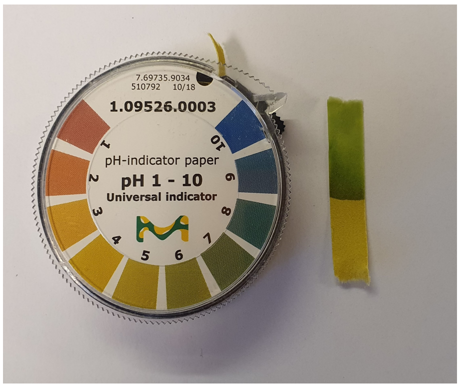


Figure 2.22: pH roll 1-10.

Figure 2.23: pH test strips 1-14.

2.7.8 E. coli

The bacterium Escherichia coli (E. coli) is often used as an indicator organism in order to evaluate the microbial quality of water [Ødegaard, 2014, p. 132]. E. coli's presence in human and animal faeces together with its slow growth rate in the environment, makes it a reliable indicator of faecal contamination [Edberg et al., 2000]. Faecal contamination poses a serious risk of exposure to pathogenic microorganisms, which can lead to the spread of waterborne diseases. Therefore, the presence of E. coli as an indicator organism, can be a valuable tool when determining the appropriate methods of treatments that is needed to ensure safe drinking water for human consumption [WHO, 2017].

As mentioned above, the presence of E. coli in drinking water is an indicative of faecal contamination, and by extension, contamination of other pathogenic microorganism [Ødegaard, 2014, p. 132]. These pathogenic microorganisms can cause serious health risks and it is therefore important with sufficient treatment of the drinking water [Ødegaard, 2014, p. 132]. Identifying which specific pathogens that may be present can be a both costly and time-consuming process [Edberg et al., 2000]. Implementing treatment based on the finding of E. coli is therefore a proactive solution that can ensure safe drinking water. E. coli can, depending on the type of strain, cause a wide range of health problems [Ødegaard, 2014, p. 131]. Serious infections can cause dehydration and malnutrition, which is especially problematic in vulnerable populations, such as in rural Tanzania [WHO, 2017].

The E. coli (Escherichia coli) content in the water samples was measured using AquagenX GEL EC CFU KIT. The testing kit contained E. coli growth medium packs that dissolve in the water sample, GEL powder packs to make the sample gelatinous, 100 ml bags for collecting the water samples, and large reclosable plastic bags for storing the finished test sample. The method of testing consists of six steps. The water sample is collected in the 100 ml bag and mixed with the growth medium powder. The GEL powder is distributed into the large plastic bags before the water sample and growth medium mixture are poured into the large plastic bag. The mixture is now massaged and pressed until the powder is fully dissolved and no lumps are left. In order to prepare the sample for incubation, the now gelatinous mixture is spread and flattened in the large plastic bag. The sample is then placed in ambient temperature incubation at 25°C or higher. After 20-48 hours, depending on the temperature, the sample is ready to be analysed by counting the number of formed E. coli colonies (figure 2.24 and figure 2.25).

During the fieldwork, two water samples were collected for E. coli testing at most of the water points. After the samples were ready for incubation, they were placed flat in a plastic box in a closet with no lights. Temperatures were described as ambient and above 20 °C. The incubation time varied from 45-87 hours. The difference in incubation time for the different samples was because of external factors when conducting the fieldwork such as incubation temperature, travelling and scheduling.

When analysing E. coli samples, a classification provided by the test kit manufacturer was used in order to determine the risk associated with the results. The classification provided is retrieved from WHO's Guidelines for Drinking Water Quality [WHO, 2017, table 5.4]. The classification assesses the hazard in terms of how many E. coli colonies are found and the susceptibility to contamination from faeces from animals or humans (see figure 3.6). The susceptibility of contamination in this study is based on visual inspection of the water point area and the surrounding area, which includes human and animal activities and agricultural activities.

Limitations

Limitations in the methodology of E. coli testing mainly concerns the accuracy of the tests and the incubation time and temperature. An independent laboratory evaluation of the test kits used in this study was issued by WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) and conducted by KWR research laboratory, with a report being published in October 2022 [WHO et al., 2022]. This report states that at a temperature of 25 °C, with 48 hours incubation time, 95% of the tests matched the expected value. In the case of this study, some samples were incubated for longer than the suggested 40-48 hours. The effect of this is also evaluated in the JMP report, and the results suggest that the increase in E. coli organisms found because of prolonged incubation time is small [WHO et al., 2022, table 27]. The incubation temperatures were not controlled during the full duration of testing, which might also affect the results.

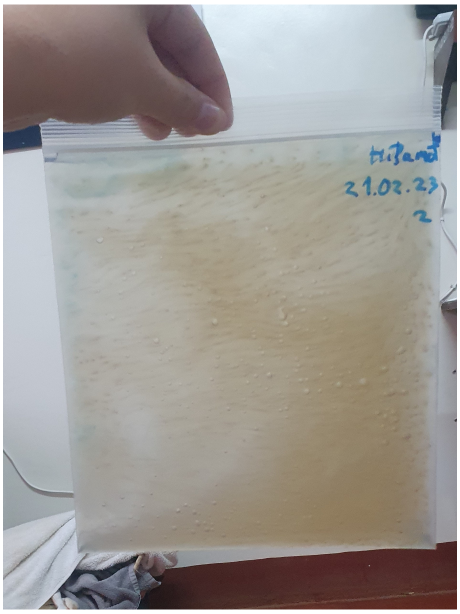


Figure 2.24: E. coli test without colonies.

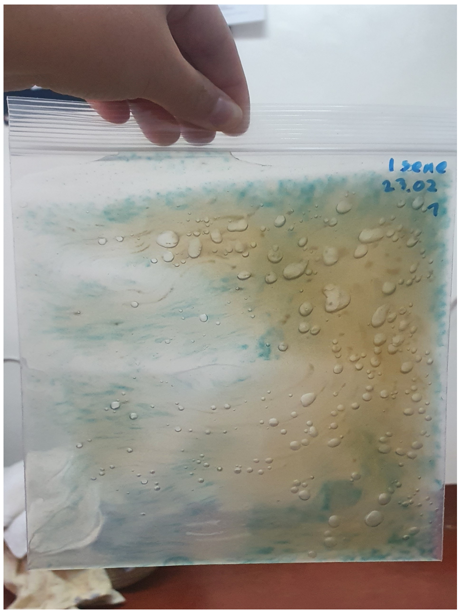


Figure 2.25: E. coli test with colonies.

2.8 Remote monitoring system

The Community Management approach is an accepted and widely used strategy for rural water supply management [Thomson, 2020]. Many pumps in SSA are currently non-functional and it has been pointed out that the water committee in charge of managing a community's water supply system frequently faces numerous technical and financial challenges that are difficult to overcome without sufficient support [Andres et al., 2018]. Difficulties with excessive management responsibility in relation to community capacity are also an issue that has been reported in this project [Røer, 2020, Asklund, 2020, Evang and Bakken, 2021]. Several of the CBWSOs stated that financial and technical support from RUWASA is often needed for major repairs or maintenance. This was confirmed by 4CCP staff [Personal communication, James Mmbando and Ahadi Mollel, 26th of February].

According to Thomson [2020], by directly connecting rural water infrastructure to the information-transfer infrastructure of the mobile phone network, and thus into the Internet of Things, automated monitoring may be able to address some of the shortcomings in community management and make it easier for more centralised management support. Remote monitoring systems could automate data generation and distribution and provide information for more efficient maintenance and repair services, enabling new models for rural water management and helping to blur the line between rural and urban contexts [Thomson, 2020].

According to 4CCP, [Personal communication, James Mmbando and Ahadi Mollel, 26th of February] and affirmed by the representatives from the district engineer [Personal communication, Representatives from the district engineer office, 21st of February] and several CBWSOs, if a problem occurs today, the current chain of reporting begins with the seller notifying the CBWSO that calls either 4CCP or the Water Ward. They then call the RUWASA on the CBWSOs behalf. Someone from RUWASA is dispatched to the water points to evaluate the issue. If the required spare parts are not already in stock, they are ordered. They return to the water point and complete the repair once they have all the necessary equipment. Since this process frequently takes a long time, the villagers are forced to travel great distances in search of water or use unsafe water sources like rivers and open wells. The area's inadequate road system and low technician density contribute to the lengthy repair times.

The resources needed for maintenance increase in magnitude as the areas' water supply systems develop. The representatives from the district engineers interviewed both reported that the water access coverage in rural areas is around 60% [Personal communication, Representatives from the district engineers, 21st of February]. Tanzania has a goal that 85% of the country's population should have sufficient access to clean water by 2025 [RUWASA, nd]. This leads to a substantial increase in the number of water points. In the Hanang district, they plan to build 16 new groundwater wells during the next two years. This will drastically enhance the workload connected to supervision and repairs for the RUWASA. This issue is enhanced by poor road infrastructure, long distances, few technicians and increasingly complex water supply systems [Personal communication, Representatives from the district engineer office, 26th of February].

Therefore, technology that enables remote monitoring and management of water system performance by several stakeholders is a relevant tool in this context and could decrease repair time and enhance the management and operation of the water points [Thomson, 2020].

2.8.1 Relevant parameters to monitor

The parameters chosen for operational monitoring should be effective ways of assessing how well each control measure works, give a timely indication of performance, be simple to measure, and allow for an appropriate response.[WHO, 2017]. Relevant parameters to monitor in a RWSS according to Thomson [2020] are pump rate, water use, the water level in the borehole and the pump power [Thomson, 2020]. The manufacturer of the pumps used in this project also lists running current, water output and water quality as parameters that should be monitored regularly [Davis and Shirtliff, nd]. The list below includes some potential uses for the information on these parameters.

Measuring the power generated by the solar cells in a solar-powered system enables continuous monitoring of solar energy production and allows operators to identify any deviations from expected power levels [Edodi et al., 2022]. This information allows for a timely detection of potential issues, such as shading, dirt accumulation on the panels or malfunctions in the solar system, enabling quick maintenance or repairs to ensure optimal power generation. It also provides valuable data for system optimisation. By analysing the power output under different conditions, such as varying weather patterns or times of day, operators can identify trends and patterns. This information allows for better resource planning and allocation, such as scheduling water pumping during times of peak power generation. Furthermore, monitoring the power generated by solar cells allows for effective system management and resource allocation. Operators can use the data to assess the system's capacity and determine if additional solar panels or storage capacity are required to meet the demand [Edodi et al., 2022]. Unstable electrical supply affecting pump operations and reliability of service is one of the major issues that affect sustainability in RWSS [Lockwood et al., 2003] and is, therefore, important to monitor.

The water level can be monitored by a pressure sensor in the borehole below the water level [Asklund, 2020]. The fluctuations in the water level can indicate if the extraction is sustainable in the short and long term. Stakeholders can use this information to make informed decisions about the long-time management of water resources, making it possible to initiate appropriate actions to ensure sustainability and a continuous water supply to the community [Thomson, 2020].

The output from the pump is a valuable parameter to monitor since it is a direct measurement of the pump's performance [Thomson, 2020]. The velocity measured by a water metre can be used to calculate the flow [Davis and Shirtliff, nd]. Although calibrations are required to provide accurate estimates, incorporating a sensor to detect the presence of water in the outlet is another method of estimating the volume of the water output, but this is likely to be susceptible to errors if the pump is experiencing mechanical problems [Thomson, 2020].

Monitoring user habits in solar-powered water well systems can be achieved by measuring the flow out of the storage tank using a water meter [Cardell-Oliver, 2013]. This data provides valuable information about the amount and timing of water demand, enabling accurate prediction of user patterns. By understanding these patterns, storage and pumping can be effectively managed to meet user needs efficiently [Cardell-Oliver, 2013].

Groundwater has a natural protection against contamination, but can still have water quality issues as described in 2.7. Potential risks and issues can be identified by regularly assessing the water quality parameters, and ensuring the supply of safe and clean water [Gokulanathan et al., 2019]. By proactively monitoring water quality, appropriate measures, such as implementing filtration systems, disinfection treatments, or maintenance protocols, can be taken to address any identified issues as soon as possible [Gokulanathan et al., 2019].

Monitoring the parameters mentioned above offers numerous benefits. These include early detection of issues, efficient management of water resources, and timely repairs[Davis and Shirtliff, nd]. By closely monitoring these parameters, you can improve the sustainability of the RWSS by ensuring a smooth operation of the system, extending its lifespan, and providing a reliable water supply to meet the needs of the users [Thomson, 2020].

2.8.2 Previous work

The first remote monitoring system installed on this project was installed in 2018 by NCA in two villages, Munguli and Gidarudagaw and monitored one solar-driven water well and one hand pump. The system was made with Ardiuno hardware elements, and a code inspired by the online Ardiuno community [Martinsen, 2018]. The system could both store data locally and transfer using a SIM card. The power source was a battery that was recharged with a small solar panel. The sensor used was a basic turbine meter that measured the water flow from the pump to the outlet. The system sent the data to a web page where the data could be used by relevant stakeholders, but the local storage of data also made it possible to read and access the stored data by reading the memory card [Martinsen, 2018].

The system in Munguli did only record water flow values as zero, and the system in Giderudgaw did not transmit the values it recorded [Martinsen, 2018, p. 28-33]. Unfortunately, these issues could not be resolved, and it was decided to replace the modules with ones that only stored data locally. The main challenge was the issue of mobile network coverage since both locations are rural. The system in Giderudgaw was placed in a box of metal for protection, but that posed a challenge for data transfer. Additionally, the high temperatures in the area caused the system to shut down, so the installation of a fan component to cool the system was mentioned as a possible solution [Martinsen, 2018, p. 28-33].

In the spring of 2020, Trine Ånestad Røer [2020] and Maria Asklund [2020] used the lessons from the last system and installed a remote monitoring sensor system in Endagaw Chini, Mewadani and Basonyagwe in relation to their master thesis. The system was designed by El-watch and was made up of a set of

Figure 2.26: Remote monitoring system installed in 2018 by NCA as described by Martinsen [2018, p. 30-31]

sensors, a data transmission unit, a power supply, a regulator, and a user interface [Asklund, 2020, p. 27]. These sensors gathered information which was then sent to the data transmission unit i.e., the gateway. The gateway sent this information to the El-Watch cloud solution through the mobile network. The sensors recorded data every 10 minutes and the gateway roamed among networks to choose the best signal using an integrated eSIM. The information was downloaded from a protected login via a webpage called https://neuronsensors.app. This is El-watch's own user interface for remote monitoring systems. At each pumping station, several sensors were installed, including a pressure sensor that measured the water level in the tank and the current of the pump. Two pumping stations, Mewadani and Basonyagwe, installed an additional pressure sensor (UNIK5000) inside the borehole to measure the water level [Asklund, 2020, p. 26]. These pressure sensors are reused in the current system. The sensors were installed at 80 m below the borehole top in Basonyagwe and 69 m below the borehole top in Mewadani [Evang and Bakken, 2021, p. 27]. The UNIK5000 Pressure sensor is designed to measure the hydrostatic head, which then is used to determine the water level inside the well. The sensor generates an analogue signal measured in milliamperes (mA), with a range from 4-20 mA which corresponds to the measuring range of 0-100 meter water column (m wc). The analogue data from the sensors was converted into a digital signal by a digitizer and then transferred by the gateway. [Asklund, 2020, p. 26]

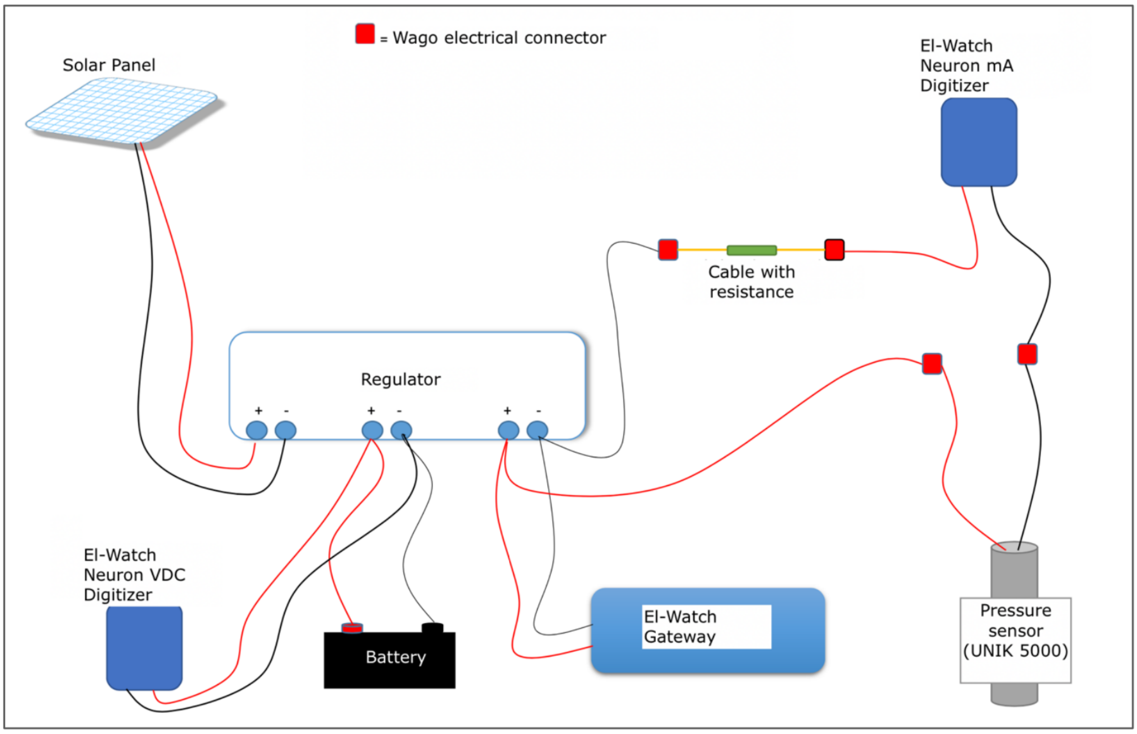


Figure 2.27: Remote monitoring system configuration [Personal communication, Endre Våland Bø, 28_{th} of January 2020 [Asklund, 2020, p. 27]]

The remote monitoring system was generally successful, but had some mobile network problems, that sometimes led to a stop in transmitting, but this seldom lasted longer than a couple of hours. The pressure sensor in the tank in Endagaw Chini and the current sensor in Mewadani both stopped working in the spring of 2020. The UNIK5000 pressure sensor also had some disturbance in the data. However, the system was expensive to keep operational due to the high cost of data. Therefore the subscription was stopped in the spring of 2021. It was believed that the system could easily be started up again by resubscribing [Røer, 2020, Asklund, 2020].

2.8.3 The system

During the fall of 2022 it was discovered that the El-watch system could not simply be rebutted and resubscribed. Therefore it was decided to make a new system for monitoring the water well in Basonyagwe, Mewadani and Endagaw Chini, reusing as much of the old system as possible. For this task, Bendik Sægrov-Sorte was contacted. He is a Senior Automation Engineer at SINTEF and agreed to design the system and build a new gateway in his free time. He also wrote a user manual listed in its entirety in Appendix G. The system was designed within a short time scope and some of the design choices in the system have been made based on what was possible and what was available at such short notice. During planning and instalment, there was an understanding that there had also been a pressure sensor installed in the well in Endagaw Chini by Asklund and Røer in 2020. There had not been installed a pressure sensor in the well in Endagaw Chini [Asklund, 2020, Røer, 2020], but this misunderstanding affected the design choices and implementation of the system.

The main focus of the new system that Sægrov-Sorte designed was to have a cheaper and more reliable way to transmit the necessary data since this had been an obstacle in the past [Asklund, 2020]. 2G has the best reach in this area [TCRA, nd] and was chosen as the preferred mobile service. Due to limited bandwidth and cost considerations, it was important to transfer data as compactly as possible.

It was decided to use as much of the old system as possible. This included the solar panels, the UNIK5000 pressure sensors in the well in Basonyagwe, the regulator and some of the wires. The old wooden boxes used to contain the old system were also reused. This equipment was only three years old and was believed to be functioning. The batteries were replaced and the El-watch's gateway was replaced with the one Sægrov-Sorte made. In addition to the water level in the well in Basonyagwe, the ampere and voltage of the pump were monitored with a sensor at both locations. It was also deemed useful to have a pressure sensor in the water tanks to see the yield and the usage. The gateways are designed for such a sensor but this was not implemented because we could not find appropriate pressure sensors in the short time period before the fieldwork. The system is illustrated in Figure 2.28 below.

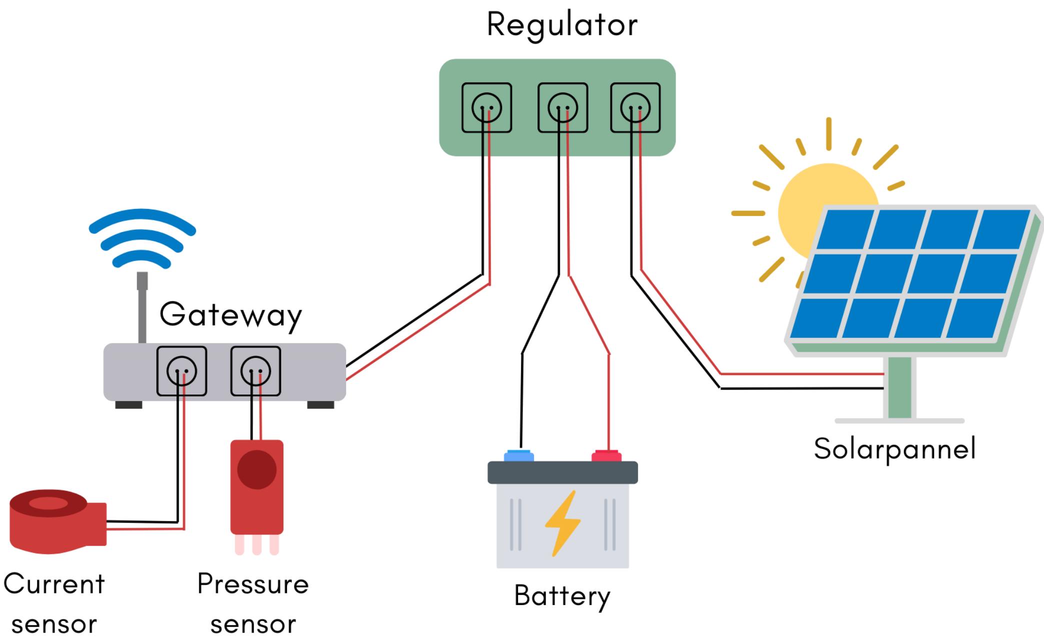


Figure 2.28: Illustration of the installed remote monitoring system.

The gateways are made with pieces that can be easily bought online and cost approximately 50 USD in parts each. The boxes are connected to the 12V DC battery that is recharged by the small solar panel that was bought for the El-watch system. Each box is equipped with 2 channels for pressure sensors and one channel for a clamp-on sensor that measures the AC current through the pump. Each box must have its own sim card with a preferably cheap prepaid mobile subscription with available data. The microcontroller in the gateway is programmed with the Arduino IDE by Bendik Sægrov-Sorte. The microcontroller is accessed via a micro-USB port, which makes it easy to change relevant parameters in the field. The code can be seen in its entirety in Appendix G. This microcontroller calculates the water column in the tanks with a range of 0-100m which corresponds to a signal from the pressure sensor in the range of 4-20mA using Equation 2.7. This is the same method as described by Evang and Bakken [2020, p. 23].

$$H = \frac{H_{max} - H_{min}}{I_{max} - I_{min}} * (I - I_{min}) + H_{min}$$
$$= \frac{100 - 0}{20 - 4} * (I - 4) + 0 = \frac{100}{16} * (I - 4) \quad (2.7)$$

where:
H = meter water column
I = sensor signal

It also uses the converted analogue signal from the clamp-on sensor to calculate the AC current in ampere and the pump power in kW assuming a voltage of 230 V. The pump time is determined by observing the changes in pump power that exceed the predetermined threshold of 500 W. Specifically, it notes the transition from power levels below the threshold to levels above it and vice versa and then calculates the time the pump was above the threshold. All this data is then transmitted by the gateway to a cloud solution called ThingSpeak. This is done at chosen intervals programmed into the microcontroller. ThingSpeak was chosen as a cloud service by Sægrov-Sorte because the system is designed for use at universities with Matlab integration and offers both a free and a paid version [MathWorks, nd]. The free version can have 4 channels (or wells/boxes) connected and has enough storage capacity to send data every half hour from the 3 wells for 50 years. It is also user-friendly and has tools that make it easy to present the data in an accessible way, as shown in Figure 3.7 or 3.9.

The technical function of the gateway

This section is a summary of how the gateway is built up as described in Appendix G. The gateway is built up of different components. An esp32 microcontroller communicates with a sim800l 2G modem with a sim card over rs232. A 4-channel 16-bit ADC (analogue to digital converter) communicates over the I^2C bus (adr 0) and is used to acquire signals from the two planned pressure transducers (24 V DC, 4-20 mA) placed in the well and in the water tank. It also acquires signals from the clamp-on AC current meter mounted on one of the conductors of the pump (after the inverter). The signal from the clamp-on meters is 200 mV AC and is rectified with an OpAmp rectifier on the way to the ADC. A 220 Ohm resistor is mounted on the pressure inputs between the channel input and ground, this gives a measurement range of 0.88-4.4 V for the 4-20 mA sensor. There are 3 power supplies inside the box; 1 boost converter that converts 12 V DC to 24 V DC and provides voltage to the pressure transmitters and 2 step-down converters that create respectively 5 V DC to esp32 and 4 V DC to sim800l modem and ADC.

2.8.4 The sensors

The sensors were chosen based mainly on two factors: what data was considered to be valuable in the management of the system, and what sensors were possible to acquire on short notice. The system in Basonyagwe has two sensors, one pressure sensor in the well and one clamp-on current sensor that measures pump power. The system in Endagaw Chini only has the current sensor. Furthermore, the gateway is designed for an additional pressure sensor that could be installed in the water tank.

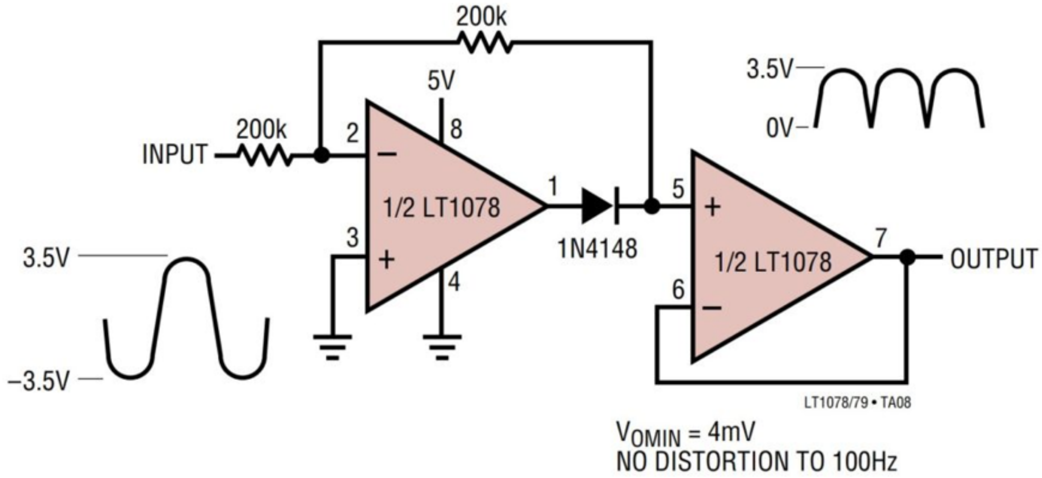


Figure 2.29: Overview of the technical function of the gateway [Sægrov-Sorte, 2023]

Monitoring the water level

The changes in water level are an important factor to monitor when using groundwater for water supply. The groundwater level fluctuates due to seasonal changes, climate changes and human consumption, among other things [Cuthbert et al., 2019]. From a sustainable water supply perspective, monitoring the water level in groundwater wells can therefore be argued to be beneficial. Early detection of signs of declining water levels can be critical for initiating appropriate actions to prevent negative consequences such as water scarcity and environmental impacts [Thomson, 2020]. The data from the sensor could also be used to calculate the drawdown or recovery during a pump test as described in 2.4.

Monitoring the pump current

The data from the current meter is used to calculate ampere, pump power and pump time. Each of these parameters can be valuable from a management perspective as they indicate when the pump is on and how much power the pump is getting at different times of the day [Thomson, 2020]. Additionally, data on the amount of power the pump is getting can be used to evaluate whether it is able to provide sufficient lifting height, by comparing the data to the pumps' operation point and the kW curve provided by the manufacturer[Davis and Shirtliff, nd]. This method is described in 2.4

Calibrating of the sensors

The current sensor was calibrated by Sægrov-Sorte by comparing the readings with a fluke multimeter against 3 resistive sources (heaters 400, 600, 1000W) which gave a linear response.

The UNIK5000 was not calibrated by Asklund [2020, p. 86], but an initial control was conducted using Equation 2.7 and measurements from an amperemeter and a Pocket Dipper. The ampere meter was a Fluke87 True RMS Multimeter, with an accuracy of $\pm$ (0.2 % + 2) mA and a resolution of 0.01mA [Asklund, 2020, p. 86]. The Pocket Dipper is a device that monitors water level with an approximated accuracy of $\pm$ 0.5m. The measured water level done by the Pocket Dipper was then compared to the ampere reading by the multimeter of the UNIK5000 sensor. In Basonyagwe the two different measurements gave slightly different results with the Pocked Dipper measurements recording a hydrostatic head above the UNIK5000 pressure sensor of 50.0 ± 0.5m, and the amperementer recording a hydrostatic head of 49.00 ± 0.17m [Asklund, 2020, p. 86].

Limitations to the system

There were not taken verification measurements on different parts of the system. If two sensors measure the same quantity, it increases confidence in the accuracy of the measurements and ensures that the system is functioning as expected. This could have helped mitigate the uncertainty and improved the accuracy of the results.

Asklund [2020] found the measurements from the UNIK5000 sensor to experience some disturbances and argued that the measurement range of 0-100 m may be too large and that this lead to relatively large changes in recorded water level based on a small change in pressure [Asklund, 2020]. Nothing was done to mitigate this uncertainty.

Another potential limitation is that the pump time threshold may be set incorrectly, which can result in the system failing to record all the times when the pump is turned on or reporting it to be shut off prematurely. This can be particularly problematic in this pumping station because it is solar powered and a cloud can lead to fluctuations in power [WB, 2018]. This can lead to an underestimation of how much water is being pumped, or how much the pump is used.

The system only monitors the water level and current to the pump. As described in 2.8.1 there are several other parameters that would give information about other important aspects of the system. Additionally, the information from monitoring additional parameters could be used to verify the quality of the data from the sensors installed. The water point has a water meter in the outlet pipe from the tank that measures usage, but this has to be manually read at the site. By digitising and remotely monitoring the data from the water meter, it would be possible to track water usage patterns in real time. This would give stakeholders a better understanding of how and when water is used and would therefore enable better management of the water supply and help ensure its sustainability [Cardell-Oliver, 2013].

2.8.5 The instalment

Before the instalment, the villages of Endagaw Chini, Mewadani and Basonyagwe were visited to see how much of the old system could still be used. In Basonyagwe the entirety of the old system was intact. In Mewadani the pump had been changed into an electric pump and in the process, the pressure sensor had been removed from the well and misplaced. In Endagaw Chini the monitoring system had been removed.

Unfortunately, at this time there was an incorrect understanding that a pressure sensor had also been installed in Endagaw Chini. The location had a wire coming up from the well similar to Basonyagwe and it was decided that the equipment from Mewadani was moved to Engadaw Chini and connected to the presumed pressure sensor in the well there. It was later found out that this was not the case, explaining why there were no readings from the water level data in Endagaw Chini.

The system reused the wooden box, the solar panel, the pressure sensor in the well (in Basonyagwe) and the converter from the old system. The new battery was connected to the converter along with the gateway as shown in Figure 2.28. The old UNIK5000 sensor in the well was then connected to the gateway along with the sensor measuring current. The current sensor was clamped around the pump's power cord on the AC side of the converter for the pump. Some of the wires needed to be lengthened. This was done by splicing on a new wire. In the joints, the wires were stripped and then twisted together, and finally protected with electrical tape.

The transferring frequency was set to 30 minutes to ensure enough space for the sensors to run for several years on the Thingspeak-platform. It was not possible to acquire a working prepaid sim card, so it was decided to get the cheapest available subscription. It was a subscription for 10000 TZN (approx. 5 USD) a month, and an arrangement was made with 4CCP for the subscription to be refilled each month. This increased the cost of data transfer for the system drastically, although being significantly less than the El-watch system previously used.

Important parts of the old system had been removed in two out of three villages. It was noted that a possible explanation for this could be an insufficient understanding of the system, including its functions and maintenance requirements. It was therefore decided to go back to the villages after the instalment to meet with the CBWSOs and to talk to them about how the system worked and what it monitored. It was also important to provide CBWSOs with an accurate understanding of the extent of the information that could be accessed by outsiders to prevent misunderstandings and potential privacy concerns.

Limitation to the instalment

The measurement frequency was set to 30 minutes which could lead to relevant data being lost. This means that the system may not be able to detect rapid changes in the pump's performance or provide real-time feedback on its operation. In some cases, this may be acceptable, but in others, it may limit the usefulness of the system and the ability to identify potential problems before they cause damage or downtime. This was counteracted by the system sending data every time the pump was shut off (when the pump power fell below the threshold of 0.5 kW).

Another limitation is the technical skills of the installers. The installers were inexperienced with this kind of work and this may have caused errors or unnecessary bad connections. A bad connection can occur when the wires are not properly spliced, causing a weak or intermittent electrical connection. This can lead to a loss of signal or noise interference, which can affect the quality of the data being collected by the sensor system.

It was unfortunate that a prepaid sim card could not be installed, because the subscription needs to be refilled, which makes it vulnerable to human error. A solution with a monthly subscription requires more maintenance to function, which can cause problems with reliability. This is a vulnerability that could be solved with a prepaid sim card or decreased if the subscription is checked regularly.

2.8.6 Analysing the data

The focus of the analysis will be on the function of the transmission and the quality of the data gathered, as the data is primarily used to determine how well the remote monitoring system performs. The data was also used to find the operating point of the well in Basonyagwe.

The factors determining data quality are relative to the use of the data [Bennett et al., 2015], but key factors that often are evaluated are validity, relevance, accuracy, consistency and completeness [Chen et al., 2015, Bennett et al., 2015]. The ability of data to represent the processes that are to be monitored is often referred to as validity. The relevance of the data refers to the data providing information that is relevant to management or decision support [Bennett et al., 2015]. Accuracy refers to the data's ability to accurately represent a value [Chen et al., 2015]. The lack of gaps in data is referred to as completeness. In this system, data gaps can occur due to for example poor mobile reception or malfunctioning sensors. Data gaps are unfortunate and can result in important situations going unreported. Consistency is a measure of how well the values are consistent with other data sets or with themselves. This can imply there's a smaller amount of noise in the values and that the values do not have nonphysical changes or values [Chen et al., 2015]. These are all factors that are important to asses when evaluating the quality of data. The accuracy, completeness, and consistency are all directly linked to the sensor. The performance of the system can be assessed by visual representation, analysing for nonphysical changes or values or gaps in data [Bennett et al., 2015].

The quality of the data gathered from both the pressure sensor and the current meter was analysed by plotting the data to detect gaps and outliers as well as nonphysical changes. The data from the pressure sensor could theoretically be used to monitor fluctuations in the groundwater level, which could indicate the trends of recharge and discharge of the groundwater [MacDonald and Davies, 2000]. This would require a longer data series than it is possible to obtain within the scope of a master's thesis. It is important to note that future studies with longer data series may be able to provide more comprehensive insights into the fluctuations of groundwater levels from the data given by the sensor.

The data from the current meter was used to assess the pump performance. This was done by calculating the system characteristics to find the operation point and then comparing the measured pump power to the corresponding pump power given by the manufacturer via the power curve, as described in 2.4.2 This calculation was done to see the effect of the pump and the function of the system to exemplify how the data could be used in a management setting.

The calculation of the operating point of the well in Basonyagwe

The calculation of the system curve was done according to the method described in 2.4.2. The pump curve was given by the manufacturer, and the system curve was calculated. The system curve is, as mentioned earlier, a function of the total head and consists of static water level, drawdown (Δs) and energy losses. Both drawdown and energy losses are functions of flow.

The static water level was measured by both NCA in 2016 and Asklund in 2020 to be 20m [Asklund, 2020]. The drawdown can be measured during a pump test. This was not conducted, so the drawdown was calculated using Equation 2.8. According to Gjengedal et. al. [2023], if the velocity of the flow is low and the flow is linear, the viscous flow forces dominate and the acceleration forces are negligible. This means that the drawdown of the well is proportional to the pump rate [Gjengedal et al., 2023]. The NCA conducted a pump test before the construction of the well and found that the drawdown was 31 m when the pump rate was 4 m^3. Parameter B was then calculated by finding the gradient of the line between the value of the drawdown from the pump test conducted by NCA and the boundary condition of zero drawdowns for zero flow. B was found to have the value 9. The drawdown was then calculated using Equation 2.9 The values are listed in Table 3.14.

$$\Delta s = B * Q + c * Q^2 \tag{2.8}$$

where:
Δs is drawdown.
Q = flow
$B * Q$ = the viscous flow force contribution.
$C * Q^2$ = the acceleration force contribution.

$$\Delta s = B * Q = 9Q \tag{2.9}$$

where:
Δs = drawdown.
Q = flow
B = the linear correlation coefficient dependent on the viscous flow force.

The energy loss was calculated by adding the friction loss and minor loss calculated using Equation 2.1 and 2.4. The Reynolds number used in the calculation is calculated according to Equation 2.3, and the friction factor was calculated according to Equation 2.2 using the value 0.1 for roughness in PE pipes as listed in Table 3.1 from [Ødegaard, 2014, p.71]. The velocity was calculated according to Equation 2.5. The values are listed in the Tables 3.13, 3.12 and 3.14.

The minor loss was calculated using Equation 2.4. The k_s used was taken from Table 3.3 in Ødegaard [2014, p.74]. Assuming two 90-degree bends (k_1=1.5) in the pipe with a diameter of 38 mm, one constriction from 38 mm to 15.6 mm (k_2=0.6) and one T-cross (k_3=1), two 90-degree bends (k_1=1.5) and one outflow to the tank (k_4=1) in the pipe with a dimension of 15.6 mm, the total $k_{s,38}$ has value 3.6 and $k_{s,15.6}$ has the value 5. The different parameters of the system used in the calculation of friction and minor losses are listed in Table 2.6 below. Both the velocity, singular loss, friction factor and Reynolds number were calculated for each of the diameters.

Table 2.6: Parameters used in the calculation of friction and minor losses.

Parameter	**Description**	**Value**	**Unit**
D,	Rising pipe	0.038	m
Diameter	Rest of pipes	0.0156	
L,	Length of rising pipe	100	m
Length of pipe	Length of vertical pipe to tank	5.4	
	Length of horizontal pipes	4.0	
k,	In PE-pipes	0.1	mm
Roughness cofficient			
k_s,	Total k for 38 mm pipe	3.6 ,	Unitless
Singular coefficient	Total k for 15.6 mm pipe	5.0	

The water tank inlet is approximately 5.4 m above ground [Asklund, 2020]. The horizontal distance from the borehole to the tank is 3 m, approximated from pictures of the water point. The rising pipe has a dimension of 38 mm [Røer, 2020], and the additional pipes have a dimension of 38 mm and 15.6 mm approximated from pictures in the field and values measured by Asklund [2020], as shown in Table 2.6.

Limitations to the analysing method

There are uncertainties connected to several of the parameters used to calculate the operation point. The estimate of the drawdown at various discharges was calculated using the premise that the aquifer in Basonyagwe has a low flow velocity. Also, it is predicated on the notion of linear flow. It is not likely to be linear flow near the borehole [Gjengedal et al., 2023], and there was not conducted any test to measure the velocity of flow. If the assumptions made are not correct, the drawdown would no longer be linear, but parabolic. This would mean that the operation point with a pump rate of less than 4 m3/h would be underestimated, while the subsequent points would be overestimated.

Additionally, NCA did not consistently use the same pump when conducting the pump test as they installed [Røer, 2020]. As a result, the drawdown and discharge utilised to determine the drawdown's slope (B) are uncertain.

The dimensions and length used are based on pictures and approximated measurements in the field, as well as values listed by Asklund [2020] and Røer [2020]. The values listed by Asklund [2020] and Røer [2020] are not identical, and so the decision of which values to use in this calculation was made by analysing pictures and making an educated guess. The values used for dimensions and length should be regarded as approximations.

The uncertainties mentioned above contribute to uncertainty related to the accuracy of the operation point for this pumping station. It is important to keep that in mind and carefully consider what the calculations are used for and what certainty is needed in order to ensure the necessary accuracy of the final result.

Chapter 3

Results

This chapter presents the results obtained from the analyses conducted in this study. The findings are organised into four distinct sets of results, each linked to one of the research questions. The limitations of a result are discussed immediately after its presentation. The purpose of this approach is to provide a clear and nuanced understanding of the individual results before a broader contextual discussion is conducted in the subsequent chapter.

Firstly, the paths found to lead to community-driven development by the QCA are presented, before the designed expansion of the water supply system in Dang'aida is outlined and reviewed. Thereafter, the results from the water quality analyses are conveyed. Finally, the data from the implemented remote systems is presented, and the function of the systems is examined.

3.1 Qualitative comparative analysis

In this section, the results from the qualitative comparative analysis conducted on the interview data will be presented. The results will be commented on and discussed on the basis of the main research question:

"Which conditions contribute to community-driven water system development in rural Tanzania and how can such a development be facilitated?"

In this section, the results pertaining to the first part of this question will be presented and discussed. This will be done by assessing the conditions used in the analysis and evaluating the validity of the results. The pathway(s) obtained from the analysis will also be assessed and a discussion on how these results translate into the real world will be conducted. The framework for the analysis is elaborated on in section 2.5.4.

The second part of the main research question will be discussed and answered in the final discussion (chapter 4). This will be done using the results and insights gained through the discussions of research sub-questions in the previous parts of this study as well as this one. It will be the final discussion before drawing the conclusion.

3.1.1 Causal conditions

The different scores for the villages for each condition and the outcome is presented in table 3.1 As mentioned in section 2.5.4, the villages are scored either 1 (presence of a condition), 0.67 (not full presence), 0.33 (not full absence) and 0 (absence of a condition). The full scoring table of all considered conditions is found in Appendix A. Explanations of the outcome and conditions, as well as examples of the scoring, are found below table 3.1.

Table 3.1: Scoring matrix for conditions and outcome for each village.

Village	UA	RS	FD	SSR	AAWS	Outcome
5	1	0.67	1	1	0.67	1
11	1	0	0.33	1	1	1
12	0.67	0.67	0.67	0.67	1	1
13	1	0.67	0.33	0.67	0.67	1
1	1	1	0.33	1	0.67	0.67
3	1	0.33	0.67	0.67	1	0.67
2	0.33	0.67	0.33	0	0.33	0.33
7	0.67	0	0	0.67	0.67	0.33
4	0.33	0.33	0.33	0	0	0
6	0	1	1	0.67	0	0
8	0.33	0	0.33	0.33	0.33	0
9	0.33	0	0.67	1	0.67	0
10	0.67	0	0.33	0	0	0

UA: User acceptability; RS: Repair service; FD: Financial durability; SSR: Storage and supply reliability; AAWS: Absence of alternative water source.

Development (OUTCOME)

In total 13 villages were included as cases in the QCA. In the case of the selected outcome (development), four of the villages scored the highest of 1. A score of 1 implied that the village had expanded the water system to include a tap in a different area from the borehole. One example of a top-scoring case is Village 5. In Village 5, they have extended the water infrastructure with a tap at the primary school and they have plans of expanding to sub-villages in the area. Another case, Village 11, has expanded with multiple taps around the village and the schools. It was important not to differentiate between multiple taps and one tap when scoring since most of the villages are somewhat different in size and population density, and therefore their needs might be different.

Furthermore, two villages scored 0.67. These two villages were evaluated to have feasible plans for major development, i.e., expansion of the water infrastructure, and being reasonably close to the implementation of such developments. This assessment was based on CBWSO interviews and field observations and the in-depth knowledge gained through the QCA method. In one of the villages, Village 3, plans to expand to the primary school are in place.

The lower scores of 0.33 and 0 were given to the cases with the least amount of development. A score of 0.33 was given to two villages and a score of 0 was given to five villages. In the cases where 0.33 was given, they had either at least two small physical developments, such as office buildings, cattle troughs or vegetable gardens, or one income-generating development. One example of the implementation of income-generating development is Village 2, where the CBSWO had started renting out the land around the water borehole for agricultural use. The villages with the lowest score did not have any development or they had only one small development.

An important factor to mention is the age of the water systems assessed in the QCA. It is reasonable to assume that older water systems have more development. In order to evaluate whether this is the case, the correlation between the age of the system and the outcome was calculated. This yielded a correlation coefficient of 0.17, which is a negligible correlation [Mukaka, 2012].

User acceptability

User acceptability assesses the community satisfaction with the water system by evaluating four factors (see 2.5.3). The scoring of the cases was based on how many of these factors the users in each village were satisfied with. 1 for satisfaction with all four, 0.67 for satisfaction with 3 of them, and so on. If we take Village 2 as an example, when asked whether they were satisfied with the water quantity they were getting, 6 out of 8 respondents said yes, while 2 said no. In this case, satisfaction with water quantity was interpreted to be present. These types of evaluations were conducted for each factor for each case.

Repair service

The repair service is scored based on what kind of repairs have had to be done as well as the time it takes to get the repairs done. Cases where no major repairs are needed and small repairs are rarely needed are awarded a top score of 1. Access to a quick repair service is often unavailable, with Village 11 reporting that they had to wait 2 months for their last repair. Thus, a score of 0 was given in this case.

Financial durability

Financial durability is assessed based on several factors such as the ability to generate enough income for expenses through tariff collection and having savings for major repairs and future development. Village 5 is an example of a case where the tariff collection is enough to cover all salaries and contribute towards savings, and are therefore being scored with the highest score of 1. The number of users will naturally affect the income generation, and it has therefore been taken into account as best as possible by relating savings to the population size.

Storage and supply reliability

Another conditions included in the QCA were storage and supply reliability. This was scored based on the ability to store and supply water without issues. Issues include problems with filling the storage tanks and not having water during operational hours. Village 8 reported not having enough storage, leading to the tanks sometimes being empty at the end of the day. This case was scored 0.33, as the issues were less frequent than other cases.

Absence of alternative water source

This condition was not derived from the sustainability indicators but was included because of relevance. Although having multiple water sources is positive for the communities, it is in the analysis seen as a drawback in the evaluation of one specific water system. Cases reporting frequent use of other water sources, especially for domestic use, were therefore given a score of 0. Village 5 mostly reported that other sources were only used as drinking water for the cattle and were therefore given a score of 0.67.

3.1.2 Pathways to development

Using the conditions mentioned above, the QCA identifies two pathways to development, which are presented in table 3.2. Both pathways consists of a combination of four conditions, where three of the conditions: user acceptability, storage and supply reliability and absence of alternative water source are present in both pathways. The difference in pathways is the inclusion of repair service in one, and financial durability in the other. Both pathways are the intermediate solution proposed by the QCA. The intermediate solution was used as it was referred to as the superior solution in QCA literature (see section 2.5.4). Also included in table 3.2 is which of the villages follows which path to development. In table 3.3, it is seen that one of the conditions surpassed the consistency value (see 2.5.4) limit of 0.90 needed to become a necessary condition. This indicates that this condition, user acceptability, is a necessity for the outcome to be reached.

Table 3.2: Pathways to development identified by the QCA.

Pathways									**Villages included in pathway**
1:	UA	+	RS	+	SSR	+	Absence of AWS		1, 5, 13
2:	UA	+	FD	+	SSR	+	Absence of AWS		3, 5, 12, 13

UA: User acceptability; RS: Repair service; FD: Financial durability; SSR: Storage and supply reliability; AWS: Alternative water source.

Table 3.3: Consistency scores from the necessary conditions analysis (development).

Condition	**Consistency**
User acceptability	0.95
Absence of alternative water source	0.89
Storage and supply reliability	0.84
Financial durability	0.67
Repair service	0.45

3.1.3 Pathways to non-development

The pathways to non-development are given in table 3.4. Here, the QCA identified three potential pathways to the negated outcome. One pathway combines the lack of repair service, the lack of financial durability, the lack of storage and supply reliability and the use of alternative water sources. The second pathway combines low user acceptability, repair service, financial durability, storage and supply reliability and the use of alternative water sources. The final pathway combines low user acceptability, lack of repair service, low financial durability, storage and supply reliability and the absence of alternative water sources. The intermediate solutions found by the QCA are used also for the negated outcome. As seen in table 3.5, none of the conditions was found to be necessary conditions.

Table 3.4: Pathways to non-development identified by the QCA.

Pathways										**Villages included in pathway**
1:	Lack of RS	+	Low FD	+	Low SSR	+	Use of AWS			2, 4, 8, 10
2:	Low UA	+	Lack of RS	+	Low FD	+	SSR	+	Absence of AWS	9
3:	Low UA	+	RS	+	FD	+	SSR	+	Use of AWS	6

UA: User acceptability; RS: Repair service; FD: Financial durability; SSR: Storage and supply reliability; AWS: Alternative water source.

Table 3.5: Consistency scores from the necessary conditions analysis (non-development).

Condition	**Consistency**
Lack of repair service	0.86
Use of alternative water source	0.76
Lack of financial durability	0.69
Lack of user acceptability	0.62
Lack of storage and supply reliability	0.62

3.1.4 Discussion

In this section, the validity of the pathways to both development and non-development will be discussed. Additionally, the conditions and the combination of conditions will be further investigated based on the knowledge gathered from the interviews in order to identify which pathways, if any, will be recommended by this study to follow.

Validity of the pathways to development

Both pathways presented in figure 3.2 share many of the same conditions. User acceptability, Storage and supply reliability and the absence of alternative water source is part of both pathways. Additionally, user acceptability, which essentially refers to community satisfaction with the water systems [Domínguez et al., 2019], is identified as a necessary condition in order to reach development. User acceptability is an important condition that takes into account many aspects of a water system (see section 2.5.3), and several of the considered conditions (table 2.1) were excluded due to their similarity to user acceptability based on the interview answers. Increased community satisfaction is also associated with higher community engagement and support [Marks et al., 2014], further confirming the validity of user acceptability as a necessary condition.

The fact that both storage and supply reliability and the absence of an alternative water source are also included in both pathways, does not imply that these conditions should also be referred to as necessary conditions. It rather indicates that the combination of the two is necessary in order to reach the outcome (combination has consistency = 0.95). In a case where a system has a high storage and supply reliability, i.e. a functioning water system, it can be assumed that there is less need to use alternative water sources. The opposite can also be assumed, that a low-functioning water system would promote the use of alternative water sources. These conditions, in combination with user acceptability thus form a valid base for pathways to development, as they together represent a well-functioning water system that is the primary source of water in the area and that the users are satisfied with it. The pathways presented in the results does however include additional conditions which needs to be discussed further.

In Pathway 1, repair service is included and financial durability is excluded. In Pathway 2, financial durability is included and repair service is excluded. Financial durability, which represents the ability of the system to generate enough income for repairs and development, was hypothesised to be an influential condition before the beginning of the analysis. The results from the analysis of the necessary conditions do however give this condition the second-to-lowest consistency score (above repair service). Since financial durability only focuses on tariff-based income generation, a potentially important aspect was left out. In some villages, collective community action might have funded repairs and developments. This was not included in the analysis nor specifically asked about during the interviews. Such a collective action would most likely be a result of high community engagement, which again could be associated with high user acceptability. Pathway 1 does therefore potentially represent a pathway where collective community funding is needed, although the presence of a good repair service would naturally indicate a lower need for funds for repairs. Village 1 is an example where such a pathway is followed, where financial durability is poor (0.33) and repair service was good (1). In light of the limitations surrounding Pathway 1, it is evident that Pathway 2 represents a more robust path to development, as it depends on having good financial durability through stable tariff-based income generation.

Validity of pathways to non-development

For non-development, three pathways have been identified (see figure 3.4. Pathway 1 applies to most of the villages and consists of the lack of repair service, low financial durability, low storage and supply reliability and use of alternative water sources. This combination of conditions somewhat confirms the findings found in the development pathways by expressing that "not having" conditions that were important in order to reach development will lead you to non-development. An interesting difference is the exclusion of user acceptability in Pathway 1. As seen in table 3.5, the lack of user acceptability has one of the lowest consistency scores. This indicates that even though it is necessary to have user acceptability in order to reach development, the lack of it is not necessary in order to not reach development. It also further reiterates that user acceptability alone is not enough to reach development, as it is shown that any level of user acceptability in combination with Pathway 1 will still lead to non-development. Examples of this are villages 8 and 10, where Village 8 has a high user acceptability (0.67) and Village 10 has a low user acceptability (0.33), with both having no development.

The other two pathways are only followed by one village each, and can therefore be seen as unique cases. Although these pathways might lead to non-development, they are too case-specific in order to have potential generalisability. They are therefore excluded from further discussions of "pitfalls" on the way to development.

In the final part (chapter 4), when further discussing the conditions that contribute to the development and generalising how these conditions can be used in future developments, it is important to assess the conditions that were evaluated to be constant. These include participation and activity level and due to the high-scoring nature of these conditions, they can be assumed to be of importance in the final discussion. Furthermore, other conditions that might be of importance should also be discussed. Although the construction year of the water systems did not show any correlation with the outcome, the time available to prepare savings for development could be a relevant factor. Likewise, the population size or the number of users will also affect the ability to gather funds for development. Additionally, the data was collected during the month of February in 2023 and although questions regarding previous states were asked in order to get a wider temporal perspective, defining situations and events might have not been reported.

3.2 Development of local water infrastructure

This section outlines the proposed system design. It also aims to demonstrate the possible performance variations from different design choices. Additionally, limitations to the results will be discussed. Through this, this section will seek to answer the research question:

How can an expansion of the water system in the village of Dang'aida be designed, and how can this design be used in the future development of water systems in rural Tanzania?

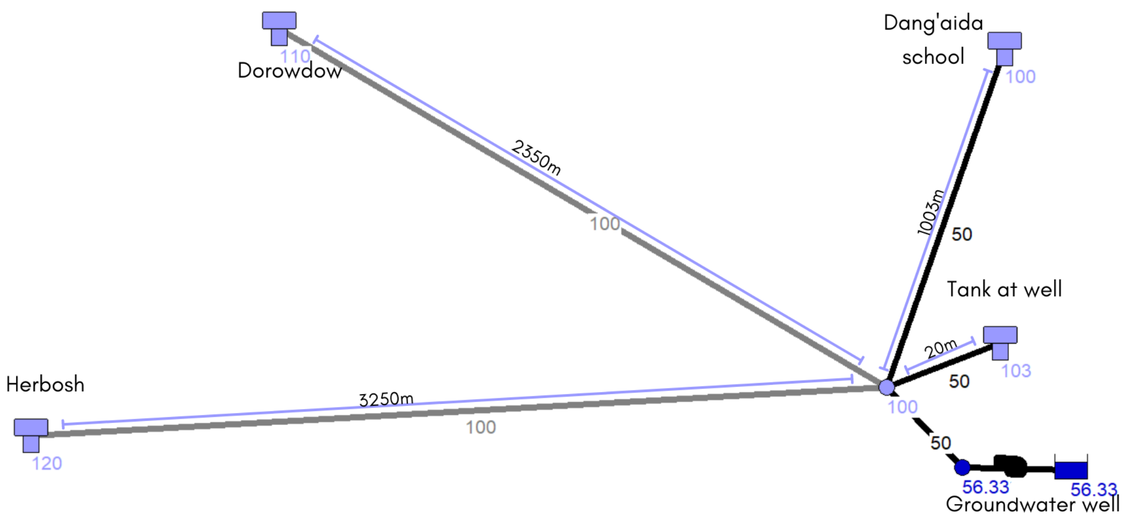


Figure 3.1: Map of the system in Epanet with the dimensions of the pipes in grey and elevation at the water tanks in purple

The system was simulated in Epanet as shown in Figure 3.1. The dimensions of the pipes and the elevation of the nodes are noted in the figure. The pipes in black have already been constructed. The pipes in grey are designed expansions of the system. The system will only pump to one tank at a time and this will be controlled manually at the location of the pump via valves. The designed system has a tank at each sub-village. The performance was checked against how long it would take to fill up a 10000 l tank at each location as shown in Figure 3.2. With four different locations, the yield at the different locations is important to counteract supply shortages in the system.

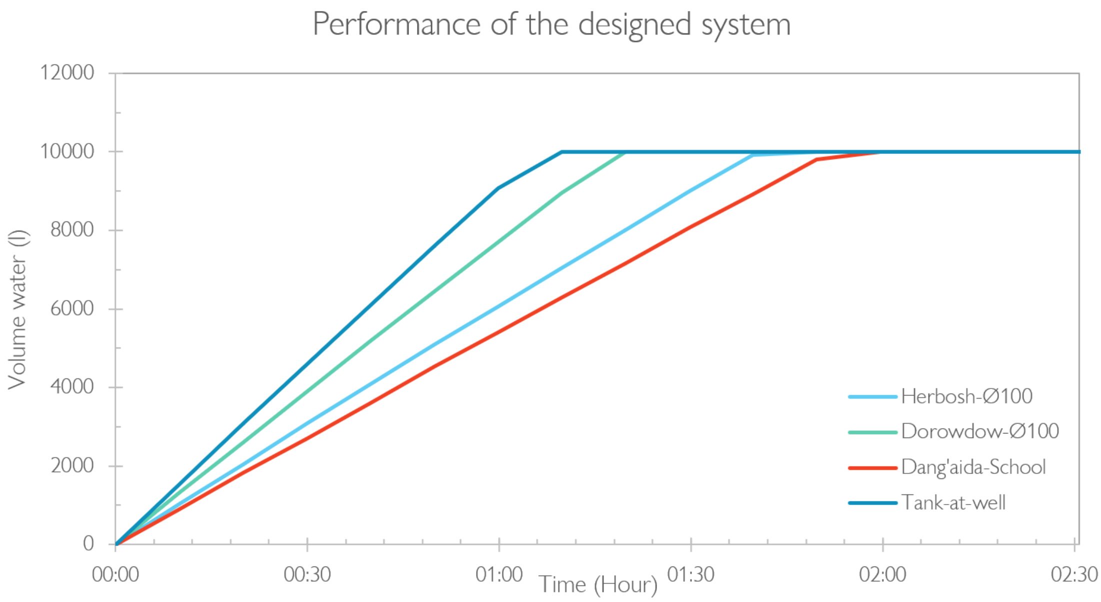


Figure 3.2: The time it takes to fill up a 10000l tank at the different locations.

This solution has the storage capacity to supply 7.3 litres of water per person, provided all tanks are full, including the two tanks by the well. In comparison, the old system's storage could supply 2.9 litres of water per person, which amounts to a 152 % increase. Despite this, the minimum water needed for survival is 20 litres of water per person per day [Reed and Reed, 2013], so the inhabitants of Dang'aida will still suffer from water shortage.

3.2.1 Discussion of design choices

The design decisions were based on adjusting the simulation's variables to determine the system's ideal configuration. The justification for decisions made regarding pipe dimension, tanks, and valve setup will be disclosed in the following section. Finally, a comparison of the system's performance with varying pumps with different heads is used to evaluate how the characteristics of the pump affect the system. This also gives an indication of how the performance of the pump affects the system. This analysis will provide insights into how design choices impact the performance of a system and serve as a useful reference for future system design projects.

The system is designed with a tank at each of the sub-villages. This is a big investment and increases the financial scope of the project. One new tank costs approximately 1300 USD (According to a COWSO and confirmed by Ahadi Mollel in 4CCP). This is an amount that can take a long time to save for a community, keeping in mind that 58 % of the rural population in Tanzania lived below the poverty line in 2018. This means that they live on less than 1.9 USD a day [WB, 2020]. The increase in financial scope can slow the development down. Despite this, the tanks are included in the design because they contribute to ensuring a robust supply service. This is especially the case because the pump can only pump to one location at a time, and is dependent on the sun to run. The added tanks also make it possible to further develop the system with gravitational flow from the water tanks.

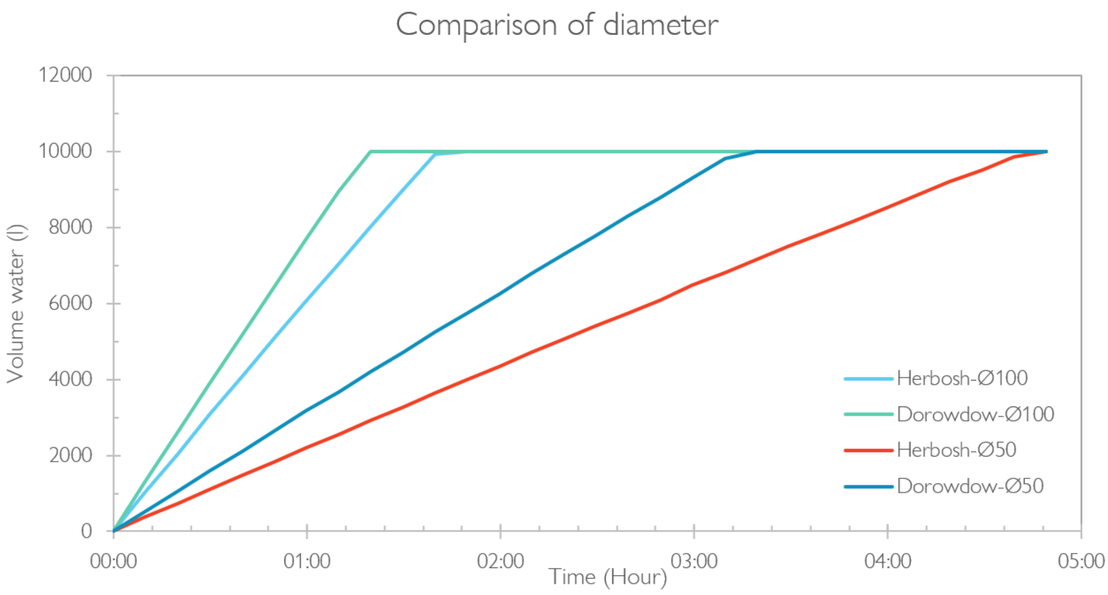


Figure 3.3: Comparison of the time it takes to fill up a 10000l tank with different dimensions.

The dimension of the pipes to the sub-villages is an important factor for the yield, and the difference between Ø50 and Ø100 is illustrated in Figure 3.3. The simulation also showed that the system could not pump to several locations at once, except for to the tank at the well and to Dang'aida primary school. Pumping to the two locations at once gives a much smaller yield and is less efficient than pumping to the locations individually. This is showed in Figure 3.4

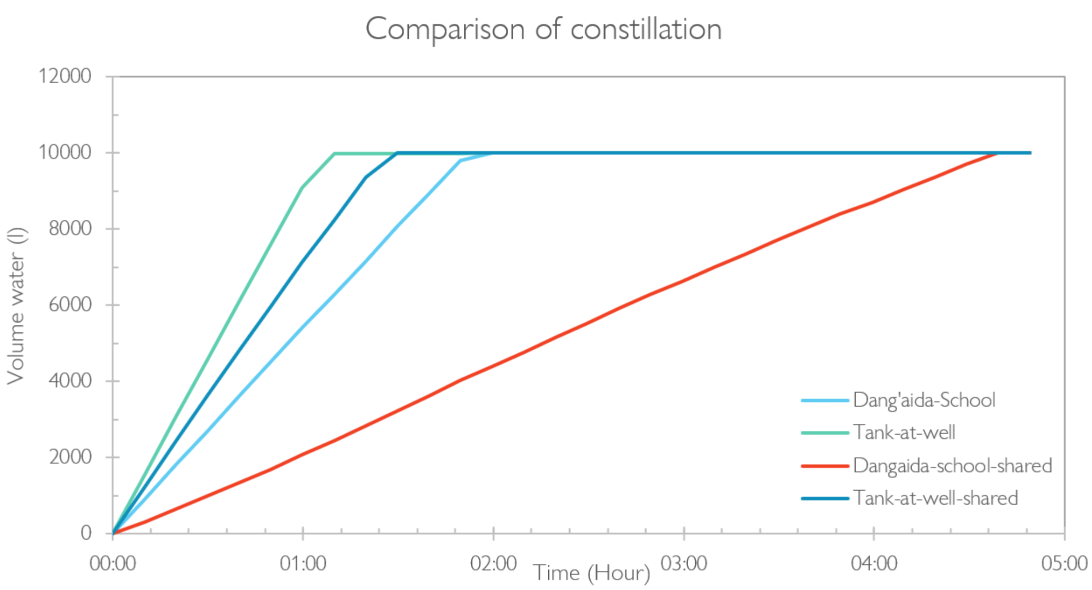


Figure 3.4: Comparison of the time it takes to fill up a 10000l tank with different connections

The simulation using different pump curves showed that it was impossible to pump water to Dorowdow or Herbosh when using the pump with a lower head. Additionally, it had a significantly lower yield for the areas it could pump to. The pump with a higher head had a higher yield in all tanks. Figure 3.5 displays the variation in yield to the well's tank. The pump's performance is therefore essential for the opportunity to develop a system. The community loses the chance to adapt the system to its changing needs through development if the pump is too weak. This also indicates that if the performance of the pump is reduced it can have a massive negative impact on the function of the system.

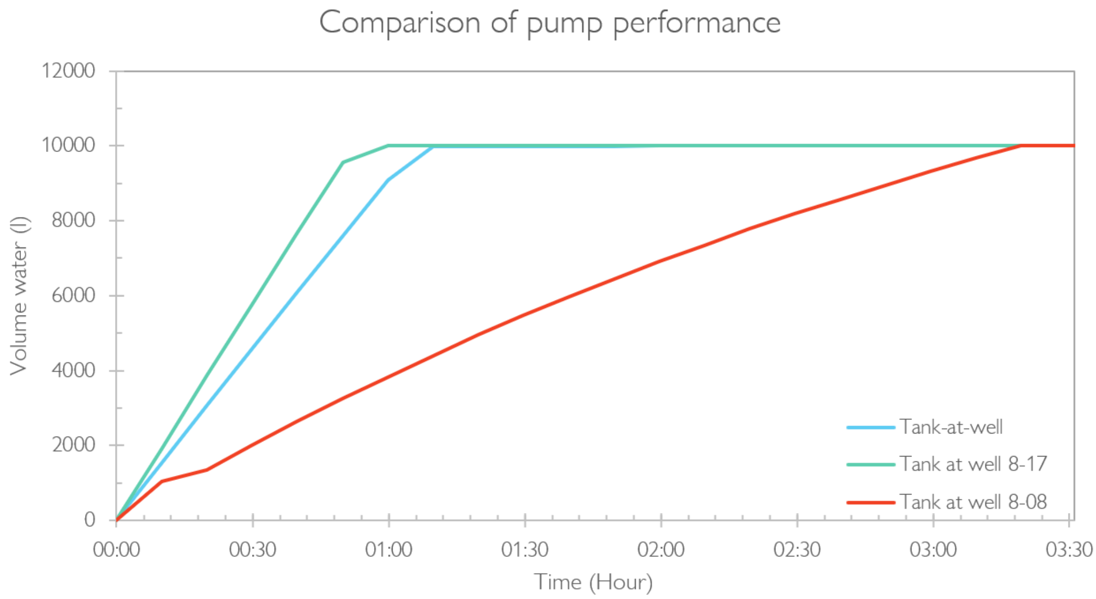


Figure 3.5: Comparison of the time it takes to fill up a 10000l tank with the different pumps. Numbers from: David and Shirtliff (2023b)

3.3 Water quality

In this section, results from the water quality tests will be presented and the limitations surrounding these results will be discussed. Additionally, this section discusses the research question: [Davis and Shirtliff, nd]

"What do the water quality tests tell about the water situation in the project area, and how can this knowledge contribute to ensuring a sustainable water supply in the future?"

By investigating this question, the study hopes to explain how the quality of drinking water is affected by the environment and infrastructure surrounding the water source. It will also evaluate whether the drinking water is suitable for human consumption, and by doing so, highlight what is necessary in terms of water quality, in order to ensure sustainable water supply. A detailed assessment of the treatment opportunities is also presented in this section. The role of water quality in future developments will be discussed in the final discussion (chapter 4).

The theory behind the water quality parameters, which includes temperature, conductivity, fluoride, nitrate and nitrite, phosphate, chlorine, pH and E. coli, and the methodology of the testing are presented in section 2.7. For the locations where two or three samples were collected, an average value is displayed in the tables below along with the sample standard deviation. This applies to every water quality parameter.

3.3.1 Conductivity and temperature

Table 3.6 contains the results from the conductivity and temperature measurements collected from all water points visited during the fieldwork for this study. The conductivity values range from 0.02

mS/cm measured at Geterer school's rainwater tank, to 4.92 mS/cm measured at the water borehole in Dang'aida village. Values surpassing the Tanzanian Bureau of Standards (TBS) guideline value for natural (untreated) potable (drinking) water of 2.5 mS/cm [TBS, 2019] are highlighted in red. As mentioned in subsection 2.7.1, the temperature of the water affect the conductivity. It is therefore included in the table in order to properly assess the conductivity values presented. It is also suggested by theory (2.7.1) that groundwater should have a higher conductivity than rainwater, due to the presence of salts and minerals [MacDonald and Davies, 2000].

Table 3.6: Results from conductivity and temperature measurements.

Village	Conductivity (mS/cm)	Temperature (°C)
Dang'aida	4.92 ± 0.01	24.53 ± 0.76
Dang'aida primary school	4.87 ± 0.01	24.87 ± 0.06
Basonyagwe	0.99 ± 0	22.40 ± 0.26
Murkuchida	0.62 ± 0.01	22.83 ± 1.11
Haydom hospital (spring)	0.75 ± 0.01	26.57 ± 0.32
Mewadani	1.23 ± 0.02	27.93 ± 0.15
Geterer school (rainwater tank)	0.02	25.00
Geterer school (borehole)	2.03 ± 0.01	27.93 ± 0.15
Mamagi	1.57 ± 0.01	21.83 ± 0.50
Labey secondary school	0.53	24.30
Labey secondary school (government)	1.14	24.00
Dotina primary school	1.22 ± 0.01	24.23 ± 0.15
Gidhim secondary school	0.81 ± 0.01	24.25 ± 0.21
Gaye primary school	0.91	26.40
Gidhim 4CCP well	0.93 ± 0.01	28.25 ± 1.06
Dilling'ang	2.06	24.90
Getunawas	2.22 ± 0.01	24.30 ± 1.27
Hilamoto	1.78 ± 0	25.10 ± 0.28
Endagulda	1.45 ± 0	28.20 ± 0
Isene	0.63 ± 0.02	27.35 ± 0.78
Haydom school (tap. mixed tank)	1.46 ± 0.01	24.15 ± 0.21
Haydom school (tap. borehole)	0.74	25.30
Haydom office	1.79	25.20
Matere	1.05 ± 0.02	24.75 ± 0.21
Munguli	2.46	26.60
Munguli (rainwater tank)	2.33	26.70
Basotu lake (tap. church)	0.84	26.50

3.3.2 Fluoride

In table 3.7, the results from the fluoride tests are presented. The TBS guideline value for fluoride is 1.5 mg/l [TBS, 2019], with values above being marked red. Values range from 0 mg/l to 2.95 mg/l with most of the values being below the suggested guideline value. This result is contradictory to what was expected before testing, as previous fluoride test conducted at several of the same locations indicated very high levels [Røer, 2020]. Other research also suggest that fluoride levels tend to be high in the East African rift valley area [Ayoob and Gupta, 2006]. An additional table (3.8) presents the differences in values over the years from certain locations. These differences will be further elaborated on in the discussions (chapter 4).

Table 3.7: Results from the fluoride measurements.

Village	Fluoride (mg/l)
Dang'aida	0.15 ± 0
Dang'aida primary school	0.78 ± 0.65
Basonyagwe	0.10 ± 0.09
Murkuchida	0.35 ± 0.17
Haydom hospital (spring)	0.1+ ± 0.09
Mewadani	0.38 ± 0.4
Geterer school (rainwater tank)	0.15
Geterer school (borehole)	0.45 ± 0
Mamagi	0.80 ± 0.07
Labey secondary school	0.15
Labey secondary school (government)	0
Dotina primary school	0.08 ± 0.11
Gidhim secondary school	0 ± 0
Gaye primary school	0.15
Gidhim 4CCP well	0
Dilling'ang	0.45
Getunawas	0.3 ± 0.21
Hilamoto	0.98 ± 0.72
Endagulda	0.30 ± 0.21
Isene	1.18 ± 0.39
Haydom school (tap. mixed tank)	1.18 ± 0.39
Haydom school (tap. borehole)	0.45
Haydom office	0.85
Matere	0.75
Munguli	0.75
Munguli (rainwater tank)	1.55
Basotu lake (tap. church)	1.55 ± 1.98

Table 3.8: Differences in fluoride measurements (mg/l) from 2023 and 2020 [Røer, 2020].

Village	2023	2020
Basonyagwe	0,1	1,2
Murkuchida	0,35	1,4
Mewadani	0,38	1,4
Dilling'ang	0,45	3
Hilamoto	0,98	2,8
Isene	1,18	2,8
Haydom school (borehole)	0,45	2,4
Munguli	0,75	4,8

3.3.3 Nitrate, Nitrite and Phosphate

The TBS guideline values for nitrate, nitrite and phosphate are 45 mg NO_3^-/L, 0.003 mg NO_2^-/l and 2.2 mg PO_4^{3-}/l, respectively [TBS, 2019]. As seen in table 3.9, nitrite is non-existent in the test results and phosphate is only found in one location. Nitrite can therefore be excluded from further consideration on the basis mentioned in the theory (section 2.7.3, explaining how nitrite is an intermediate product and that it is not expected to be found in high quantities [EPA, 2002]. Phosphate, on the other hand, will be included in further discussions as the test result indicates a high concentration in one location.

Table 3.9: Results from the nitrate, nitrite and phosphate measurements.

Village	Nitrate (mg/l)	Nitrite (mg/l)	Phosphate (mg/l)
Dang'aida	75.00 ± 17.68	0	0
Dang'aida primary school	87.50 ± 0	0	0
Basonyagwe	2.50 ± 1.77	0	0
Murkuchida	25.00 ± 4.33	0	5.00 ± 2.83
Haydom hospital (spring)	7.50 ± 0	0	0
Mewadani	100.00 ± 0	0	0
Geterer school (rainwater tank)	0	0	0
Geterer school (borehole)	7.50 ± 3.54	0	0
Mamagi	50.00 ± 0	0	0
Labey secondary school	17.50 ± 0	0	0
Labey secondary school (government)	5.00 ± 0	0	0
Dotina primary school	7.50 ± 0	0	0
Gidhim secondary school	62.50 ± 0	0	0
Gaye primary school	0	0	0
Gidhim 4CCP well	50.00 ± 0	0	0
Dilling'ang	5.00 ± 0	0	0
Getunawas	75.00 ± 12.50	0	0
Hilamoto	32.50 ± 17.68	0	0
Endagulda	0 ± 0	0	0
Isene	75.00 ± 0	0	0
Haydom school (tap. mixed tank)	25.00 ± 0	0	0
Haydom school (tap. borehole)	62.50 ± 0	0	0
Haydom office	25.00 ± 0	0	0
Matere	0	0	0
Munguli	62.50 ± 17.68	0	0
Munguli (rainwater tank)	75.00 ± 0	0	0
Basotu lake (tap. church)	0	0	0

3.3.4 Chlorine, Iron and pH

Chlorine, iron and pH test results are presented in table 3.10. All the pH values are within the limit range of 5.5-9.5, proposed by the Tanzanian guidelines [TBS, 2019]. Iron was only detected in 3 of the 19 locations it was tested for, and the values were comfortably lower than the guideline value of 0.3 mg/l. Iron can therefore be excluded from further considerations on the basis of the test results and the limitations of the testing methodology mentioned in subsection 2.7.6.

Chlorine was also only found in a limited number of location, but due to nature of why the compound is present in the drinking water, it is necessary to include it in further discussions. As chlorine is used as a disinfectant [WHO, 2017] and because three of the water points had installed chlorine disinfection systems (field observation), it is interesting to monitor whether the chlorine levels are within the recommended guideline range for treated drinking water of 0.2 - 0.5 mg/l [TBS, 2019]. The locations with disinfection systems are marked with an asterisk (*). As seen in table 3.10, none of the locations fitted with a disinfection system are within the limit proposed by TBS. For the locations without a disinfection system, the guideline states that no chlorine should be present in the water [TBS, 2019].

Table 3.10: Results from the chlorine, pH and iron measurements.

Village	Chlorine (mg/l)	pH	Iron (mg/l)
Dang'aida	0.10 ± 0	8 ± 0	0
Dang'aida primary school	0.10 ± 0	7.50 ± 0.71	0
Basonyagwe	0*	7 ± 0	0
Murkuchida	0.05* ± 0.07	7 ± 0	0
Haydom hospital (spring)	0	7 ± 0	0
Mewadani	0.05* ± 0.07	7 ± 0	0
Geterer school (rainwater tank)	0	7	0
Geterer school (borehole)	0	7 ± 0	0
Mamagi	0	7 ± 0	0
Labey secondary school	0	7 ± 0	0
Labey secondary school (government)	0	7.25 ± 0.35	0
Dotina primary school	0	7 ± 0	0
Gidhim secondary school	0	7 ± 0	0.05
Gaye primary school	0	7	0.05
Gidhim 4CCP well	0	7	0
Dilling'ang	0	7	0
Getunawas	0	7.25 ± 0.35	0
Hilamoto	0.10	7 ± 0	0
Endagulda	0	7 ± 0	0
Isene	0	7 ± 0	0
Haydom school (tap. mixed tank)	0.10 ± 0	7 ± 0	0.05
Haydom school (tap. borehole)	0	7	0
Haydom office	0.10	7	0
Matere	0	7 ± 0	0
Munguli	0	7 ± 0	0
Munguli (rainwater tank)	0	7 ± 0	0
Basotu lake (tap. church)	0	7	0

3.3.5 E. coli

For E. coli, the TBS guideline states that no organisms should be present in a 100 ml drinking water sample [TBS, 2019]. The results from the E. coli tests are presented in table 3.11. All values indicating a presence of E. coli is displayed in red. An additional classification (figure 3.6), provided by WHO [2017], can be used to evaluate the severity of the risks associated with different numbers E. coli organisms found in a sample. This classification is used when differentiating villages in further discussions. At Haydom hospital, Gidhim secondary school and Endagulda village, only one of two samples tested indicated a presence of E. coli. These locations are treated as special cases, and the results will have to be discussed in terms of the accuracy of the test kit and test methodology in order to be classified alongside other positive cases.

Table 3.11: Results from the E. coli measurements.

Village	E. coli (# of organisms)
Dang'aida	0
Dang'aida primary school	8.50 ± 4.95
Basonyagwe	0 ± 0
Murkuchida	2.50 ± 0.71
Haydom hospital (spring)	1 ± 1.41
Mewadani	0
Geterer school (rainwater tank)	6
Geterer school (borehole)	0
Mamagi	0
Labey secondary school	0
Labey secondary school (government)	0
Dotina primary school	0
Gidhim secondary school	0.50 ± 0.71
Gaye primary school	11 ± 1.41
Gidhim 4CCP well	0
Dilling'ang	73
Getunawas	0
Hilamoto	0
Endagulda	1.50 ± 2.12
Isene	100
Haydom school (tap. mixed tank)	52.50 ± 53.03
Haydom school (tap. borehole)	0
Haydom office	28
Matere	13
Munguli	1
Munguli (rainwater tank)	2
Basotu lake (tap. church)	0

3.3.6 Discussion

In order to fully understand what the presented results reveal about the water quality situation in the case villages, it is important to discuss the results along with the limitations of those results. This will be done in the context of the aspects (environmental and infrastructural effects, suitability for human consumption and treatment) mentioned in the elaboration of the research question earlier in this section (see section 3.3).

Conductivity

The results presented in table 3.6 suggest that Dang'aida and Dang'aida primary school has very high conductivity. Since Dang'aida primary school water source is a mix of water from Dang'aida borehole and rainwater, it is natural that a high conductivity is recorded also here. High conductivity is often related to a high content of salts [EPA, 2022a] and conversations with users of Dang'aida water borehole and students at Dang'aida primary school corroborates this assumption, as they talk of a salty taste when referring to the drinking water. For the other measurement locations, the fact that any given EC reading has an accuracy of ±0.4 mS/cm (see section 2.7.1) could affect which location is considered safe. Locations such as Getunawas, Munguli (borehole) and Munguli (rainwater tank) can go over the limit and join Dang'aida well and Dang'aida primary school as water points with worryingly high conductivity when including the measurement errors.

Generally, the best use of EC as a water quality parameter is when a value range the groundwater has been established [EPA, 2022a]. By doing so, it is possible to monitor whether the groundwater has been exposed to other water sources or pollution by measuring changes in EC [EPA, 2022a]. This is important in order to ensure stable water quality and sustainable water supply. In cases such as Dang'aida, where additional information suggests a high content of salts, it is necessary to conduct additional measurements and implement treatment in order to ensure that the drinking water is suitable for human consumption. Treatment methods for the removal of salts (desalination) usually consist of reverse osmosis (membrane) or thermal treatment [Likhachev and Li, 2012]. These are both considered to be energy-demanding treatment methods and are often implemented in large-scale projects [Zhou et al., 2015]. Even so, a study conducted at a borehole in rural Tanzania, where renewable energy was used to power a reverse osmosis treatment system for the removal of salts and fluoride [Shen et al., 2016], shows promise for future use of such technologies in small scale water systems.

Fluoride

The fluoride results presented in table 3.7 initially depict fluoride as a non-issue in most of the locations tested, with the exception of Munguli (rainwater) and Basotu Lake. These results are however heavily affected by the limitations mentioned in section 2.7.2. As mentioned in the results, previous research indicates high fluoride levels in the East African Rift Valley [Ayoob and Gupta, 2006]. This is not indicated by the results found in this study. In order to further investigate these discrepancies, a comparison with location-specific fluoride measurements gathered from previous master thesis projects in the same study area [Røer, 2020], are presented in table 3.8. Here it is clear that all the compared values are lower in 2023 than in 2020. Additionally, there is no consistent difference between the years, which would be symptomatic of a systematic measurement error. Some of the results presented in table 3.7 also show a large standard deviation, which suggests non-stable readings from different samples from the same location. Based on these points, it is reasonable to assume that the results presented in this study do not represent the real fluoride levels at the measurement locations.

Nonetheless, it is important to consider the possibility of a reduction in fluoride levels and discuss the reason for this. A study researching the fluoride concentrations in groundwater at several locations in India, found a relationship between fluoride and rainfall [Ali et al., 2019]. The relationship suggests that an increase in rainfall results in a decrease in fluoride in groundwater [Ali et al., 2019]. This could be viewed as a plausible reason for the observed decrease in fluoride levels, as all of the samples were collected during the beginning of the rainy season in Tanzania. Despite this, fluoride levels continue to be a cause for concern in the study area and treatment methods should be discussed.

As mentioned in section 2.7.2, too high fluoride levels in the drinking water can cause dental and skeletal fluorosis [WHO, 2017] as well as browning of the teeth (CDC). Browning of the teeth was (non-medically) observed in several of the water quality test location, which might be an indication of prolonged exposure to high fluoride levels. Treatment methods suggested by WHO [2017] includes clay, activated alumina, bone charcoal and contact precipitation. These methods does however have issues when treating drinking water with naturally high fluoride levels [WHO, 2017]. In the master thesis project conducted by Evang and Bakken [2021], cost-effective treatment methods suitable for rural Tanzanian conditions, such as neem and moringa leaves were investigated. It was found that substantial preparation of the leaves was needed in order to have satisfactory treatment results [Evang and Bakken, 2021]. One study with promising results was mentioned in the conductivity discussion, where solar energy was used to remove salts (including fluoride) from groundwater using nanofiltration/reverse osmosis [Shen et al., 2016]. The results from this study suggested a 98.2% retention of fluoride with the most energy-efficient membrane [Shen et al., 2016]. Fluoride treatment methods have to be further discussed in the context of the economic situation in rural Tanzania and in the context of community-driven development (see chapter 4). It is important to explore both cost-saving easily implementable solutions such as neem and moringa leaves and sustainable long-term cost-efficient solutions such as reverse osmosis.

Nitrate

The results from the nitrate measurements showed that 11 of 27 locations tested higher than the guideline limit provided by TBS [TBS, 2019]. The village of Mewadani is an example of a case where testing indicated well above 100 mg NO_3^-/l. This is a cause for concern due to the health risks associated with high nitrate levels (see 2.7.3) as well as the implications from nitrate in the water, such as animal waste, wastewater and fertilisers (2.7.3). In terms of animal waste and fertiliser, both animal grazing and agricultural activities close to the water well were observed at several locations. Detailed observation notes from the fieldwork does however show that only 3 of the 11 locations with high levels had agricultural activities close to the borehole and only 2 of the 11 had substantial amounts of animal droppings close to the water borehole. Although animal waste cannot be excluded as a reason based on one-time observations, it constitutes the need to explore other reasons for high nitrate levels at several of the locations.

Nitrate can be found naturally in the groundwater due to leaching from bedrock and vegetation [WHO, 2017], and although this could be a reason, other anthropogenic pathways should be discussed in order to properly implement actions and treatment to reduce nitrate levels. One study reviewing the occurrence of in groundwater in Tanzania suggests that a correlation between nitrate levels and the presence of coliform bacteria would indicate faecal contamination from human and animal activities [Elisante and Muzuka, 2017]. This relationship will be further investigated in the discussion of the E. coli test results. Furthermore, it is suggested that in areas close to sewage effluents, leaching of nitrate from the sewage into groundwater is possible [Nkotagu, 1996].

Based on these reasons for high nitrate levels, several preventive actions or treatment methods can be implemented. In cases where the high nitrate levels are due to anthropogenic nitrate pathways into groundwater, preventive actions such as suspending human, animal and agricultural activities close to the water source might be a solution. An assessment of the fate and behaviour of nitrate in the soil should be performed in order to quantify the areal limits needed. In cases where this is not a viable solution, nitrate removal has to be implemented. WHO [2017] suggests ion exchange, biological denitrification, reverse osmosis and electrodialysis as treatment methods for nitrate. These treatment methods are however expensive and complex [WHO, 2017], which is not suitable for implementation in rural Tanzania. Absorption methods have also been tested for the removal of nitrate and agricultural waste has been suggested to be used as an adsorbent [Bhatnagar and Sillanpää, 2011]. This could be a relevant treatment method for rural Tanzanian conditions, although adsorbent selection and preparation and implementation costs should be further investigated [Bhatnagar and Sillanpää, 2011].

Phosphate

Only one of the phosphate measurements resulted in the detection of phosphate in the water. Due to the phosphate levels in Murkuchida being more than twice the guideline limit value proposed by TBS [TBS, 2019], it is necessary to shortly discuss the reasons for phosphate in the groundwater and the necessary treatment.

Like nitrate, phosphate can reach the groundwater through the runoff from agricultural activities [Ødegaard, 2014, p. 128]. The observation log from the fieldwork indicates that Murkuchida has agricultural activities close to the water borehole, which confirms that such a phosphate pathway to the groundwater is likely. The presence of phosphate in drinking water is primarily a cause of concern because it promotes the growth of algae and causes eutrophication [Ødegaard, 2014, p. 128], which can be an issue if open-top water tanks are used to store water. Since the presence of phosphate indicates agricultural runoff to the groundwater, other substances such as pesticides might also be included in the runoff [Vymazal and Březinová, 2015]. This cannot however be confirmed nor implied using the data gathered in this study.

A treatment method suggested by Ødegaard [2014, p. 412] is biological phosphate removal with active sludge. This process contains several complex steps and is therefore less suitable for rural Tanzanian conditions. Instead, some of the preventive actions mentioned in the nitrate discussion above could be useful also for high levels of phosphate.

E. coli and chlorine

In terms of the E. coli in the drinking water, several of the results from the test locations indicate worryingly high levels. A thorough examination of the results is therefore necessary due to the severe health risk associated with E. coli contamination (see 2.7.8). According to the TBS guideline, any presence of E. coli is regarded as over the limit [TBS, 2019], and by this standard, 14 of the 27 locations are over the allowable limit. 3 of these 14 locations, Haydom Hospital, Gidhim secondary school and Endagulda village, did however only indicate the presence of E. coli in one of two tests. Using WHO's [2017] classification table (3.6) and observation notes from the fieldwork, a risk assessment of each location can be conducted based on the test results and the location's susceptibility to contamination from animal and human faeces.

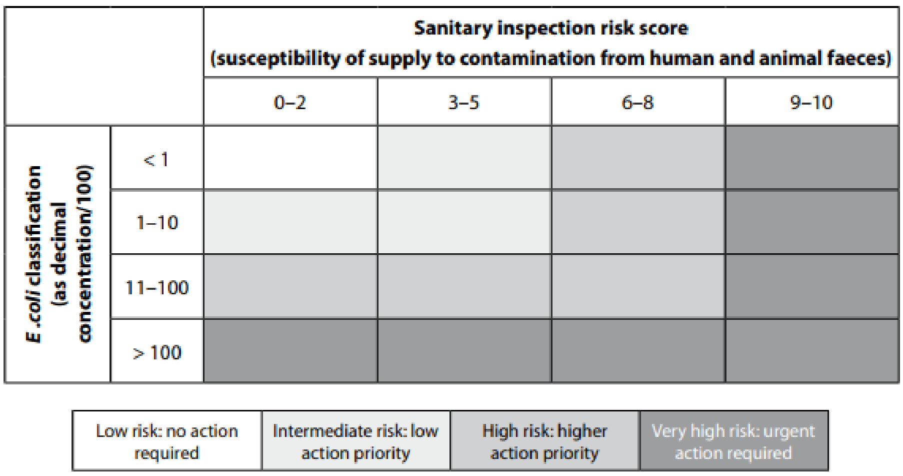


Figure 3.6: Classification of E. coli risk based on concentration and susceptibility [WHO, 2017, table 5.4]

The samples referred to as Haydom Hospital were collected at the source, which is a natural spring. It is also part of a larger water system supplying the hospital, and it is therefore treated at a later stage before reaching the users. It can therefore be excluded from E. coli risk assessment. The other two locations where only one test indicated the presence of E. coli, Gidhim secondary school and Endagulda village, are more relevant to this study. Based on the observation log it is difficult to establish the possibility of faecal contamination and a subsequent risk at Gidhim secondary school. The observations made in Endagulda show both human and animal activity close to the water borehole. The taps were also unprotected from animals. It is therefore evaluated to be highly susceptible to contamination, and even though only one test showed the presence of E. coli, high-priority action (high risk) is needed.

For the rest of the locations where the tests indicated the presence of E. coli, a risk is evident. The classification of risk does however vary from case to case. In the locations where samples were collected from rainwater or mixed (rainwater and groundwater) tanks, the rainwater can be the source of contamination. Rainwater collected in open tanks and harvested from roofs, which is the case for all relevant locations in this study, has been related to elevated E. coli presence [Ahmed and andc S. Toze, 2011]. The faecal contamination might be due to bird droppings, as they also contain E. coli [CDC, 2022]. Very high risk is therefore associated with the use of rainwater for human consumption, and urgent action, i.e. treatment or preventive measures, is needed. In locations where the presence of E. coli was found in groundwater samples, observed human and animal activity close to the water borehole and water taps might be the reason. All of these locations lacked protective barriers against animals around the water taps. In Isene, the water from the well was pumped straight out at ground height through a large pipe without any use of taps or protective barriers. The size of the pipe allows for small animals to enter the pipe, which might be an explanation for the very high E. coli levels.

Treatment methods for the inactivation of pathogenic microorganisms are several. The most used include chlorination, ozonation and UV radiation treatment [Ødegaard, 2014, p. 167]. Each disinfection method has different inactivation efficiency depending on which pathogenic organism it is used for. For bacteria, such as E. coli, chlorination is a cheap and efficient disinfectant method [Ødegaard, 2014, p. 167] that has already been put to use in the project area [Personal communication, Representatives from the District Engineer office, 21st February 2023]. As mentioned in the results, three of the locations reported the use of chlorination as a disinfection method, while tests from seven locations showed the presence of chlorine in the water. Out of the three who reported the use of chlorine, two had a detectable presence, although under the recommended range in order to have efficient disinfection [TBS, 2019, WHO, 2017]. The presence of chlorine in cases where use was not reported is highly debatable, as chlorine is not naturally found unbound [Emsley, 2011]. Conversations with the district engineers in the area did however uncover that a free trial of chlorine-based disinfectant was offered to most of the villages. This could explain the presence of chlorine, as information of use where only gathered through interviews and not confirmed with detailed inspection. Additionally, measurement limitations (2.7.5) could also be the reason for chlorine detection. In general, the use of chlorination as a disinfection method is recommended for all drinking water sources, including where no E. coli was detected [Ødegaard, 2014, p. 167]. This is due to the health risks associated with not only bacteria but all pathogenic microorganisms [Ødegaard, 2014, p. 167].

In addition, the correlation coefficient between measured nitrate levels and E. coli levels was calculated in order to investigate whether high nitrate levels were due to faecal contamination. The correlation was found to be negligible, i.e. $r = 0.03$ [Mukaka, 2012], which indicates that most of the high nitrate levels were not due to faecal contamination.

General situation

In general, the water quality tests show a situation with varying degrees of issues pertaining to the water quality parameters tested in this study. The discussions above indicate that some of the issues involving high nitrate, phosphate and faecal contamination could be solved with preventive actions. This will be elaborated on in the main discussion.

An overall important aspect of all the provided results is their representativeness of the general situation in the study area. The water quality can change over time, and the results and the subsequent discussion therefore only portray the situation at the time of testing. It is therefore recommended to continuously monitor the water quality in order to get the full situational picture [WHO, 2017].

Water quality reports

During the fieldwork, it became evident that the communities wanted to be updated on the results of the water quality test. Therefore 27 individual reports containing the measurement results, the TBS guideline values [TBS, 2019], a classification of risk based on results and guideline values and notes about each water quality parameter were made and sent to 4CCP for distribution to the relevant communities (see Appendix F). This was done out of gratitude towards the communities for their help in conducting the fieldwork as well as the communities' need for information about their own drinking water quality. The latter will be discussed further in terms of community-driven water system development (chapter 4). Per today, the reports are being translated by 4CCP in preparation for further distribution to the CBWSOs and other stakeholders.

3.4 Remote monitoring system

This section will seek to answer the research question:

How can remote monitoring data from solar-powered water boreholes be used by stakeholders to improve the management of these systems, and what are the challenges associated with implementing such monitoring mechanisms in rural Tanzania?

The data series from the remote monitoring systems are too short to use for any reliable analyses but give insight into how the remote monitoring systems functioned the first three months after installation. A preliminary analysis of some of the data will be conducted to exemplify how stakeholders can use the data to improve the sustainability and efficiency of the system. Additionally, the data series will be used to discuss the performance of the system and the challenges associated with its implementation.

3.4.1 Performance of the monitoring system

In Endagaw Chini, the system receives data from the current sensor. The remote monitoring system transfers data every half hour, or when the pump turns off, and has few gaps in the data. The pump time and the measured currency correspond to a large degree, but not completely as can be seen in Figure 3.7. The pump type in Endagaw Chini is not known, so it is not possible to compare the value of the pump power with the one given by the manufacturer, but the values seem feasible, although a bit low.

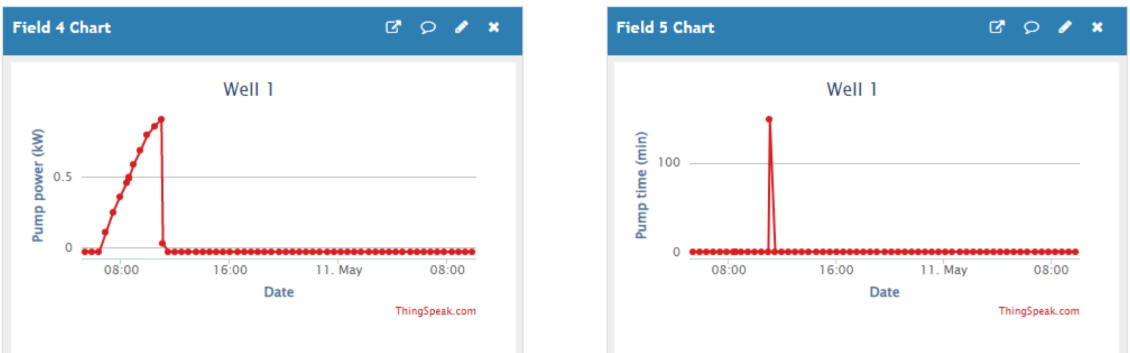


Figure 3.7: Plot of pump time and pump power from Thingsspeak in Endagaw Chini. Note the increase in pump power as the sun gets stronger during the day.

One month after installation, both the Endagaw Chini and Basonyagwe systems stopped transmitting data for an entire month due to the mobile subscription not being paid. This is clearly visible in Figure 3.8. The problem was fixed by resubscribing to the mobile subscription.

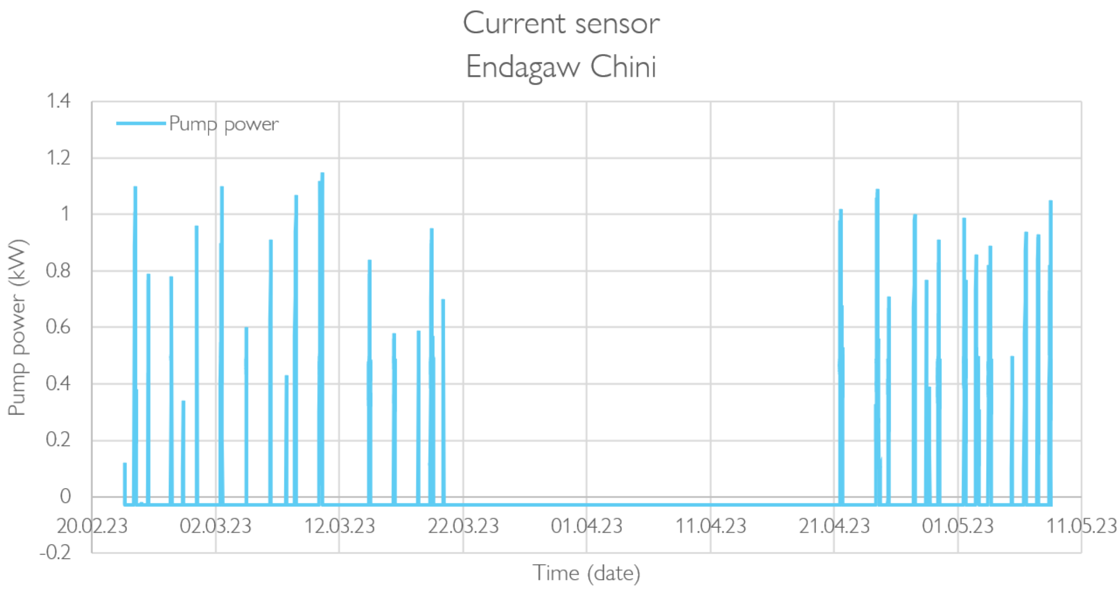


Figure 3.8: Plot of the entire pump power data series from Endagaw Chini.

In Basonyagwe the system provides data from the pressure sensor in the well as well as the current sensor. The system does not transmit regularly but occasionally has long gaps in service that last for up to a couple of days. The data from the pressure sensor in the well do not provide data that seem to be representative of the underlying process and also have some disturbance as can be seen in Figure 3.11. The current sensor has a lot of disturbance in the measurements and this makes the data for pump power, last pump power, ampere and pump time corrupted, as can be seen in Figure 3.9. The values are also quite low, and there are only 9 times the pump power is over 1 kW in the measurement period as can be seen in Figure 3.10

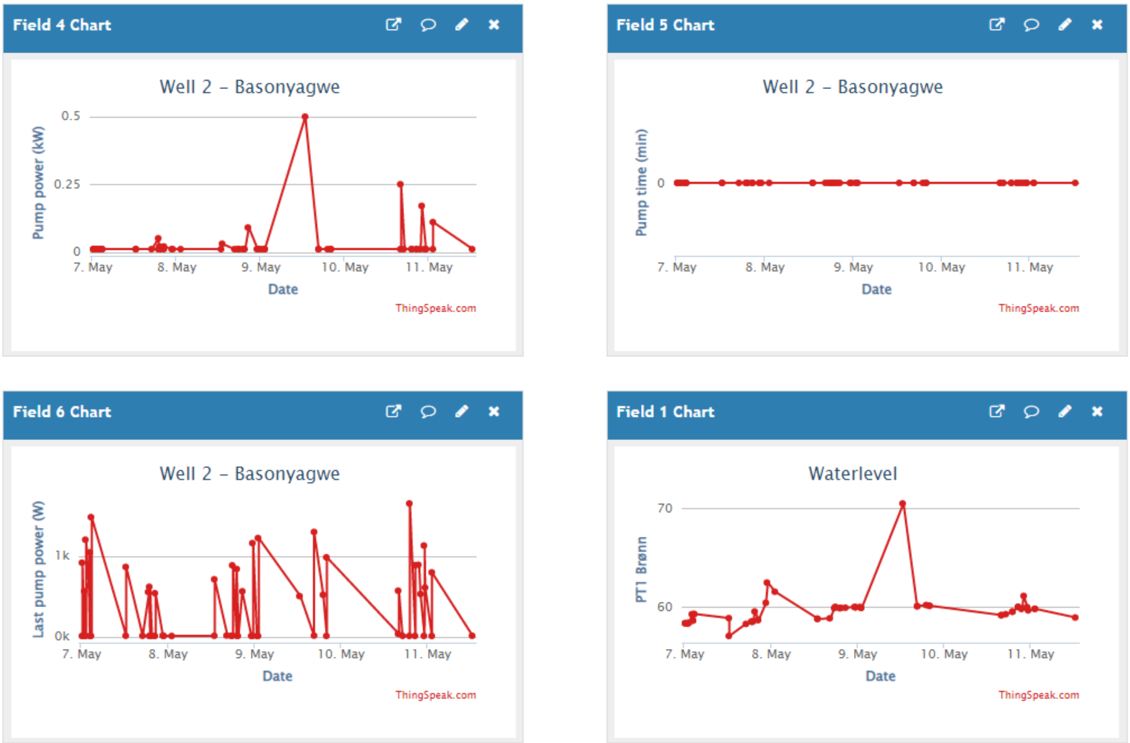


Figure 3.9: Plot from Thingsspeak. The pump time and the pump power are not coherent, and the last pump power fluctuates a lot. The change in the water level still indicates that the pump has been on in accordance with the values in pump power.

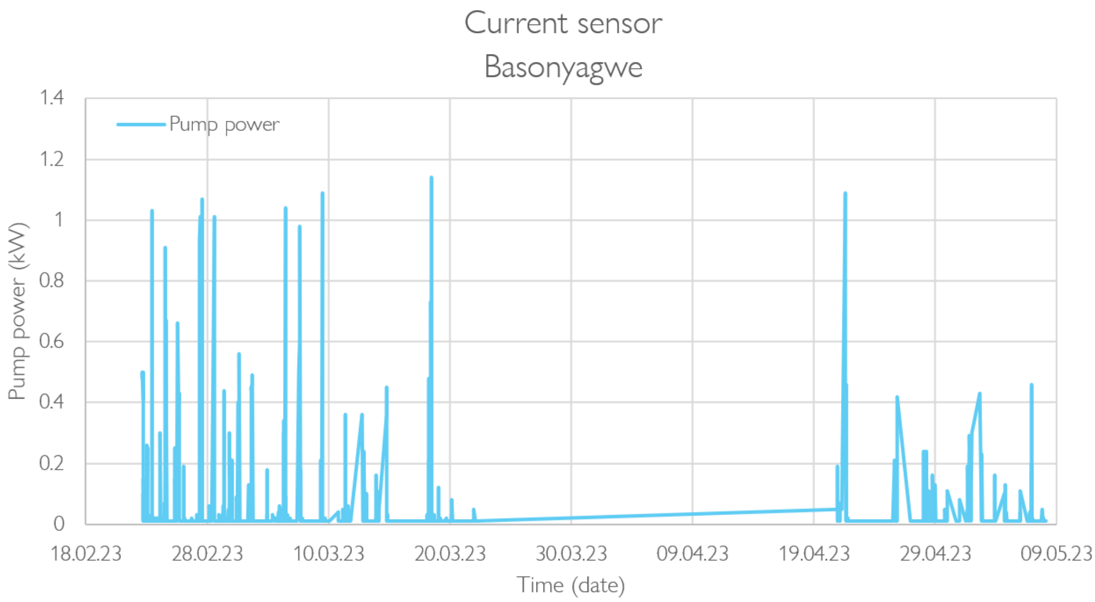


Figure 3.10: Plot of the entire pump power data series from Basonyagwe.

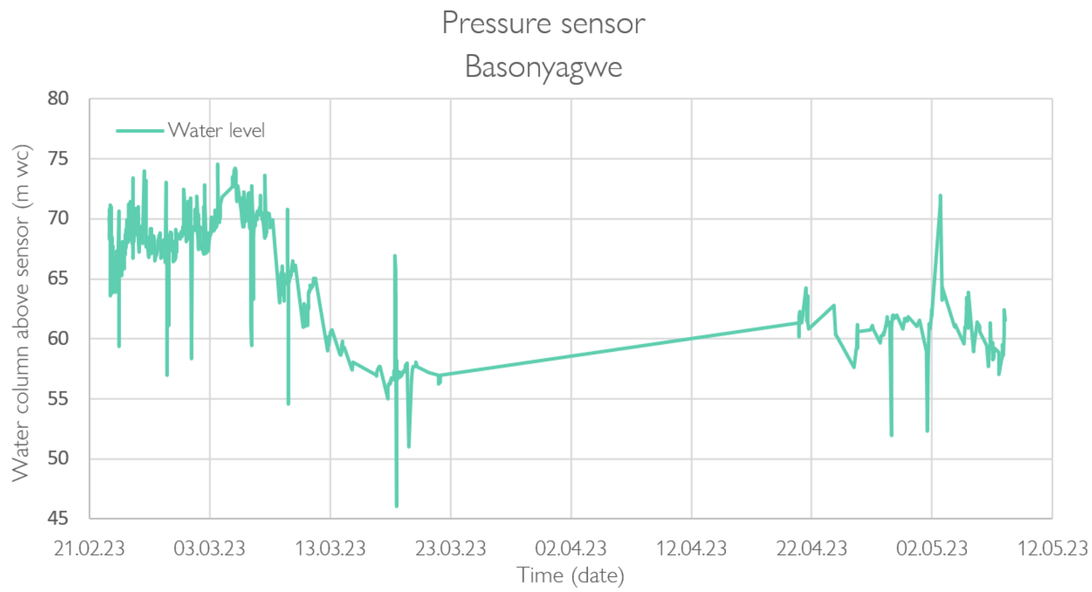


Figure 3.11: Plot of the entire water level data series from Basonyagwe.

3.4.2 Operation point and measured pump power

The operation point of the system in Basonyagwe was calculated to be a total head of 86.5 m which corresponds to a flow of 3.5 m^3/h. This again corresponds to a necessary pump power of 1.7 kW when the pump is running at the set speed of 2900 rpm.

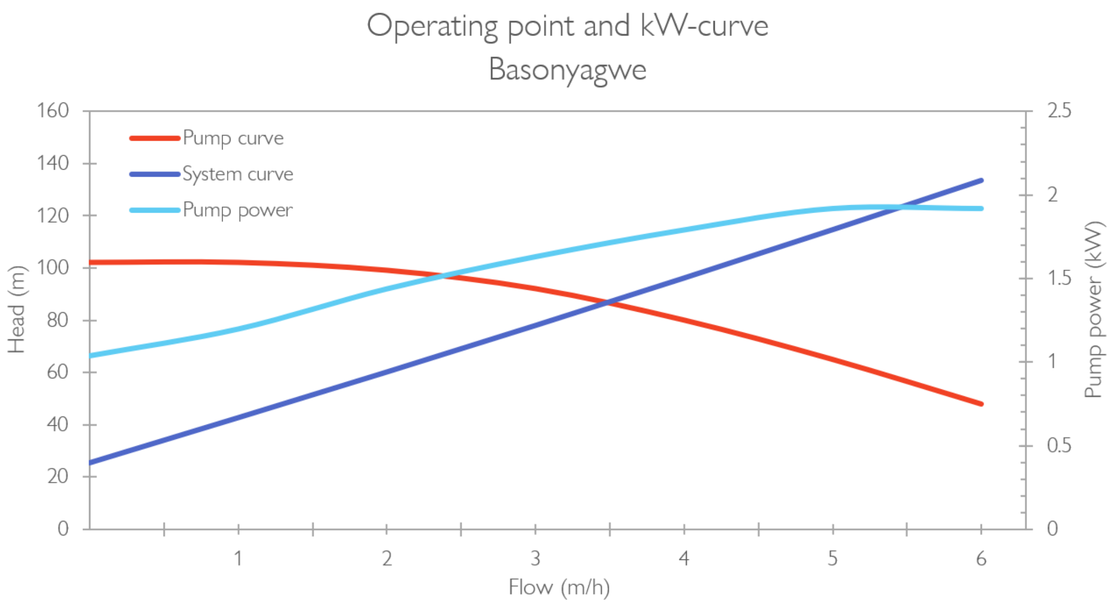


Figure 3.12: Calculated operation point and corresponding pump power curve from Basonyagwe.

The calculated friction loss, minor loss, and other parameters used to calculate the losses are listed in the tables (3.12 and 3.13) below.

Table 3.12: Calculated parameters used in finding energy losses in the pipe with diameter 38 mm.

Flow ($\frac{m^3}{s}$)	Minor loss (m)	Friction loss (m)	Velocity (m/s)	Friction factore	Reynolds number
0	0.00	0.00	0.00	0.0000	0
1	0.18	1.18	0.24	0.0350	10204
2	0.72	2.11	0.49	0.0312	20409
3	1.62	3.00	0.73	0.0296	30613
4	2.88	3.88	0.98	0.0287	40817
5	4.50	4.76	1.22	0.0281	51021
6	6.48	5.63	1.47	0.0277	61226

Table 3.13: Calculated factors used in finding energy losses in the pipe with diameter 15.6 mm.

Flow ($\frac{m^3}{s}$)	Minor loss (m)	Friction loss (m)	Velocity (m/s)	Friction factore	Reynolds number
0	0.00	0.00	0.00	0.0000	0
1	5.96	1.14	0.24	0.0363	24857
2	11.92	2.18	0.49	0.0347	49713
3	17.88	3.21	0.73	0.0341	74570
4	23.83	4.24	0.98	0.0338	99426
5	29.79	5.27	1.22	0.0337	124283
6	35.75	6.30	1.47	0.0335	149139

Table 3.14: Calculated factors used in finding system head.

Flow ($\frac{m^3}{s}$)	Drawdown (m)	DWL (m)	Total lifting height (m)
0	0	20	25.4
1	9	29	34.4
2	18	38	43.4
3	27	47	52.4
4	36	56	61.4
5	45	65	70.4
6	54	74	79.4

The calculated head loss from lifting height is listed in Table 3.14.

3.4.3 A review of the data

A discussion of the reliability of the data transmission and the data quality will be done in the section that follows. Finally, the inconsistency between the calculated operation points and the operation point found in previous master theses will be discussed.

Transmitting the data

The high reliability in measurement frequency in Endagaw Chini indicates that both the mobile coverage is good and stable and the power supply to the gateway is reliable. The battery configuration in both locations is similar. Therefore, this indicates that the reason for the gaps in data in Basoyagwe is due to unreliable mobile service at the location of the pump.

The large gap in measurements occurred due to a vulnerability in the system that allowed for human error, as the SIM cards were recharged late. Such gaps can lead to missing important changes or trends that might have occurred in the system being monitored, potentially limiting the usefulness of the collected data. This was especially damaging when the data series was only three months long.

The short time period over which data has been collected from this monitoring system is a cause of uncertainty. This can limit the usefulness of the collected data, as it does not provide a comprehensive understanding of how the monitoring system behaves over time. This limits the usefulness of the data in making informed decisions about the system's management or optimisation.

The current based data

The current sensor in Basonyagwe has a lot of disturbance in the measurements and this makes the data for pump power, last pump power, ampere and pump time corrupted. The measured pump power and the calculated pump power do not correlate. The measured pump power is too low based on the pump power given by the calculated operation point. The highest pump power measured is 1.14kW and the pump power needed to run at the given speed at the operation point is 1.7kW. This discrepancy can be due to a calibrating error, or a low power supply. If the power supply is low this could be because of undersized solar panels in relation to the power need of the pump. It could be due to dirt accumulation on the solar panels. This was observed at several of the water points. Dirt accumulation has been seen to reduce the performance of solar cells by 85% [Sulaimana et al., 2014].

There are several instances when the pump seems to be on, but the pump power does not go above 0.5kW, only 30% of the power given by the operating point and the kW-curve. This can be because the pump may be running at different frequencies based on the available current. This was listed as a possibility by Røer [p. 73, 2020] as the pumps were observed running at 40Hz and 30Hz in addition to the 50Hz listed by the manufacturer. The possibility to run at a lower frequency was proposed by Christopher Bolter from TU Berlin [Personal communication, 9th of April 2020, cited in Røer 2020, p. 73]. He emphasised that this would result in a lower pumping curve and subsequently lower pump rate. If the pump head gets too low, the pump may not be able to lift the water to the tank. Additionally, Bolter [2020] pointed out that this could also be due to a rise in the water level leading to the total head decreasing and the pump working at a different frequency. The effect of lower frequency and/or the higher water level is illustrated in Figure 3.13.

According to Paul Uwe Thamsen, a professor at TU Berlin and Chair of their Fluid system dynamic source, it is unlikely that a current of 0.5 will be able to lift the water to the tank with this pump [Personal communication, 15th of May 2023]. This indicates that either the pump's motor is just consuming power without pumping and generating heat, or the pump is pumping, but the water does not reach the tank and the pump is generating heat. Both are unfortunate but should not greatly impact the deterioration of the pump as the pump is often only on for a short time according to our data. It is however not possible to say if or why the pump is using a low amount of power. Furthermore,

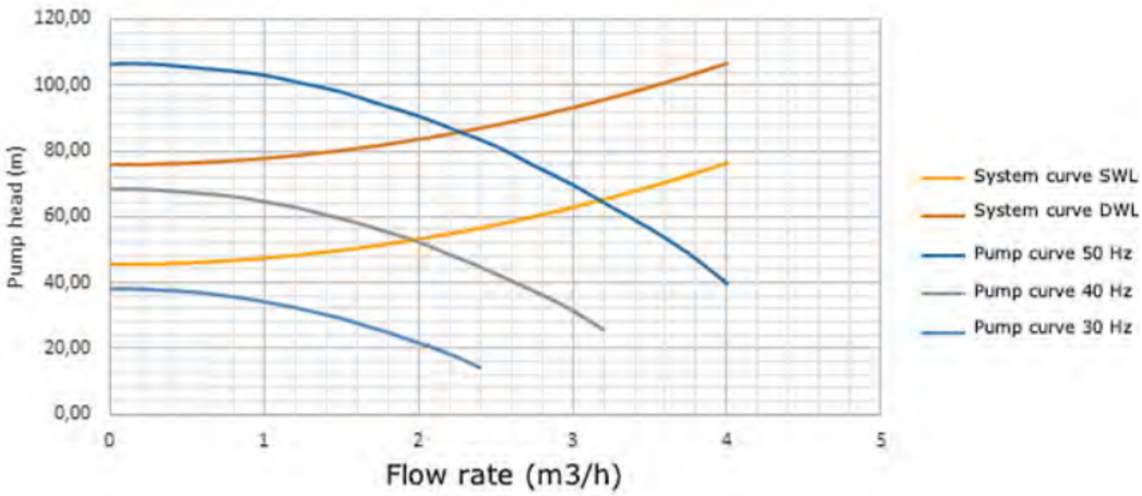


Figure 3.13: Pump curves and system curves at different frequencies and water levels. Made by Christopher Bolter [personal communication, 9th of April 2020, cited in Røer [p.73, 2020]

the system does not have a solution for the manager of the pump to see if there is water coming into the tank, so this would most likely go unreported. During the fieldwork, it was observed that the usual pumping procedure was to run the pump until there was an outflow from the tank or the manager goes home or out for lunch, so the pump could be on for some time without pumping. [Personal communication, Paul Uwe Thamsen, 15th of May 2023]

As noted, the values from the current meter fluctuate a lot. The fluctuations can be due to bad connections, or an error with the sensor. The values for pump time, last pump power and the frequency of data transmission are particularly impacted by this disturbance because the system's configuration initiates a new timer for the pump time each time the pump's power exceeds a certain threshold set to 0.5 kW. The pump time is derived from a counter that starts whenever the pump power exceeds the threshold of 0.5 kW and stops whenever it goes below. The disturbance in the signal from the current sensor in Basonyagwe makes the pump power value fluctuate frequently, and the time is calculated and the counter is set to zero each time the value falls below 0.5 kW. When this happens multiple times in a minute, this leads to the pump time being under-reported by the remote monitoring system in Basonyagwe, as can be seen in Figure 3.9. This figure also shows that this fluctuation affects the value for the last pump power to a larger degree than pump power. This is because the value for the last pump power is updated more frequently in the code than the pump power (see the code in Appendix G). The pump power is therefore more reliable, and together with the water level in the well, it provides insight into when the pump is used.

The threshold also affected the pump time value in the system in Endagaw Chini. Although the quality of data from the current meter in Endagaw Chini is much higher, there are still some problems. The gateway does not register the pump as on before the pump power is higher than the threshold of 0.5 kW. As illustrated in Figure 3.7, the pump appears to be turned on for quite some time before the power exceeds 500W. It can also be a result of the low frequency of measurements or unsuccessful attempts to turn the pump on. It is a common problem during the rainy season that there is a low or insufficient electrical current in the network to power the pump, due to cloud cover [Asklund, 2020, Røer, 2020]. It is possible that this can show as a spike in pump power, but no pump time. Additionally, the system is designed to send data whenever the pump is registered as being turned off, which occurs when the power falls below the threshold. If the output from the current sensor fluctuates significantly, as it does in Basonyagwe, it results in a situation where the pump seems to be turned on and off repeatedly and data is transmitted at a higher frequency.

The pressure sensor data

There are reasons to believe that the water level derived from the pressure sensor is highly inaccurate and unreliable. It has several gaps and varies more and faster than one may anticipate the water level to do when the pump is not running [Personal communication, Paul Uwe Thamsen, 15. of May 2023]. Furthermore, when the pump is running, the water level appears to be rising when it should be falling, as can be seen in Figure 3.14. Both Asklund [2020] and NCA [2015] measured the static water level to be 20m below ground. The pressure sensor is extremely sensitive, which led to inaccuracy and fluctuations according to Asklund [2020]. The problems that were experienced in 2020 could still exist since the sensors have not been re-calibrated. Nevertheless, the gateway's ability to gather and transmit data, and the application software's ability to store and visualise the data prove that a remote monitoring system is feasible in this area at a relatively low cost.

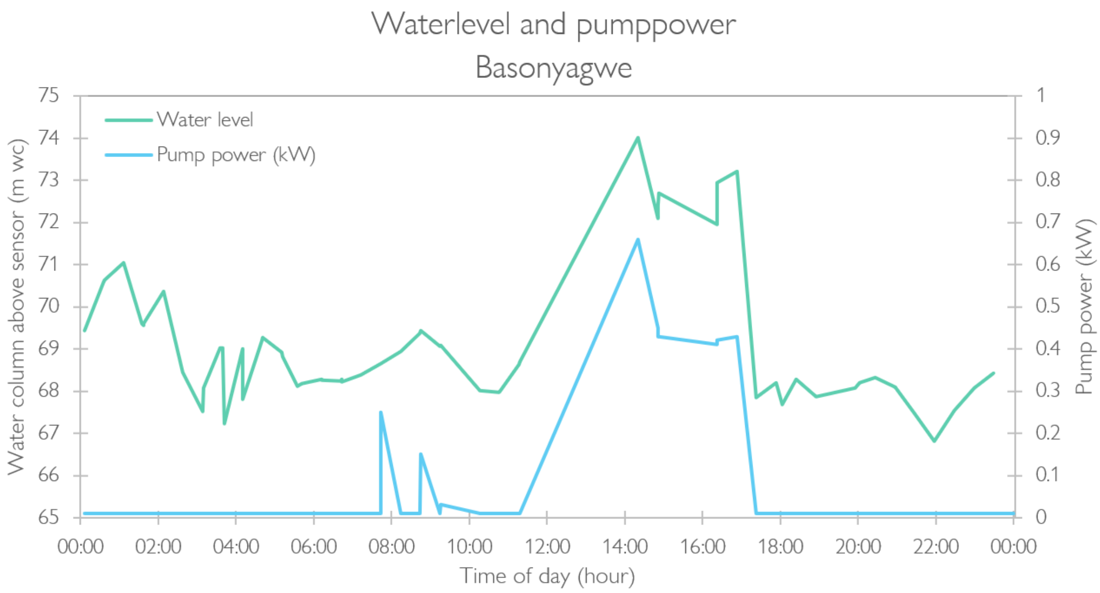


Figure 3.14: Plot of how the pressure sensor reacts to the pump being turned on.

Inconsistency regarding the operating point

It is important to note that the calculated operation point in this thesis is different from the operation point calculated on the same pump in the same location by Asklund in 2020. Asklund [2020] calculated the operation point to a head of 86.9 m and a pump rate of 3.4 m^3/h. The reasons for these inconsistencies are related to different methods of calculating drawdown and different values used for minor loss coefficient.

Asklund [2020] also did a bucket test to measure the pump rate at ground level. The pump rate was calculated to be 5.1 m^3/h with a total head at that point in the system of 63.1 m, but the bucket test only gave a pump rate of 2.7 $m^3/h \pm 0.1$. This indicates that the actual pump rate is much lower than the calculated pump rate. One explanation for this is a poorly performing pump [Davis and Shirtliff, nd]. It is also important to mention that the users and COWSO in Basonyagwe reported that they get sufficient water for domestic use, as they also reported in 2020 when Asklund [2020] asked them.

Chapter 4

Discussion

4.1 Conditions of community-driven development

In this chapter, the results from the previous chapter will be discussed against the findings from the QCA, community-driven development and future developments in general. This is done in order to give a detailed and comprehensive answer to the main research question (section 1.3.2).

In CDD literature, community participation in terms of community control, access to information and inclusion in decision-making processes is highlighted as important principles for sustainable and effective CDD [Dongier et al., 2003]. These principles should be discussed against the causal conditions found to be of importance in this study to assess the similarities and differences.

In the QCA conducted in this study, participation was excluded as a condition due to its lack of variation in the selected cases. The criteria chosen for participation assessed how involved the community members were in the decision-making processes as well as in village meetings about the water systems. The scoring of participation as a condition reveals constant high scores throughout the case villages (see Appendix A, showing high involvement in the decision-making process. This study can therefore confirm the importance of such involvement, corroborating CDD literature. It does not however identify involvement in decision-making as a necessity for reaching development instead of non-development. Furthermore, community access to information is also mentioned as an important principle of CDD. This was assessed in this study through the condition of accountability and transparency. Accountability and transparency were excluded from the QCA due to high scores (see Appendix A) across most of the case villages. This can therefore, in the same way as participation, based on the findings of this study, be confirmed as an important part of development without being the driving factor.

An important finding in this study through the QCA is the identification of user acceptability as a necessary condition for development. As mentioned in previous discussions, user acceptability, i.e. community satisfaction with the water system, can be related to community engagement, with increased community satisfaction yielding higher community engagement [Marks et al., 2014]. This also corroborates CDD literature, which states that community engagement is an integral part of all stages of CDD ([Tantoh and Simatele, 2016]). The pathways identified by the QCA does however reveals the need for more than just high user acceptability alone in order to implement community-driven development. The other conditions and combinations of conditions identified by the QCA will therefore be discussed in the context of the rest of the findings in this study.

In addition to identifying pathways to development, the scoring of the conditions and outcome shows a picture of the general situation in the study area today. A closer look at the interview data shows that almost half of the villages said that they are not getting as much water as expected when the boreholes were first constructed. This will naturally affect both storage and supply reliability and the use of alternative water sources. As mentioned in earlier discussions, the combination of these conditions is necessary for reaching development. It can therefore be assumed that many of the villages were already at a disadvantage from the beginning, which is another factor not shown through the QCA pathways. The analyses of the data from the remote monitoring in Basonyagwe indicated that limitations in pump power could be a factor that affects the performance of the water wells, but this would have to be investigated further to conclude.

It is important to note that the absence of alternative water sources is only seen as positive in terms of the development of the village water borehole. The use of alternative water sources is an essential part of the water systems in rural Tanzania and in an overall assessment of the water situation in a village, having additional sources that are safe and clean would be seen as a strength.

4.2 Development of local water infrastructure as a self-reinforcing effect

Dang'aida's performance in the QCA could be significantly impacted by the proposed expansion of the village's water supply system in a number of ways. The installation of additional tanks in the sub-villages would increase the village's overall storage capacity, which is essential for ensuring reliable supply and storage. There are some uncertainties in the calculations of the pump rate as described in 2.8.6. Several problems, including trouble filling the tanks, not always having water during opening hours, and service interruptions because of water scarcity, may occur if the pump rate is too low to handle the demand. These variables directly influence the criteria used to assess storage and supply reliability conditions. As a result, if the pump runs slower than anticipated, the village's performance in relation to the storage and supply reliability condition could be negatively affected by the expansion.

By bringing water sources closer to the sub-villages, the expansion would significantly reduce the time and effort required for residents to fetch water, thereby enhancing user acceptability. Multiple taps would also decrease the lines, which would decrease the total fetching time. Because proximity to water and total fetching time are important factors of whether a user decides to go fetch water from that source [WB, 2018] and the willingness to pay [Misund and Møller, 2019], it can also be argued that this would increase the revenue from selling water and subsequently increase the financial durability of the water source. If more people choose to fetch water from the improved water source it would also lead to fewer people using alternative water sources for domestic use, which would increase the villages' score in the absence of alternative water sources condition.

The implementation of a more complex water supply system would likely require additional management and repairs due to the increased number of components. This could have a negative impact on the criteria that represent repair service in the QCA. However, by establishing effective repair routines and maintenance protocols, the village can maintain a high level of repair service despite the increase in the total amount of repairs. Furthermore, the increased number of repairs could provide valuable opportunities for the person doing the repair to develop better routines and gain technical expertise, which could lead to a lower repair time per repair and could ultimately lead to a more proficient and resilient repair service.

Due to the factors addressed above and the findings from the conducted QCA the proposed expansion of the water supply system in Dang'aida has the potential to trigger a self-reinforcing cycle of community-driven development and investment in the water source, if the pump rate and the management routines are sufficient. However, the boreholes' ability to meet the anticipated increased demand of the expanded system has not been thoroughly assessed. It is likely that people in the sub-village who previously used alternative water sources would, with an improved water source that is closer, prefer to purchase water for domestic use. The COWSO reported that, given the current demand, the well produces enough water for domestic use, and the pump test conducted prior to construction revealed a yield of 8000 l/h which further support this (as reported in the Technical report shown in its entirety in Appendix H). But the capacity of the well to meet this increase in demands in the long term has not been assessed, nor has the anticipated increased demand been quantified. However, given the increased storage, it is likely that the expanded system would be able to supply more water overall.

Numerous studies and extensive research have consistently shown that better access to water leads to better living conditions and opportunities for community members [Hulton, 2012, UN, nd, Tantoh and Simatele, 2016, UN, 2015, Cleaver and Toner, 2016, SNV-Tanzania, 2010, Fierro et al., 2017]. This can also be seen in the RWSS in the study area. 4CCP noted in their report from 2022 that better access to clean and safe water had increased the women's opportunities to participate in village democracy, as less time is spent fetching water. Children's performance in school was also reported to be improved because more of the students' time was freed up for studying [4CCP, 2022]. The report also found that people had more time for economic activities and that there were fewer waterborne diseases. This lead to an improved socioeconomic situation for the inhabitants, which in turn can provide them with greater resources and opportunities to invest in their water infrastructure [4CCP, 2022]. As a result, the initial development can initiate a self-enhancing effect that encourages further development and ultimately benefit the entire community.

The expansion in Dang'aida therefore has implications for the development of other RWSS. The design decisions made for the system expansion in Dang'aida are specific to their system and needs, but the factors that have been shown to have a significant impact on the system's performance and the likelihood of encouragement for further community-driven development, are crucial elements to take into consideration in other comparable community-driven developments of RWSSs.

4.3 The role of water quality in future developments

In section 3.3, the water quality test results were presented and discussed in terms of origin and treatment. From the discussion, it became clear that substantial improvements in water quality might be made by implementing various preventive actions. Agricultural runoff was seen as a potential reason for high nitrate and phosphate. Restricting agricultural activities close to the water source can therefore be a potential solution. Preventive action will also reduce the need for treatment and thereby reduce operational costs [WHO, 2017]. In order to properly implement preventive actions, it is important to understand the local runoff patterns and pathways to contamination. This is because restricting agricultural activities might be seen an intrusive action that limits the development of the communities.

Understanding why and where the contamination is coming from will help implement actions that are less intrusive and restrictive in terms of land use. In order to accomplish this, proper coordination between all stakeholders should be established [WHO, 2017].

WHO [2017] suggests the use of a catchment management plan which consists of preventive actions that needs to be implemented in order to protect the groundwater sources. In the setting of the study area, this would translate into stakeholders on national and district levels providing the communities with technical assistance and information. This will help the communities understand their water source and the runoff in their catchment, as well as promote awareness of the impact of human, animal and agricultural activities on the water source. This can potentially be achieved by including the communities in several of the stages in the implementation of the water system, including technical training and involvement in the planning of land use, as suggested in CDD literature [Tantoh and Simatele, 2016]. A detailed management plan, made by the government or the district, and applied by the community members, could also help distribute responsibilities and provide a sense of ownership on all levels [WHO, 2017].

In cases where preventive actions are deemed as not enough, such as for high fluoride levels, treatment options need to be considered. As discussed in section 3.3, finding treatment options for fluoride removal that are suitable for rural Tanzanian settings has been problematic. Although effective treatment methods for fluoride removal do exist, such as activated alumina, they are seen as too expensive [WHO, 2017]. Cheaper options suggested by Evang and Bakken [2021] were found to be less effective, further confirming the problematic nature of fluoride in the study area. The technologies surrounding solar-powered nanofiltration and reverse osmosis are improving, with studies conducted in rural Tanzania showing promise [Shen et al., 2016]. The implementation of such a treatment facility will not only be useful for fluoride removal but also the removal of nitrate, phosphate and other salts and contaminants [Shen et al., 2016]. How this treatment method should be implemented is also a topic of interest. A scenario such as the one piloted in the nanofiltration study [Shen et al., 2016], where the technology is used to treat all water from the borehole, might prove expensive and could therefore be a solution for future, improved water systems. Another potential scenario uses the suggestion mentioned in Asklund's [2020, p. 100] master thesis, where it is recommended to treat water at the household level. This opens up the possibility of implementing smaller filtration units, which can be used to treat only water needed for domestic use. Such an implementation must however be assessed further against cost and available technology.

How water quality affects the pathways to development identified by the QCA is primarily connected to the condition user acceptability. The analysis of the interview data shows widespread satisfaction with the water quality, and almost all villages report improvements in health after the installation of the water boreholes. The results from the water quality test does not however show universally good water quality (based on TBS guideline [TBS, 2019]). The perceived water quality therefore differs from the actual water quality. Studies conducted in other water-deprived rural areas confirm this, as it is shown that perceived water quality is often more positive than the actual water quality [Rowles et al., 2018]. This indicates that even though water quality in terms of user acceptability might be guaranteed and the development pathway secured, additional assessment of the actual water quality is needed to ensure a sustainable water supply and protect public health. Additionally, community knowledge about the actual water quality and involvement in treatment management might also help further strengthen the sense of ownership. If treatment is implemented and water quality increases, this involvement might also limit the use of alternative water sources, which is part of the pathways identified in this study to further development. Another argument for the importance of community involvement and education on water quality is reflected in the use of chlorination. As mentioned in earlier discussions, chlorine disinfection was offered to most of the villages, first as a free trial, and then by purchase. The results from the chlorine measurements showed that chlorine was either not used or used improperly. It can therefore be assumed that proper knowledge about water quality through involvement and a detailed management plan would better the use of such treatment methods.

Another important aspect is the role of water quality when the water system infrastructure is expanded. As mentioned in previous discussions, a water systems vulnerability increases with the inclusion of more pipes and parts [Ødegaard, 2014, p. 262]. Pressure fluctuations can cause contaminants to leak into the distribution network. Thus, a larger system has the potential to reduce the water quality, which should therefore be considered. One potential solution for this is having a management plan that includes routine flushing of the pipes [Ødegaard, 2014, p. 262].

Additionally, conversations with the CBWSOs in some of the villages indicate that more people have moved to the villages due to the installation of water boreholes. It is reasonable to assume that such a trend continues with further developments made in the water systems. This can cause issues if proper treatment is not implemented, as more people will rely on the water system. As suggested in earlier discussions, chlorine disinfection against E. coli i.e., faecal contamination, should therefore be implemented at all locations where further developments are planned. Preventive actions against animal and human activities close to the water borehole can also help reduce the possibility of faecal contamination, but such actions should be taken using proper guidelines and management plans, as suggested above.

4.4 Would remote monitoring contribute to the management of water supply in rural Tanzania?

It is the CBWSOs that own and are responsible for the management of the water wells, but water committees have been found to lack the capacity and resources to take full charge of system management, despite strong investment in capacity building [Wong and Guggenheim, 2018]. Poor repair service is a common problem in SSA. Andreas et. al. [2018] found that in SSA, as many as one-third of all hand pumps are not working at any given time. 30%–70% of the pumps are broken within two years of installation. Even though solar-powered groundwater wells have a much smaller failure frequency [WB, 2018], this shows that management issues and poor repair service are widespread problems. The World Bank [2003] found in a report from 2003 that the full costs to cover operation and maintenance in RWSS in SSA were not recovered from users [Lockwood et al., 2003], and according to Wong [2018] little has changed. This leads to the communities requiring follow-up support, which is also the case in this study, as several of the villages have at one point needed assistance from the district for major repairs. According to Lockwood [2003] this follow-up support must also include technical assistance [Lockwood et al., 2003].

Thomson et. al. [2020] found that a large improvement in system uptime was achieved in studies that implemented remote monitoring with an ambulant technician team when measured against systems that relied on self-reporting issues [Thomson, 2020]. As described in section 2.8, the current reporting system is slow and inefficient, and the interviews reveal that major repairs can take as long as three years. Therefore, remote monitoring could prove beneficial in this project to increase performance and reduce repair time, which is found to be an important condition in one of the pathways to development found in the QCA.

The district engineer has the responsibility to offer support to the CBWSOs [RUWASA, nd]. Remote monitoring would make time-consuming in-situ data gathering unnecessary and can decrease the time needed for each repair since the technicians would be able to work more targeted [Andres et al., 2018]. It would also make it possible to keep track of progress and hold service providers, governments, and development partners accountable. The district engineer lacks the necessary data to evaluate and, when necessary, contest incorrect claims. For policy and decision-making to be informed, for investments to be made in the right places, and for political commitment to be sparked, dependable and consistent data is necessary. Additionally, remote monitoring has the potential to bring much-needed additional funding into the rural water sector by providing a more cost-effective monitoring of projects for existing donors who are becoming more sceptical about the value of their aid. [Andres et al., 2018]

Installing and managing an extensive remote monitoring system is a big investment [Thomson, 2020]. According to the representatives of the district engineer that was interviewed, the government does not have enough funds to be able to take much responsibility for the management of the water points and ensure timely repairs [Personal communication, Representatives from the District Engineer offices, 21th of February 2023]. It will likely be difficult for the district engineer to prioritise a remote monitoring program as the office is held responsible for the use of money from the public and the government is typically unwilling to invest money in "invisible" projects like remote monitoring. Investing scarce government money into building groundwater wells clearly poses far less of a political risk [Lockwood et al., 2003]. Furthermore, the district engineer is under big pressure to increase the coverage of improved water sources from around 60% to around 85% in 2025. Today, a remote monitoring system is marginally less costly with the assumed cost reductions and revenues from it, than traditional management. However, as the field of remote monitoring matures, performance and reliability will improve, and the investment and operation costs will decrease. This will result in remote monitoring being more financially rewarding [Thomson, 2020].

Remote monitoring data gathered from the water wells could also help indicate how to improve performance, and hence be beneficial to the CBWSOs. Røer [2020, p. 73] found that none of the solar-powered pumping systems studied within the study area was providing enough water to cover both domestic and productive uses. Røer [2020, p. 73] concluded based on this that it would be difficult to expand the water systems without increasing the pump rate. This problem is still seen today. As mentioned in section 4.1, the data from the interviews show that nearly half of the villages stated that they were receiving less water than anticipated. This has a negative impact on storage and supply reliability, an important factor for development to occur. The remote monitoring data from Basonyagwe, however uncertain, indicate that insufficient pump power caused a reduction in the performance of the pump. This knowledge could make improvements more targeted, by for example indicating when it is time to clean the solar panels.

The monitoring data might potentially be used to improve the water point's operation. Users' behavioural patterns can be analysed to better understand how and when water is retrieved and consumed, and give useful insights for policy planning [Andres et al., 2018]. Furthermore, the data could inform the design and construction of a community-driven expansion of the water supply system. It could give information that can be used to decide how to prioritise initiatives and assess the cost-effectiveness and efficacy of the development [Andres et al., 2018]. However, the external support and monitoring from the district engineer could affect the CBWSO's capacity and sense of responsibility for the water point, as communities with less involvement from the government regarding maintenance have a better development of community management structures. It has been noted in previous projects that follow-up support can lead to a higher sense of dependency on external agencies [Lockwood et al., 2003].

Installing a remote monitoring as a widespread system is a big investment, and maintaining it takes up valuable time of technicians in an area with few technicians [Thomson, 2020]. Substantial evidence of the financial benefits of a generalised remote monitoring system is therefore needed. The benefits in terms of more efficient monitoring can lower costs, but under existing management procedures, this reduction is likely to be marginal. Similarly, under the current standards for acceptable repair time of RWSS, the advantages of remote monitoring appear minor [Thomson, 2020]. Remote monitoring must be used as a tool to rethink the management of RWSS, and thus enhance the standards by which the water supply in rural communities in Tanzania is measured against. An intermediate solution, and possible transitional stage, would be to only install remote monitoring systems on the most vulnerable, difficult-to-access wells. It is uncertain how much financial, institutional and human resources the District engineer has, and investing in more efficient management could prove hard to prioritise before the districts have a larger coverage of water access. There is an intangible worth that is hard to quantify related to having access to a reliable and safely managed water source. Therefore, based on the proven decrease in downtime, remote monitoring could be a crucial part of providing safe and clean water to rural Tanzania in the future.

Chapter 5

Conclusion

This master thesis has investigated which conditions contribute to community-driven development in rural Tanzania and how such a development can be facilitated. This was done by analysing interview data and conducting field observations, designing an expansion of the water system in the village of Dang'aida, measuring and reviewing the water quality at several locations and evaluating the use of remote monitoring in the management of rural water systems.

Two potential pathways to development were identified by the QCA in this study. The most robust pathway consists of user acceptability, financial durability, storage and supply reliability and the absence of an alternative water source. The use of alternative water sources is important in order to satisfy the community water demand, but it is seen to be a drawback when trying to develop the village water borehole. The QCA also identified that user acceptability is a necessity in order to reach development, which corroborates with findings in CDD literature. Furthermore, some conditions not included in the QCA, such as community participation, were also found to be of importance. Interview data reveals that almost half of the case villages reported inadequate water supply. This affects both storage and supply reliability and the use of alternative water sources, and consequently the potential for community-driven development.

The design of the water system expansion in Dang'aida shows possible solutions to improve storage and supply reliability, user acceptance and financial durability. Therefore, it has the potential to trigger a self-reinforcing cycle of community-driven development. The designed expansion of the water system in Dang'aida can provide sufficient water to all the planned locations using the existing pump, provided the well has the required capacity for the assumed increased use. It is also a requirement that the pump gets sufficient power and performs as described by the manufacturer. The choice of dimension is an especially important parameter for the outflow and should not be underestimated. However, the expansion makes effective repair routines and maintenance protocols more important to maintain a high level of repair service.

The water quality measurements conducted in this study reveal that several of the locations have drinking water with high levels of nitrate and E. coli. According to further analysis, the elevated concentration levels are most likely caused by agricultural runoff, as well as human and animal activities close to the water borehole. Thus, preventive actions and treatment is needed in order to provide drinking water suitable for human consumption. It is recommended by this study that a management plan is made by districts and implemented by the communities. This will increase the communities' sense of ownership over the water systems as well as provide them with sufficient knowledge about the importance of water quality.

The implemented remote monitoring system was, despite data quality problems, a proof of concept for a low-cost and user-friendly remote monitoring system. Remote monitoring has the ability to make the District Engineers' follow-up support of the CBWSOs easier and provide information that the CBWSOs could use to improve the management of the water point. According to the literature, it can significantly reduce repair times, improving the reliability of water access in rural Tanzania. However, under the current management regime, extensive use of remote monitoring is a big investment that only marginally reduces cost and takes up a lot of technical resources. Therefore, it is unlikely that the District Engineer will be able to prioritise investing in an extensive remote monitoring system at this time.

5.1 Future work

The research conducted for this thesis raised some new issues that require further study and left some open-ended questions. For instance, this master thesis does not consider the cost versus benefit of an expansion of a water system in terms of expenditures and revenues. This should be further explored as expansion is a big investment. An optimisation of revenue collection with multiple taps in multiple locations should in this context be reviewed. More knowledge is also needed on how the development of a water system affects the use of the system, and if the recharge of the aquifer is sufficient to support such a use. It is especially important to investigate the effect of climate change on the recharge process to assess the long-time sustainability of the systems.

Secondly, the cost in relation to the utility of a remote monitoring system should be explored further. In this setting, it would be natural to procure the wants and needs of the water committees and district engineers regarding such a system. More knowledge is also required on how to design the system and how such a remote monitoring system could be used by the CBWSO and the District Engineer to improve the management of the water points.

Thirdly, during the work with this master's thesis, there were found indications of issues brought on by a lack of pump power. These should be investigated further, as it could affect the performance of the water supply systems significantly. In this regard, the dimensioning of the solar cells should be assessed, as should the management routines and the effect of the accumulation of dirt.

Fourthly, although the water quality measurement conducted in this study did not indicate high fluoride levels, it is still believed to be a cause for concern in the study area. This, along with the high nitrate and the high salt and mineral levels found in the area, increases the need for research into small-scale widely applicable treatment methods. Solar-powered nanofiltration/reverse osmosis is emerging as a possible answer to this [Shen et al., 2016]. Further research into the costs and benefits of such a treatment method, along with research into the usability in rural Tanzanian settings should be conducted.

Finally, QCA has proven to be an effective analysing tool when trying to find out what causes development. Limitations in the number of case villages and the depth of the gathered information is however reflected in the results. It is believed that a larger study, over a longer time, with deeper case knowledge, could result in the identification of new and more generalisable pathways to development. The incorporation of a temporal dimension in the analysis could also help build further knowledge about water systems in rural Tanzania.

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Appendix

A Overview of the scoring of the cases in the conditions

Village	User acceptability	Activity level	Participation	Repair service	System function	Financial durability	Willingness to pay	Storage and supply reliability
1	1	1	1	1	0.67	0.33	1	1
2	0.33	1	0.67	0.67	0.33	0.33	1	0
3	1	0.67	1	0.33	0.67	0.67	0.67	0.67
4	0.33	1	0.67	0.33	0	0.33	0.67	0
5	1	1	0.67	0.67	0.67	1	0	1
6	0	0.67	0.67	1	0.67	1	0.67	0.67
7	0.67	0.67	0.67	0	0	0	0	0.67
8	0.33	0.67	0.67	0	0.67	0.33	1	0.33
9	0.33	1	0.67	0	0.67	0.67	0	1
10	0.67	1	0.67	0	0	0.33	0	0
11	1	0.67	1	0	0.67	0.33	0	1
12	0.67	1	0.67	0.67	0.33	0.67	0	0.67
13	1	0.33	0.67	0.67	0.67	0.33	0	0.67

Village	Absence of Alternative water source	Access to water	Accountability and transparency	Water quality	Follow government guidelines	Yield	Construction year	**Outcome**
1	0.67	0	1	1	1	0.67	0.33	**0.67**
2	0.33	0	1	0	1	1	0.33	**0.33**
3	1	0.33	1	0.67	1	0.67	0.33	**0.67**
4	0	0	0	1	1	0	0	**0**
5	0.67	0.33	1	0.33	0.33	1	0.33	**1**
6	0	1	0.33	0.33	1	0	0	**0**
7	0.67	0	1		0.33	0	1	**0.33**
8	0.33	0.67	0	1	1	0.33	0.33	**0**
9	0.67	0.67	1	0.33	0.33	0.67	0.33	**0**
10	0	0	1	0	0.33	0.67	0.33	**0**
11	1	0.33	0.67	0	0.33	0.67	1	**1**
12	1	0.67	0.67	0	1	0.33	0.33	**1**
13	0.67	0.67	0.67	0.33	0	1	0	**1**

B Questionnaire: CBWSO

Demographic Data

Name of Community:

User Acceptability

What are the positive consequences of the water well?
What else?

Are there any conflicts conserning the water well?
What else?

Is there any healthproblems related to the water from the well?

Activity Level

How many people do the day-to-day operation of the well?

What are their roles?

When does the well open and when does it close?

Participation

Are there any village-meetings and/or reports concerning the water well?

What is the content of these meetings/reports?

Approximately how many people from the village attend these meetings?

Repair Service

What kind of maintenance is done on the water well?

How frequent is maintenance done on the water well?

How much down-time of the water supply do you experience during maintenance (in days)?

System Function

Is there always water in the system during operational hours?

Do the users buy more, less or the same amount of water during the rainy season as the dry season?

If there is a difference, how much is the difference (liters)?

Do you have a waterguard connected to the big tanks?

If so, who advised you to get it?

Did you have any healthproblems with the water from the well before you got the waterguard?

Financial Durability

What is the main weekly, monthly and yearly expenditures (salaries, goods, etc.) for the water well?

Do you have any savings for future maintenance and development?

If you have any savings for future maintenance and development, how much?

What is the fee for the water?

Is it sufficient to pay salaries and maintenance costs?

If not, how much more is needed?

Willingness to Pay

Do all the water users pay for the water?

If no, is there any social arrangements for those that are unable to pay?

Reliability

How much water did you expect to get from the well and how much do you get from the well?

Long-term Stability

Have you seen any decline in the amount of water extracted from the well during the period after the well was installed?

If yes, how much decline?

Storage and Supply Reliability

Do you have any issues with filling the water tanks?

Rehabilitation and Maintenance

What happens if the water well stops producing water?

Who will be contacted and how long time will it take to get help?

Administration, Operation, and Maintenance

How is the COWSO organized?

How often do the cowso have meetings?

What is your task in the COWSO?

Alternative Water Source

Do people use any other water sources?

Which other sources are used?

Are there any seasonal conditions that influence water source usage?

Access to Water

How far from the waterpoint is the village?

Stundents, children, workers, etc.

Does anyone have priority when it comes to receiving water?

Accountability and Transparancy

How do you inform the villagers about the work you in the COWSOs are doing to operate the water well?

Do you have any questions for us or any thing you would like to say before we end?

C Questionnaire: User

I am part of a study team looking into post control of the water wells. The study includes a discussion of the use and practices connected to the water well and will take about 40 minutes. I would like to hear your views on this topic. You are not obliged to participate in the study and no services will be withheld if you decide not to. Likewise, if you decide to talk to me, you won't receive any gifts, services, or remuneration. Everything we discuss will be held in strict confidence and will not be shared with anyone else. Would you like to participate in the study?

◯ OK

Demographic Data

Name of Community:

How many people are in your family?

User Acceptability

What is the situation before and after the water well project?
What else?

Have you noticed any health changes in the community after the well was built?

Activity Level

How often do you collect water?

How much?

Other than drinking, cooking and cleaning, what do you use the water for?

Participation

Do you or any of your family attend community meetings?

Repair Service

How often are you not able to get water from the well?

IIf you sometimes are not able to get water from the well, what are the reasons?

System Function

IIs there always water in the system during operational hours?

Financial durability

Are you able to get water and pay for it later?

Willingness to Pay

Does the price for the water seem fair?

What would the maximum amount you will be willing to pay for the water?

Reliability

Are you satisfied with the amount of water you get from the well?

What do you think of the quality of the water you are getting?

Long-term Stability

Have there been any change in the amount of water received and the quality of the water during the period after the well was installed?

What changes?

Storage and Supply Reliability

Are the water tanks often empty?

How long do you have to wait in line when collecting water?

Is there a difference between rainy season and dry season?

Alternative Water Source

Do you use any other water sources?

For what?

If you use other water source, why?

Access to Water

How much time do you use to fetch water each day?

How long do you have to travel to get the water? (in kilometers)

Accountability and Transparency

Do you have confidence in that the money you pay for the water is actually used for repair and maintenance of the water well?

Feedback

Finally, do you have any questions for us?

D Questionnaire: Student

I am part of a study team looking into post control of the water wells. The study includes a discussion of the use and practices connected to the water well and will take about 40 minutes. I would like to hear your views on this topic. You are not obliged to participate in the study and no services will be withheld if you decide not to. Likewise, if you decide to talk to me, you won't receive any gifts, services, or remuneration. Everything we discuss will be held in strict confidence and will not be shared with anyone else. Would you like to participate in the study?

○ OK

Demographic Data

Name of School:

User Acceptability

What is the situation before and after the water well project?
What else?

Have you noticed any health changes in the school after the well was built?

Activity Level

How often do you collect water?

What do you use the water for?

Repair Service

How often are you not able to get water from the tap?

IIf you sometimes are not able to get water, what are the reasons?

System Function

IIs there always water in the tap?

Reliability

Are you satisfied with the amount of water you get from the well?

What do you think of the quality of the water you are getting?

Storage and Supply Reliability

How long do you have to wait in line when collecting water?

Is there a difference between rainy season and dry season?

Alternative Water Source

Do you use any other water sources?

For what?

If you use other water source, why?

Access to Water

How much time do you use to fetch water each day?

Feedback

Finally, do you have any questions for us?

E Water tests

Village	Physical parameters													
	Conductivity (ms/cm)					Temperature					Color	Solids	Turbidity	Odour
	Test 1	Test 2	Test 3	Average	STD	Test 1	Test 2	Test 3	Average	STD				
Dang'aida	4.93	4.91	4.91	4.917	0.012	25.40	24.20	24.00	24.533	0.757	Clear	No visable	Less than visible	No odour
Dang'aida primary school	4.88	4.87	4.87	4.873	0.006	24.90	24.80	24.90	24.867	0.058	Clear	No visable	Less than visible	No odour
Basonyagwe	0.99	0.99	0.99	0.990	0.000	22.60	22.50	22.10	22.400	0.265	Clear	No visable	Less than visible	No odour
Murkuchida	0.63	0.62	0.62	0.623	0.006	24.00	22.70	21.80	22.833	1.106	Clear	Some small b	Less than visible	No odour
Haydom hospital spring	0.76	0.75	0.75	0.753	0.006	26.80	26.20	26.70	26.567	0.321	Clear	Some small b	Less than visible	No odour
Mewadan	1.22	1.23	1.25	1.233	0.015	27.80	27.90	28.10	27.933	0.153	Clear	No visable	Less than visible	No odour
Geterer school rainwater	0.02			0.020	-	25.00			25.000	-	Clear	No visable	Less than visible	No odour
Geterer school well	2.03	2.02		2.025	0.007	28.10	27.90	27.80	27.933	0.153	Clear	No visable	Less than visible	No odour
Mamagi	1.57	1.56	1.57	1.567	0.006	22.30	21.90	21.30	21.833	0.503	Clear	Few small wh	Less than visible	No odour
Labey secondary school	0.53			0.530	-	24.30			24.300	-	Clear	No visable	Less than visible	No odour
Labey secondary school government source.	1.14			1.140	-	24.00			24.000	-	Clear	No visable	Less than visible	No odour
Dotina primary school	1.22	1.22	1.23	1.223	0.006	24.40	24.20	24.10	24.233	0.153	Clear	No visable	Less than visible	No odour
Gidhim secondary school	0.81	0.80		0.805	0.007	24.10	24.40		24.250	0.212	Clear	No visable	Less than visible	No odour
Gaye primary school	0.91			0.910	-	26.40			26.400	-	Clear	No visable	Less than visible	No odour
Gidhim 4CCP well	0.93	0.92		0.925	0.007	29.00	27.50		28.250	1.061	Clear	No visable	Less than visible	No odour
Dilling'ang	2.06			2.060	-	Unknown from source.			-	-	Clear	No visable	Less than visible	No odour
Getunawas	2.21	2.22		2.215	0.007	23.40	25.20		24.300	1.273	Clear	No visable	Less than visible	No odour
Hilamoto	1.78	1.78		1.780	0.000	24.90	25.30		25.100	0.283	Clear	No visable	Less than visible	No odour
Endagulda	1.45	1.45		1.450	0.000	28.20	28.20		28.200	0.000	Clear	No visable	Less than visible	No odour
Isene	0.64	0.61		0.625	0.021	27.90	26.80		27.350	0.778	Clear	No visable	Less than visible	No odour
Haydom school, tank	1.45	1.47		1.460	0.014	24.30	24.00		24.150	0.212	clear	No visable	Less than visible	No odour
Haydom school, well	0.74			0.740	-	25.30			25.300	-	Clear	No visable	Less than visible	No odour
Haydom office	1.79			1.790	-	25.20			25.200	-	Clear	No visable	Less than visible	No odour
Matere	1.06	1.03		1.045	0.021	24.60	24.90		24.750	0.212	Clear	No visable	Less than visible	No odour
Monguli	2.46			2.460	-	26.60			26.600	-	Clear	No visable	Less than visible	No odour
Monguli, rainwater	2.33			2.330	-	26.70			26.700	-	Clear	No visable	Less than visible	No odour
Bassoto lake tap	0.84			0.840	-	26.50			26.500	-	Clear	No visable	Less than visible	No odour

Village	Chemical parameters						
	Fluoride (F)						
	Test 1	Test 2	Test 3	Average	Delution factor	C	STD
Dang'aida	0.15	0-0.15	0.15	0.15	0.5	0.15	0.00
Dang'aida primary school	0.15	>0.8	0.3, 75% del	?	0.5	Unconclusive	0.65
Basonyagwe	0-0.15	0.15	0	0.075	0.5	0	0.09
Murkuchida	0.3	0.15	0.3	0.25	0.5	0.35	0.17
Haydom hospital spring	0.15	0	0.15	0.1	0.5	0.05	0.09
Mewadan	0.5og 50%di	0.15og75%di	0.15og 75%di			0	0.40
Geterer school rainwater ta	0-0.15			0.075	0.75	-0.15	-
Geterer school well	0.3	0.3		0.3	0.5	0.45	0.00
Mamagi	0.5 del 50%	0.3 del 25%		0.5	0.5	0.85	0.07
Labey secondary school	0.15			0.15	0.5	0.15	-
Labey secondary school government source.	0			0	0.5	-0.15	-
Dotina primary school	0	0.15		0.075	0.5	0	0.11
Gidhim secondary school	0	0		0	0.5	-0.15	0.00
Gaye primary school	0.15			0.15	0.5	0.15	-
Gidhim 4CCP well	0			0	0.5	-0.15	-
Dilling'ang	0.15-0.3			0.225	0.5	0.3	-
Getunawas	0.3	0.15		0.225	0.5	0.3	0.21
Hilamoto	>80 del2	0.3 del 8	0.15 del 10			0	0.72
Endagulda	0.15	0.3		0.225	0.5	0.3	0.21
Isene	0.8	0.15-0.3 del 4				0	0.39
Haydom school, tank	0.5-0.8 del 2	0.15-0.30 del 4				0	0.39
Haydom school, well	0.15-0.30			0.225	0.5	0.3	-
Haydom office	0.3-0.5			0.4	0.5	0.65	-
Matere	0.3			0.3	0.75	0.75	-
Monguli	0.3			0.3	0.75	0.75	-
Monguli, rainwater	0.5			0.5	0.75	1.55	-
Bassoto lake tap	0.5 del 8	0.15 del 10				0	1.98

Village	Chemical parameters															
	Nitrate(mg NO3/L)								Nitrite (mg NO2-/L)				Chlorine			
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Average	STD	Test 1	Test 2	Averag	STD	Test 1	Test 2	Avera	STD
Dang'aida	50-75	75-100		62.5	87.5		75.00	17.68	0.00	0.00	0.00	0.00	0.1	0.1	0.10	0.00
Dang'aida primary school	75-100	75-100		87.5	87.5		87.50	0.00	0.00	0.00	0.00	0.00	0.1	0.1	0.10	0.00
Basonyagwe	5	0-5		5.0	2.5		2.50	1.77	0.00	0.00	0.00	0.00	0	0	0.00	0.00
Murkuchida	10-25	10-26	25	17.5	17.5	25.0	25.00	4.33	0.00	0.00	0.00	0.00	0.1	0	0.05	0.07
Haydom hospital spring	5-10	5-10	5-10	7.5	7.5	7.5	7.50	0.00	0.00	0.00	0.00	0.00	0	0	0.00	0.00
Mewadan	75-100*	75-100*	250	100.0	100.0	100.0	250.00	0.00	0.00	0.00	0.00	0.00	0.1	0	0.05	0.07
Geterer school rainwater	0	0		0.0	0.0		0.00	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Geterer school well	5	10		5.0	10.0		7.50	3.54	0.00	0.00	0.00	0.00	0	0	0.00	0.00
Mamagi	50	50		50.0	50.0		50.00	0.00	0.00	0.00	0.00	0.00		0	0.00	-
Labey secondary school	10-25			17.5	17.5		17.50	0.00	0.00		0.00	-	0		0.00	-
Labey secondary school government source.	5			5.0	5.0		5.00	0.00	0.00		0.00	-	0		0.00	-
Dotina primary school	5-10	5-10		7.5	7.5		7.50	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Gidhim secondary school	50-75	50-75		62.5	62.5		62.50	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Gaye primary school	0	0		0.0	0.0		0.00	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Gidhim 4CCP well	50	50		50.0	50.0		50.00	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Dilling'ang	5			5.0	5.0		5.00	0.00	0.00		0.00	-	0		0.00	-
Getunawas	>100	25 når de	100-75	100.0	75.0	87.5	75.00	12.50	0.00		0.00	-	0		0.00	-
Hilamoto	25	50		25.0	50.0		32.50	17.68	0.00	0.00	0.00	0.00	0.1		0.10	-
Endagulda	0			0.0	0.0		0.00	0.00	0.00		0.00	-	0		0.00	-
Isene	75	75		75.0	75.0		75.00	0.00	0.00	0.00	0.00	0.00	0		0.00	-
Haydom school, tank	25	25		25.0	25.0		25.00	0.00	0.00	0.00	0.00	0.00	0.1	0.1	0.10	0.00
Haydom school, well	50-75			62.5	62.5		62.50	0.00	0.00		0.00	-	0		0.00	-
Haydom office	25			25.0	25.0		25.00	0.00	0.00		0.00	-	0.1		0.10	-
Matere	0			0.0	0.0		0.00	0.00	0.00		0.00	-	0		0.00	-
Monguli	50	75		50.0	75.0		62.50	17.68	0.00		0.00	-	0		0.00	-
Monguli, rainwater	75	75		75.0	75.0		75.00	0.00	0.00		0.00	-	0		0.00	-
Bassoto lake tap	0			0.0	0.0		0	0.00	0.00		0.00	-	0		0.00	-

Village	Chemical parameters											
	Phosphate				Ph				Iron			
	Test 1	Test 2	Average	STD	Test 1	Test 2	Average	STD	Test 1	Test 2	Average	STD
Dang'aida	0.00	0.00	0	0	8	8	8	0	0	0	0	0
Dang'aida primary school	0.00	0.00	0	0	7	8	7.5	0.70711	0	0	0	0
Basonyagwe	0-0.5	0.00	0	-	7	7	7	0	0		0	-
Murkuchida	2-5	5-10	5	2.82843	7	7	7	0	0		0	-
Haydom hospital spring	0.00	0.00	0	0	7	7	7	0	0	0	0	0
Mewadan	0.00	0.00	0	0	7	7	7	0	0	0	0	0
Geterer school rainwater ta	0.00		0	-	7		7	-		0	0	-
Geterer school well	0.00	0.00	0	0	7	7	7	0		0	0	-
Mamagi	0.00		0	-	7	7	7	0	0		0	-
Labey secondary school	0.00		0	-	7	7	7	0	0		0	-
Labey secondary school government source.	0.00		0	-	7.50	7	7.25	0.35355	0		0	-
Dotina primary school	0.00		0	-	7	7	7	0	0		0	-
Gidhim secondary school	0.00		0	-	7	7	7	0	0.05		0.05	-
Gaye primary school	0.00		0	-	7		7	-	0.05		0.05	-
Gidhim 4CCP well	0.00		0	-	7		7	-	0		0	-
Dilling'ang	0.00		0	-	7.00		7	-	0		0	-
Getunawas	0.00		0	-	7	7.5	7.25	0.35355	0		0	-
Hilamoto	0.00		0	-	7	7	7	0				-
Endagulda	0.00		0	-	7	7	7	0				-
Isene	0.00		0	-	7	7	7	0				-
Haydom school, tank	0.00	0.00	0	0	7	7	7	0	0.05		0.05	-
Haydom school, well	0.00		0	-	7		7	-				-
Haydom office	0.00		0	-	7		7	-				-
Matere	0.00		0	-	7	7	7	0				-
Monguli	0.00		0	-	7	7	7	0	0		0	-
Monguli, rainwater	0.00		0	-	7	7	7	0				-
Bassoto lake tap	0.00		0	-	7		7	-				-

Village	Bilogical parameters								
	Ecoli								
	Time of samp	Date of coun	Time of coun	Hours of incu	Storage of sa	Test 1	Test 2	Average	STD
Dang'aida	14:00	10.02.2023	14:53	48.88	Lunt, ikke i sc	0	0	0	0
Dang'aida primary school	11:45	10.02.2023	14:53	51.13	Lunt, ikke i sc	5	12	8.5	4.94974747
Basonyagwe	10:40	11.02.2023	14:45	52.08	Lunt, ikke i sc	0	0	0	0
Murkuchida	10:40	12.02.2023	14:20	51.67	Lunt, ikke i sc	2	3	2.5	0.70710678
Haydom hospital spring	14:15	12.02.2023	14:20	48.08	Lunt, ikke i sc	0	2	1	1.41421356
Mewadan	15:00	13.02.2023	16:50	49.83	Lunt, ikke i sc	0	0	0	0
Geterer school rainwater t	16:20	15.02.2023	20:20	52.00	Lunt, ikke i sc	6	-	6	-
Geterer school well	16:20	15.02.2023	20:20	52.00	Lunt, ikke i sc	0	0	0	0
Mamagi	14:50	16.02.2023	18:00	51.17	Lunt, ikke i sc	0	0	0	0
Labey secondary school	14:50	16.02.2023	18:00	51.17	Lunt, ikke i sc	0		0	-
Labey secondary school government source.	14:50	16.02.2023	18:00	51.17	Lunt, ikke i sollys	0		0	-
Dotina primary school	20:00	17.02.2023	14:00	42.00	Lunt, ikke i sc	0	0	0	0
Gidhim secondary school	18:00	20.02.2023	09:00	87.00	Lunt, ikke i sc	1	0	0.5	0.70710678
Gaye primary school	18:00	20.02.2023	09:00	87.00	Lunt, ikke i sc	12	10	11	1.41421356
Gidhim 4CCP well	18:00	20.02.2023	09:00	87.00	Lunt, ikke i sc	0	0	0	0
Dilling'ang	14:25	02.03.2023	08:30			73		73	-
Getunawas	11:00	02.03.2023	08:30			0		0	-
Hilamoto	20:40	23.02.2023	18:30	45.83	Lunt, ikke i sc	0	0	0	0
Endagulda	20:40	23.02.2023	18:30	45.83	Lunt, ikke i sc	0	3	1.5	2.12132034
Isene	16:00	26.02.2023	12:20	68.33	Lunt, ikke i sc	>100	>100	100	-
Haydom school, tank	14:00	01.03.2023	09:30	67.50	Lunt, ikke i sc	15	90	52.5	53.0330086
Haydom school, well	14:00	01.03.2023	09:30	67.50	Lunt, ikke i sc	0		0	-
Haydom office	14:00	01.03.2023	09:30	67.50	Lunt, ikke i sc	28		28	-
Matere	08:45	02.03.2023	08:30	71.75		13		13	-
Monguli	10:40	02.03.2023	08:30	69.83		1		1	-
Monguli, rainwater	10:40	02.03.2023	08:30	69.83		2		2	-
Bassoto lake tap	14:30	02.03.2023	08:30	42.00		0		0	-

F Water Quality Rapport: Basonyagwe

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Water Quality Report – Basonyagwe

The following report presents the results of the water quality parameters tested at **Basonyagwe**. These tests were conducted to assess the suitability of the water for human consumption. The test results are based on the average of several tests (2 or 3 samples).

Location: Basonyagwe village
Date of testing: 09.02.2023 10:40
Type of water point: Solar-powered water borehole
Total depth: 112 m
Water level:

Test results

Physical parameters:

Electrical conductivity, EC [mS/cm]	0.990
Temperature [°C]	22.40

Chemical parameters:

Fluoride as F [mg/L]	0.15
Nitrate as NO_3^- [mg/L]	2.50
Nitrite as NO_2^- [mg/L]	0
Chlorine as Cl_2 [mg/L]	0
Phosphate as PO_4^{3-} [mg/L]	0
Iron as $Fe^{2+/3+}$ [mg/L]	0
pH	7

Biological parameters:

E.Coli [number of colonies per sample]	0

The Tanzanian Bureau of Standards (TBS) has established standards for drinking (potable) water quality in the country. The acceptable levels for the parameters are:

Electrical conductivity, EC [mS/cm]	2.500
Fluoride as F [mg/L]	<1.5
Nitrate as NO_3^- [mg/L]	<45
Nitrite as NO_2^- [mg/L]	<0.003
Chlorine as Cl_2 [mg/L]	0.2 – 0.5 (absent if non-treated water)
Phosphate as PO_4^{3-} [mg/L]	<2.2
Iron as $Fe^{2+/3+}$ [mg/L]	<0.3
pH	5.5-9.5
E.Coli [number of colonies per sample]	0

Source: TBS - Portable Water Specification - TZS 789 – Natural potable water (non-treated).

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Date: 25.03.2023

Notes:

The area surrounding the water well is relatively flat. They have one water point for the people to use close to the well and another water point for the animals located approximately 50 m from the well. Waterguard (chlorination tank) has been fitted to the water system. There are no agricultural activities in the nearest vicinity to the water well. Animals grazing close to the water well was observed. **From the test results, no immediate actions seem to be necessary**, but it is important to be aware of that the increased presence of agricultural and animal activities close to the water well, might lead to increased levels of nitrate, phosphate and other contaminants in the water.

Explanations – Colour codes and Parameters

Colour codes:

(green)	**Below the acceptable level**
(yellow)	**Close to the acceptable level**
(red)	**Over the acceptable level**

Electrical conductivity, EC:
High electrical conductivity level can indicate the presence of dissolved minerals or salts, which can cause taste and odour issues and can contribute to scaling in pipes and appliances. A high EC level can also be an indicator of high levels of salinity (salty taste).

pH:
The pH level can affect the taste of water and can cause corrosion of pipes and fixtures. Both a too high and a too low pH can be dangerous.

Iron:
High iron levels can cause metallic taste, discoloration of clothes and fixtures, and can clog pipes.

Chlorine:
Chlorine levels should be maintained within the acceptable range to prevent the growth of harmful bacteria and viruses. Adding too much chlorine can result in a strong odour and taste, which can be reduced by letting the water stand uncovered for a few hours.

Nitrate and nitrite:
Nitrate and nitrite levels above the acceptable range can indicate contamination from fertilizer or sewage. Infants are particularly vulnerable to negative effects of these compounds, which can include blue baby syndrome.

Phosphate:
High phosphate levels can contribute to algae growth in water, which can cause odour and taste issues.

Fluoride:
High fluoride levels can cause dental fluorosis, a condition that affects the development of tooth enamel, and can cause skeletal fluorosis, a condition that affects the bones.

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E. coli:
The presence of E. coli in water indicates fecal contamination, which can cause serious illness. Chlorination can be used as a treatment option.

Important information

Please note that the water quality test results provided in this report are only representative of values found at the time of testing and may vary over time. There are several factors that can cause variations in water quality, including but not limited to changes in environmental conditions, sampling techniques, and analysis procedures.

This report is intended to present the water quality parameters obtained at the time of testing, and any notes provided are meant as a guide based on these results and the values given from the Tanzanian Bureau of Standards. It is important to note that these results may not necessarily reflect the overall quality of the water source, and additional testing or assessment may be necessary for a complete evaluation.

Therefore, we recommend that you interpret these water quality results in conjunction with other relevant information and consult with a qualified water quality professional for any further guidance about treatment recommendations.

G User manual: Remote monitoring system

Bruksanvisning for bruk av målebokser til overvåkning av drikkevannsbrønner i Tanzania

Laget av: Bendik Sægrov-Sorte, senioringeniør i automatisering, bendik@sagrov-sorte.no, 98283890

Innhold:

- Bakgrunn og valg av system
- Funksjonsbeskrivelse
- Oppkobling av sensorer
- Tilgang til ThingSpeak og bruk av tjenesten
- Oppsett av Arduino på PC
- Konfigurering av kode på ESP32 og montering av SIM-kort
- Teknisk funksjonsbeskrivelse
- Vedlegg: Arduino-kode

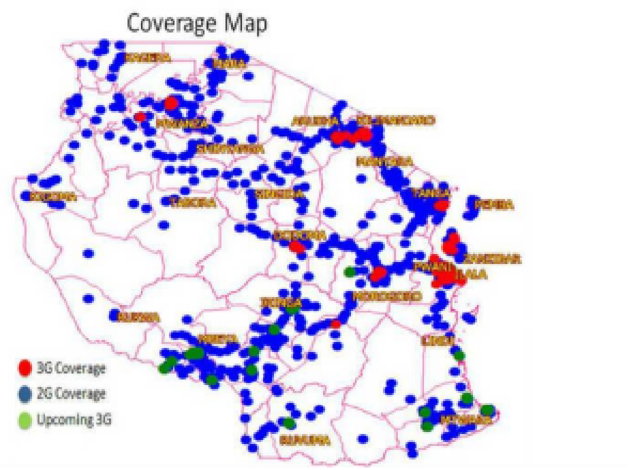
Bakgrunn og valg av system (notater fra Bendik, dere må nesten verifisere hvis info skal brukes videre)

Målesystemet fra El-watch som har vært i bruk frem til nå baserer seg på e-sim som knytter seg til 3G, 4G og 5G mobilnettverk i Tanzania. Til forveksling fra her i Norge er disse abonnementene svært dyre og jeg ble derfor spurt om å prøve å få til en annen rimeligere løsning.

2G (gsm) – har god dekning i Afrika og kommer sannsynligvis til å bestå i mange år til, mens andre nettverk bygges ut. 2G bruker relativt lave frekvenser og har dermed bedre rekkevidde enn nettverkene med høyere båndbredde som krever flere basestasjoner. Dvs 2G er greit å bruke på landsbygda i Tanzania. Jeg har valgt å lage en løsning som baserer seg på billige kontantkort som har god nok kapasitet i forhold til hva som trengs.

Dere må kjøpe kontantkort når dere kommer til Tanzania (ikke datasim, men vanlig kontantkort med telefonnr. Det må være mer enn 20MB data tilgjengelig på kortene. Da vil de vare lenge nok).

Jeg har kjøpt deler fra Tyskland og en del jeg hadde liggende. Pris pr boks (uten arbeid): ca 500kr



Figur 1 - Dekningskart over ulike typer mobilnettverk (bilde fra 2016)

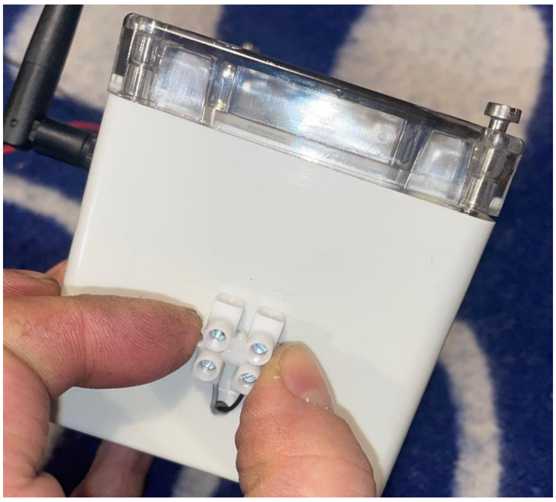
Funksjonsbeskrivelse

Boksene bærer preg av å være satt sammen på svært kort tid og har et litt Reodor Felgen-preg. Ved neste iterasjon kan andre, færre komponenter velges for å ta ned kompleksiteten noe, men dette var delene som var å oppdrive på kort tid.

Boksene kobles til 12Vdc batteri på det lille solcelleanlegget som ble laget til el-watch-systemet. Rødt på pluss (+), svart på minus (-). Hver boks er utstyrt med 2 kanaler for trykk (en i brønnen og en i vanntanken (rødt er pluss, svart er minus) og en sensor som måler strøm som pumpa bruker. Hver boks skal ha sitt eget kontantkort med billig mobilabonnement. Boksen sender måleverdier til en skyløsning som heter ThingSpeak i intervaller programmert inn i mikrokontroller. Hvert 5. min for eksempel. Den røde knappen på siden av boksen kan brukes til å sende måleverdier manuelt og det er også programmert inn en løsning som teller antall minutter pumpa er på og sender disse dataene til sky når pumpa slåes av. Vippebryteren brukes til å slå boksen av og på. Når man trykker på manuell sending, tar det litt tid (ca 20 sek) før dataene kommer frem til skyen.

Oppkobling av sensorer

Trykksensorene (brønn og tank) kobles til på fjærklemmene på siden av boksen. Rødt er pluss og svart er minus. I DIN-kontakten i trykkgiveren er pluss ofte merket med tallet 1 og minus med tallet 2. Trykkgiverne kobles til parvis fra venstre mot høyre. Den blå clamp-on-sensoren kobles via en skjøtekabel (2-leder el tilsv) til sukkerbiten på kortsiden av boksen. Det er viktig å holde i sukkerbiten mens man skrur fast ledningen slik at ikke de to ledningene som går inn i boksen slites av. Det er ikke pluss og minus på clamp-on-sensoren da denne gir et ac-signal (som likerettes inne i boksen).



Boksen kobles til 12vdc motorsykkelbatteri med den røde og svarte ledningen som stikker ut av boksen. Rødt er pluss, svart er minus. Dersom man kobler feil ødelegges boksen dessverre, så tenk to ganger.

Tilgang til ThingSpeak og bruk av tjenesten

Jeg har valgt å bruk skytjenesten ThingSpeak til mottak av data fra boksene. Dette systemet er tilrettelagt for bruk ved universiteter med Matlab-integrasjon blant annet, og tilbyr både gratis og betalt versjon. Den kostnadsfrie versjonen kan ha 4 kanaler (eller brønner/ bokser) tilkoblet og har nok lagringskapasitet til at vi kan sende data hver halvtime fra de 3 brønnene i 50 år. Dersom man trenger mer, koster det 600kr i året for en studentlisens. I tillegg til enkel visualisering og deling av data har man funksjonalitet for nedlasting av måledata i csv-format. På hver kanal eller brønn kan man ha 8 målepunkter/ fields. Jeg har valgt følgende målepunkter:

Field 1: PT1 (brønn)

Field 2: PT2 (tank)

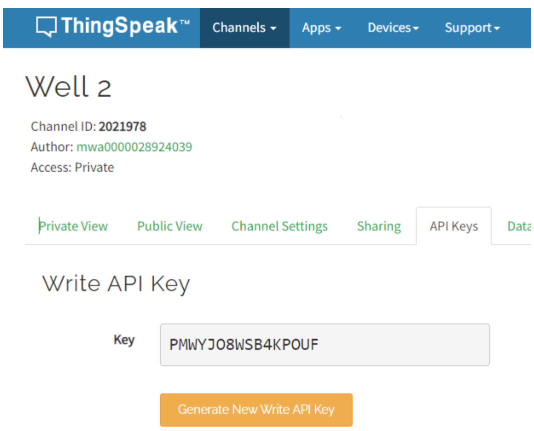
Field 3: Pump current (Ampere)

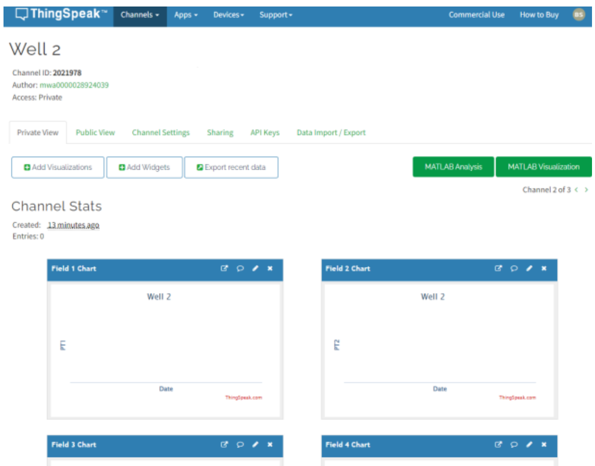
Field 4: Pump power (kW, estimert, antar 230vac spenning)

Field 5: Pump time (tid i minutter som pumpa har vært på)

Field 6: Last pump power (W, effekt som pumpa gikk med rett før den ble slått av)

Dere kan selv opprette en gratis konto hos ThingSpeak. Lag 3 kanaler og kall dem well 1, 2 og 3. Definer 6 fields med navn fra lista over. Gå til fanen API keys og kopier tallene som står i ruta Write API Key. Denne skal brukes i Arduino-koden som lastes ned til esp32-mikrokontrolleren. Mer om det litt seinere.

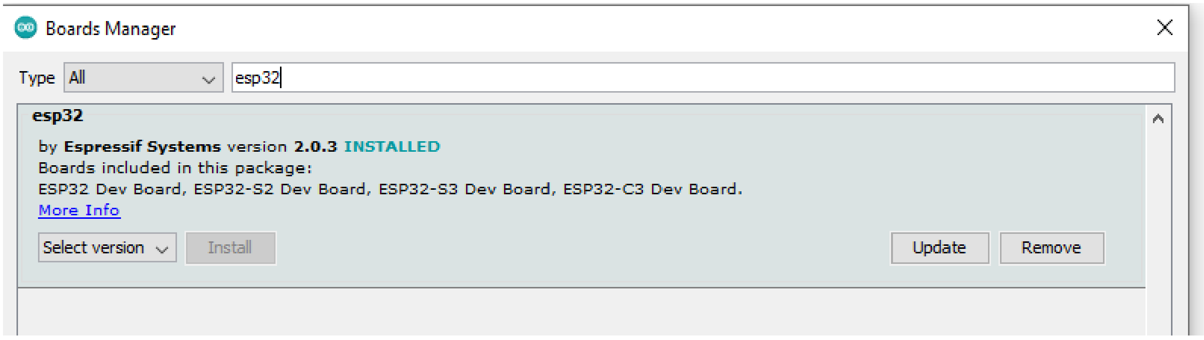




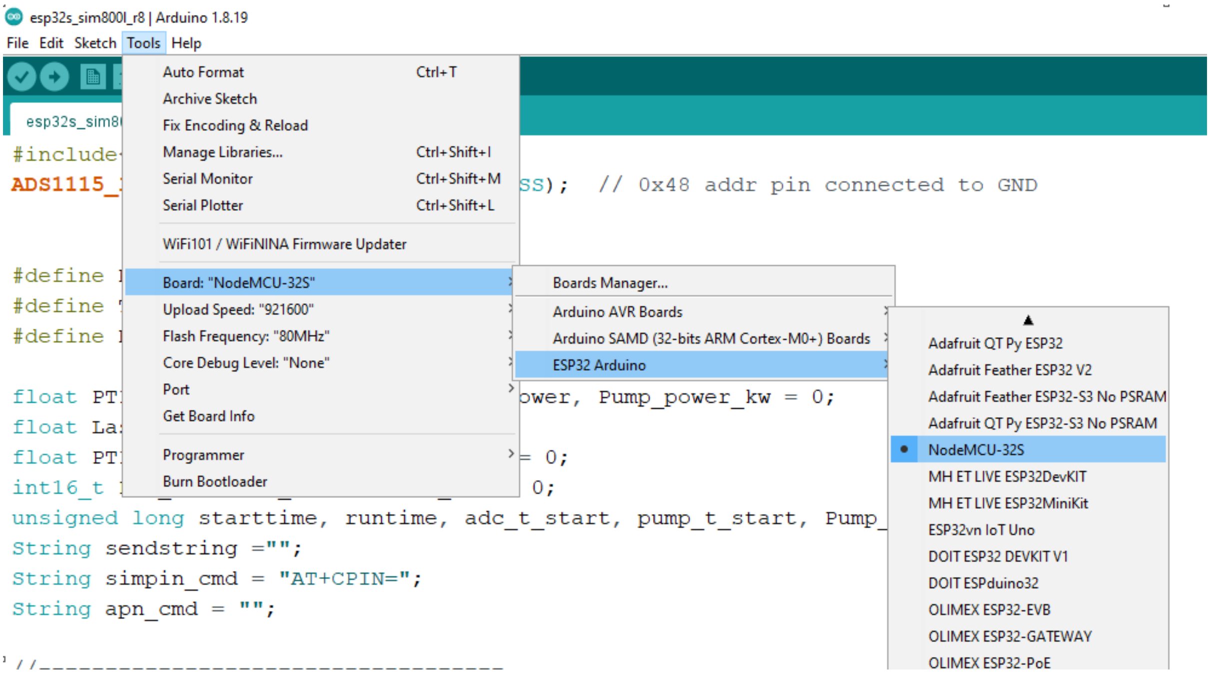
Oppsett av Arduino på PC

Mikrokontrolleren som er montert inne i boksene programmeres ved hjelp av et verktøy som heter Arduino IDE. Før boksene kan taes i bruk i Tanzania må pinkode til SIM-kort, ThingSpeak API-key og nettverksoperatør skrives inn i koden og lastes ned til mikrokontrolleren over usb-kabel.

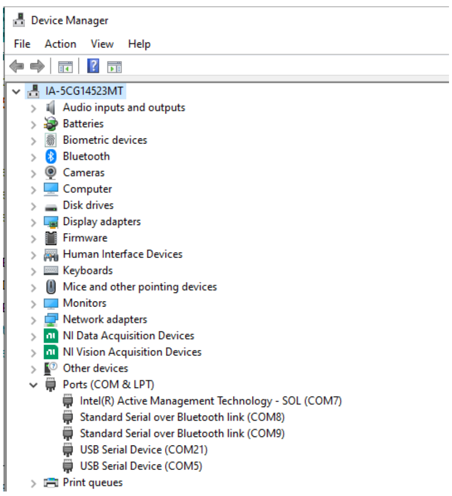
Arduino kan lastes ned og installeres herfra: https://www.arduino.cc/en/software, rull litt ned på siden og velg legacy software og versjon 1.18.19. Det er den jeg har brukt, den nye er litt treg. I tillegg trengs noen biblioteker og tilgang til esp32s. Åpne Arduino, gå til tools -> boards -> boards manager og søk etter esp32. Trykk install for versjon 2.0.3



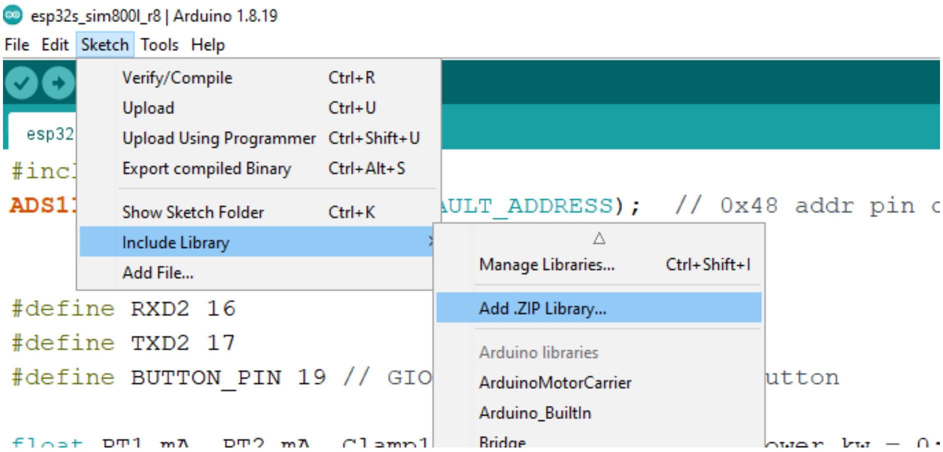
Etterpå kan esp32 velges, da skal man gå til tools-> board-> esp32 arduino -> **NodeMCU-32S**



Plugg inn USB (micro) i esp32 mikrokontroller og andre enden i pc. Gå til device manager (enhetsbehandling), ekspander porter og les ut hvilken COM-port esp32 har fått. For eksempel COM17. Gå så tilbake til Arduino IDE, velg tools->port-> «velg porten du fant istad»

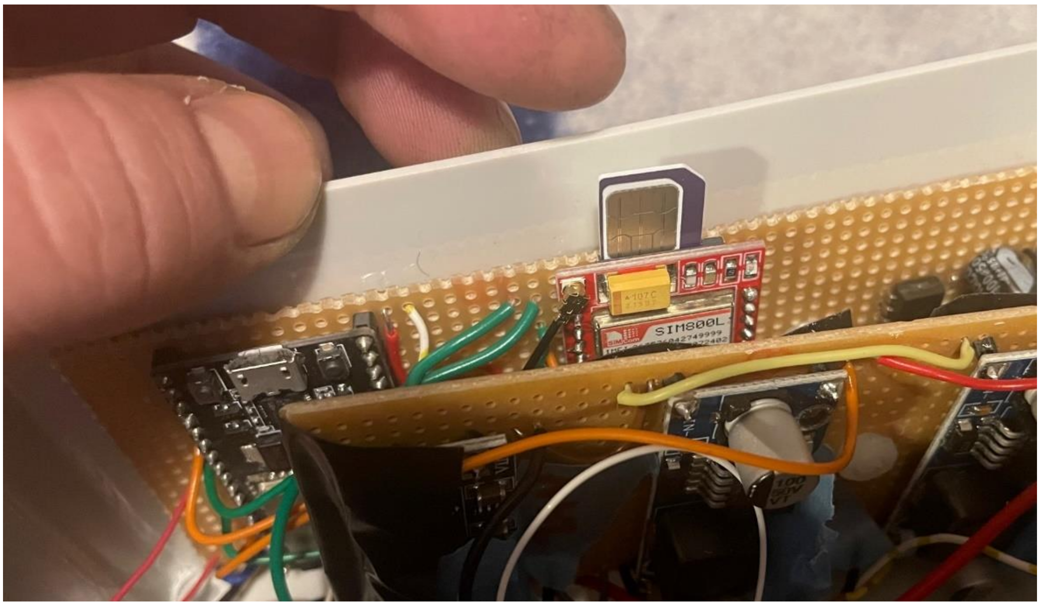


Videre trengs noen biblioteker. Gå til sketch-> include library -> add .zip library.. og velg biblioteket som Bendik har sendt på e-post. Hent deretter .ino-koden fra Bendik med file-> open



Konfigurering av kode på ESP32 og montering av SIM-kort

SIM-kortet settes i modemet som vist på bildet

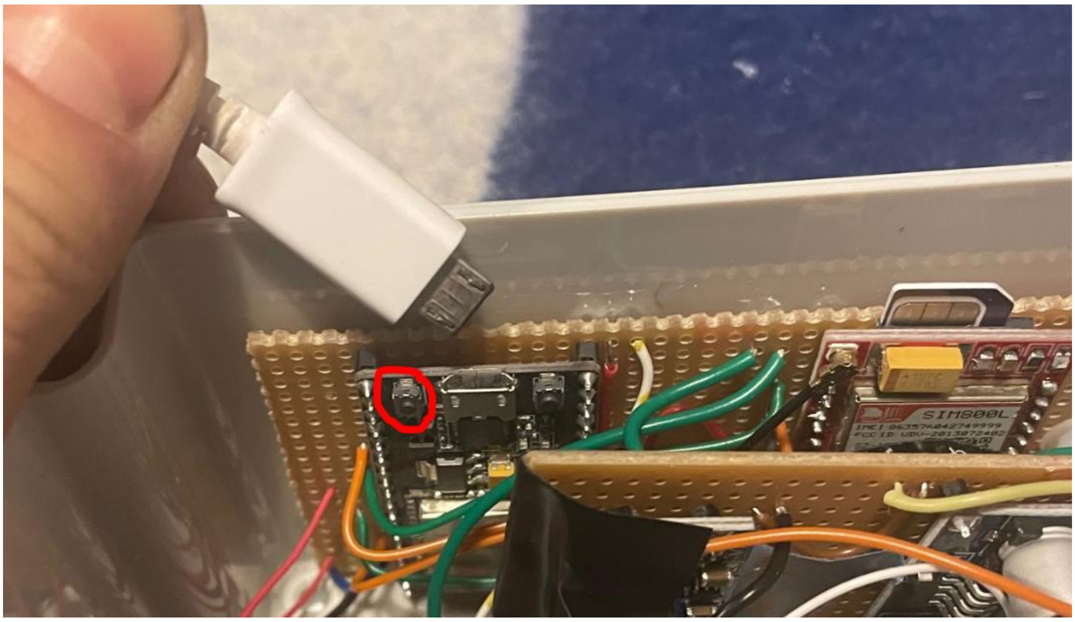


Koden er ganske lang, men jeg har samlet det dere trenger å endre på ett sted:

```
//-----------------------------------
//TO BE ENTERED BY USER FOR EVERY BOX:
String thingspeak_key = "4A9IMVKKQH82DQZE"; //important to use "" in each end
String sim_pin = "0931";
String apn = "netcom"; //use AT+COPS=? in the serial monitor to find which network operator to be used
unsigned long interval = 5; //interval between data updates to thingspeak in minutes
//------------------------------------
```

Gå til ThingSpeak og hent API write key og legg den inn i thingspeak_key. Viktig at tøddler omslutter og at det ikke blir med ekstra mellomrom. Legg inn pinkode til SIM-kortet på samme måte. Velg intervall for sending av data i minutter. Lagre og send konfigurasjonen til Arduino slik:

Trykk på v-tegnet øverst til venstre i Arduino IDE for å kompilere koden (se etter feil). Dette tar et halvt minutt eller så. Dersom dette gikk bra, kan koden lastes ned til ESP32. Da må man trykke ned og holde inne den lille knappen til høyre for usb-kontakten (se rød ring i bildet under) og trykke pil til høyre-knappen oppe ved siden av v-knappen i Arduino IDE. Etter 30 sek skal koden være lastet ned på ESP32.



NB! Pin-kode for SIM-kortet må ligge inne før nettverksoperatør (apn) kan bli funnet. Gå frem på følgende måte for å finne navnet på APN:

Trykk på forstørrelsesglasset oppe til høyre i Arduino IDE. Da kommer en serialmonitor opp hvor man kan kommunisere med esp32. Sjekk at baud rate står innstilt på 9600 (nederst til høyre i serialmonitorvinduet). For at nettverksoperatør skal komme opp må boksen være koblet til 12vdc batteri (og pinkode ligge inne). Skriv inn AT+COPS=? I feltet øverst og trykk send. Etter en stund svarer boksen og i mitt tilfelle kommer «netcom» opp som første svar. I Tanzania vil det være en annen operatør, sikkert flere. Her må dere prøve dere frem, bytt ut «netcom» med funnet operatør. Velg ctrl+s for å lagre og send deretter den oppdaterte koden til esp32 slik dere gjorde tidligere.

Test sending av data med den røde knappen på siden. Dersom dere fortsatt har serialmonitoren oppe vil dere se alle AT-kodene som sendes fra modemet. Det kan være dere må teste sending minst to ganger før data blir sendt (modemet må få IP-adresse før sending). Gå inn på ThingSpeak på valgt brønn og sjekk at dataene har kommet inn.

Det er mulig dere ønsker å skalere dataene før sending, det kan gjøres i funksjonen read_adc(). Jeg har test med en 0-10barg trykkgiver, jeg vil tro trykkgiver i brønn og i tank (sistnevnte må kjøpes inn) har forskjellig trykkområde.

```
void read_adc()
{
    //read ai0:
    adc.setMux(ADS1115_REG_CONFIG_MUX_SINGLE_0); //Set single ended mode
    adc.triggerConversion(); //Start a conversion.  This immediately ret
    PT1_raw = adc.getConversion(); //This polls the ADS1115 and wait for
    PT1_mA = (((float(PT1_raw / 32757.0) * 4.096))/220.0)*1000.0; //conv
    PT1_mbarg = (PT1_mA - 4)*625; //(4-20mA to 0-10000mbarg (-10barg)
    Serial.print("PT1 mA: ");
    Serial.println(PT1_mA);

    //read ai1:
    adc.setMux(ADS1115_REG_CONFIG_MUX_SINGLE_1); //Set single ended mode
    adc.triggerConversion(); //Start a conversion.  This immediately ret
    PT2_raw = adc.getConversion(); //This polls the ADS1115 and wait for
    PT2_mA = (((float(PT2_raw / 32757.0) * 4.096))/220.0)*1000.0; //conv
    PT2_mbarg = (PT2_mA - 4)*625; //(4-20mA to 0-10000mbarg (-10barg)
    Serial.print("PT2 mA: ");
    Serial.println(PT2_mA);
    //Serial.println(PT2_raw);
```

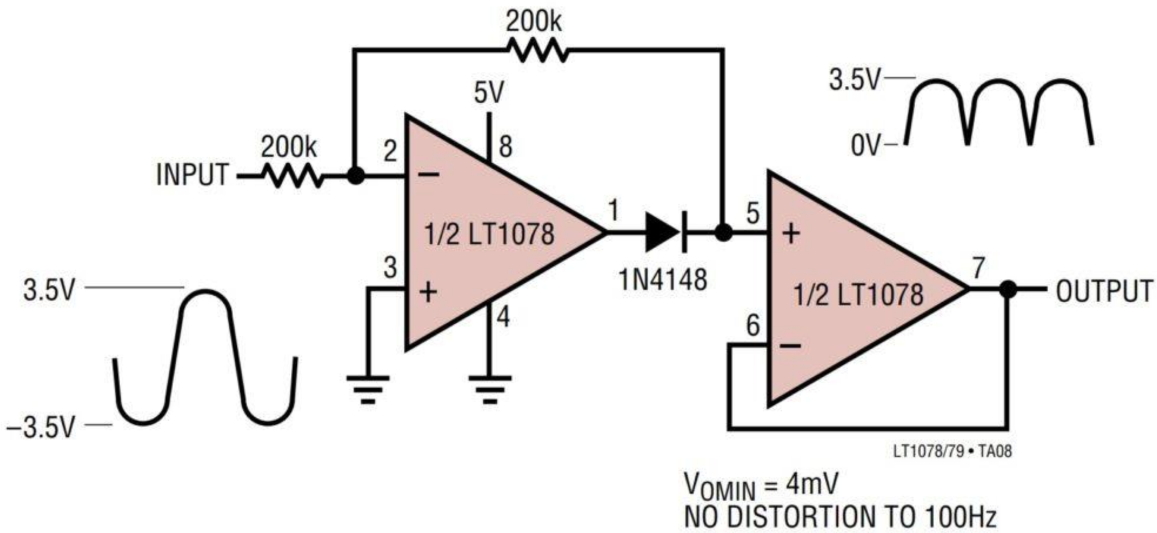
Teknisk funksjonsbeskrivelse:

En esp32 mikrokontroller kommuniserer med et sim800l 2G-modem med et kontantkort over rs232. En 4-kanals 16bit adc (analog til digital konverter) kommuniserer over i2c-buss (adr 0) og brukes til innhenting av signaler fra to stykk trykkgivere (24vdc, 4-20mA) plassert i brønn og i vanntank og en clamp-on ac strømmåler montert på en av lederne til pumpa (etter inverter). Signalet fra clamp-on-målerne er i størrelse 200mVac og likerettes med en opamp-likeretter på veien til adc. Strømmålingen er kalibrert med et fluke multimeter mot 3 resistive kilder (varmeovner 400, 600, 1000W) og ga en lineær respons. På trykkinngangene er det montert på en 220 Ohms motstand mellom kanalinngang og jord, dette gir et måleområde på 0,88-4,4V for 4-20mA-sensor.

(Motstand bør byttes til 200 Ohm, da adc saturerer på 4096mV..)!

Esp32 er programmert med Arduino IDE og dette verktøyet må brukes ved konfigurasjon av pinkode til SIM-kort med mer.

Det er 3 strømforsyninger inne i boksen; 1 stykk boost-converter som gjør om 12vdc til 24vdc og gir spenning til trykkgiverne og 2 stykk step-down-convertere som lager hhv 5vdc til esp32 og 4vdc til sim800l-modem og adc.



Figuren viser opamp-basert likeretter som har blirr brukt pga lavt ac-signal fra clamp-on-måler

Vedlegg 1: Arduino-kode (versjon 2023-02-01)

```
#include<ADS1115_lite.h>

ADS1115_lite adc(ADS1115_DEFAULT_ADDRESS);  // 0x48 addr pin connected to GND



#define RXD2 16

#define TXD2 17

#define BUTTON_PIN 19 // GIOP21 pin connected to button


float PT1_mA, PT2_mA, Clamp1_A, Pump_power, Pump_power_kw = 0;

float Last_pump_power;

float PT1_mbarg, PT2_mbarg, Clamp1_mV = 0;

int16_t PT1_raw, PT2_raw, Clamp1_raw = 0;

unsigned long starttime, runtime, adc_t_start, pump_t_start, Pump_time;

String sendstring ="";

String simpin_cmd = "AT+CPIN=";

String apn_cmd = "";


//-----------------------------------

//TO BE ENTERED BY USER FOR EVERY BOX:

String thingspeak_key = "4A9IMVKKQH82DQZE"; //important to use "" in each end

String sim_pin = "0931";

String apn = "netcom"; //use AT+COPS=? in the serial monitor to find which network operator to be used

unsigned long interval = 5; //interval between data updates to thingspeak in minutes

//------------------------------------




// Variables will change:
```

```
int lastState = HIGH; // the previous state from the input pin
int currentState;     // the current reading from the input pin



void setup() {
  Serial.begin(9600);
  Serial2.begin(9600, SERIAL_8N1, RXD2, TXD2);
  //setup adc:
  adc.setGain(ADS1115_REG_CONFIG_PGA_4_096V); // GAIN_ONE and resolution to ± 4.096V
  adc.setSampleRate(ADS1115_REG_CONFIG_DR_8SPS); //Set the slowest and most accurate sample
rate
  starttime = millis();
  interval = 1000 * 60 * interval;
  adc_t_start = starttime;

  // initialize the pushbutton pin as an pull-up input
  pinMode(BUTTON_PIN, INPUT_PULLUP);

}
void loop() {
  updateSerial();
  //------------------------------
  //send data to thingspeak:
  runtime = millis();
  if(runtime - starttime > interval){
    //send measured data to thingspeak at selected time interval
    send_to_thingspeak();
    starttime = millis();
  }
  //------------------------------
```

```
  // trigger manual gsm sending if push button pressed:
  currentState = digitalRead(BUTTON_PIN);

  if(lastState == LOW && currentState == HIGH){
    send_to_thingspeak();
  }
  // save the last button state
  lastState = currentState;
  //-------------------------------
  //poll adc every 2 sec for measurement update
  if(millis() - adc_t_start > 2000){
    read_adc();
    adc_t_start = millis();
  }
  //-------------------------------

}

void read_adc()
{
    //read ai0:
    adc.setMux(ADS1115_REG_CONFIG_MUX_SINGLE_0); //Set single ended mode between AIN0 and
GND
    adc.triggerConversion(); //Start a conversion.  This immediately returns
    PT1_raw = adc.getConversion(); //This polls the ADS1115 and wait for conversion to finish, THEN
returns the value
    PT1_mA = (((float(PT1_raw / 32757.0) * 4.096))/220.0)*1000.0; //convert 16 (15) bit data (32757)
to voltage (4.096V range) and via 220 ohm resistor to current.
    PT1_mbarg = (PT1_mA - 4)*625; //(4-20mA to 0-10000mbarg (-10barg)
    Serial.print("PT1 mA: ");
    Serial.println(PT1_mA);
```

```
//read ai1:

adc.setMux(ADS1115_REG_CONFIG_MUX_SINGLE_1); //Set single ended mode between AIN1 and GND

adc.triggerConversion(); //Start a conversion.  This immediately returns

PT2_raw = adc.getConversion(); //This polls the ADS1115 and wait for conversion to finish, THEN returns the value

PT2_mA = (((float(PT2_raw / 32757.0) * 4.096))/220.0)*1000.0; //convert 16 (15) bit data (32757) to voltage (4.096V range) and via 220 ohm resistor to current.

PT2_mbarg = (PT2_mA - 4)*625; //(4-20mA to 0-10000mbarg (-10barg)

Serial.print("PT2 mA: ");

Serial.println(PT2_mA);

//Serial.println(PT2_raw);


//read ai2:

Last_pump_power = Pump_power;

Pump_time = 0;

//Pump AC current measured using an opamp-based rectifier circuit due to low voltage signal (+/-200mVac)

adc.setMux(ADS1115_REG_CONFIG_MUX_SINGLE_2); //Set single ended mode between AIN2 and GND

adc.triggerConversion(); //Start a conversion.  This immediately returns

Clamp1_raw = adc.getConversion(); //This polls the ADS1115 and wait for conversion to finish, THEN returns the value

Clamp1_mV = (((float(Clamp1_raw / 32757.0) * 4096))); //convert 16 (15) bit data (32757) to voltage (4.096V range)

Clamp1_A = (0.0214 * Clamp1_mV) - 0.2417; //measured AC current [A] calibrated using 3 resistive loads

Pump_power = (Clamp1_A *230); //pump power in W, assuming ac voltage at 230vac

Pump_power_kw = Pump_power/1000; //power in kW

Serial.print("Pump power: ");

Serial.println(Pump_power);

//check if pump is turned on, calculate pump on time and send to thingspeak

if((Pump_power > 500) && (Last_pump_power < 500)){

  pump_t_start = millis();
```

```
    }
    if((Pump_power < 500) && (Last_pump_power > 500)){
      Pump_time = float(((millis() - pump_t_start)/1000.0)/60.0); //pump on time in minutes
      Serial.print("pump time in minutes: ");
      Serial.println(Pump_time);
      send_to_thingspeak(); //send data to thingspeak when pump is shut off
    }
  }

void send_to_thingspeak()
{
  //generate thingspeak string
  sendstring = "AT+HTTPPARA=URL,http://api.thingspeak.com/update?api_key=" + thingspeak_key;
  sendstring = sendstring + "&field1=" + String(PT1_mbarg);
  sendstring = sendstring + "&field2=" + String(PT2_mbarg);
  sendstring = sendstring + "&field3=" + String(Clamp1_A);
  sendstring = sendstring + "&field4=" + String(Pump_power_kw);
  sendstring = sendstring + "&field5=" + String(Pump_time);
  sendstring = sendstring + "&field6=" + String(Last_pump_power);
  //Serial.println(sendstring);

  //init modem and send data over gsm network:
  Serial2.println("AT");
  updateSerial();
  Serial2.println("AT+CFUN=1"); //setter full funksjonalitet på modem
  updateSerial();
  Serial2.println("AT+CPIN?");//sjekker om pin-kode er aktiv
  updateSerial();
  simpin_cmd = "AT+CPIN=" + sim_pin;
  Serial2.println(simpin_cmd); //AT+CPIN="xxxx", legg inn pinkode
  updateSerial();
```

```
  Serial2.println("AT+CPIN?"); //sjekk om pinkode godkjent
  updateSerial();
  //Serial2.println("AT+COPS=?"); //finn navn på tilgjengelig nettverksoperatør
  //updateSerial();
  //legg inn operatør fra cops-sjekk, de to andre er brukernavn og passord som oftest er blanke:
  apn_cmd = "AT+CSTT='" + apn;
  apn_cmd = apn_cmd + "','',''";
  Serial2.println(apn_cmd); //"AT+CSTT='netcom','',''" APN. denne må settes til noe annet i tanzania.
finn den med AT+COPS=?
  updateSerial();
  Serial2.println("AT+CREG?");
  updateSerial();
  Serial2.println("AT+SAPBR=2,1"); //sjekk om vi er tilkoblet i gprs-modus
  updateSerial();
  Serial2.println("AT+SAPBR=1,1"); //start gprs-modus, modem vil nå blinke raskt
  updateSerial();
  Serial2.println("AT+SAPBR=2,1"); //ny gprs-sjekk, vi skal nå få blant annet ip-adresse som svar
  updateSerial();
  Serial2.println("AT+HTTPINIT"); //initialiser http-modus
  updateSerial();
  Serial2.println(sendstring);
  updateSerial();
//"URL","http://api.thingspeak.com/update?api_key=4A9IMVKKQH82DQZE&field1=10.3&field2=5.0
"
  Serial2.println("AT+HTTPPARA=CID,1");
  updateSerial();
  Serial2.println("AT+HTTPACTION=0"); //tror dette betyr at vi sender url til thingspeak
  updateSerial();
  Serial2.println("AT+HTTPREAD"); //får nå noen tall som svar
  updateSerial();
  Serial2.println("AT+HTTPTERM"); //terminer http-modus
  updateSerial();
```

```
  //slå av gprs-modus:
  Serial2.println("AT+CIICR");
  updateSerial();
  Serial2.println("AT+CIPSHUT"); //slår av gprs-modus og sparer strøm. modemet slutter å blinke
raskt
  updateSerial();
}

void updateSerial()
{
  delay(1000);
  while (Serial.available())
  {
    Serial2.write(Serial.read());//Forward what Serial received to Software Serial Port
  }
  while (Serial2.available())
  {
    Serial.write(Serial2.read());//Forward what Software Serial received to Serial Port
  }
}
```

H Technical Report NCA

ANNEX II - Technical Report
Construction and Installation of Six Solar Micro-Water Yard Towers within selected villages in Mbulu and Hanang districts

1) Sites possession:

Six successfully drilled boreholes were handed over to Dennez Engineering Limited between 26-28 January 2021. Dennez Engineering Limited was contracted by NCA Tanzania to undertake post-construction activities as per scopes of works below. These sites are located in below villages.

During the site possession exercise at each village, brief meetings were held with village's leaders. Purpose of the meetings were to introduce Dennez Engineering limited as a selected contractor to undertake pending works, build a rapport and explore if certain local materials were available locally. Either the village chairman or village executive officers were met.

While in Ng'wandakw village, a meeting was also held with HaNg'wa community Water Users' Association. This is a Water Users Association made of two villages (Haydom and Ng'wandakw), responsible for operating, managing and maintaining a water supply network system that is currently serving both villages. While on this mission, the Consultant was also invited and had the opportunity to briefly attend a community mass meeting that was held at Ng'wandakw village

Table #1: Boreholes characteristics and location of sites

No	Village name	District	Drilled depth	Tested yield	SWL (m)	DWL (m)	Pump setting depth
1	Getanuwas	Hanang	100 meters	2500 litres/hour	17.31	60.40	80m
2	Dang'aida	Hanang	55 meters	8,000 litres/hour	17.29	43.67	50m
3	Garkawe	Mbulu	140 meters	2500 litres/hour	23.87	77.69	100m
4	Dotina	Mbulu	120 meters	1,800 litres/hour	41.00	89.99	100m
5	Labay	Mbulu	120 meters	3,200 litres/hour	22.20	67.98	100m
6	Ng'wandakw	Mbulu	80 meters	12,000 litres/hour	14.10	19.77	50m

Photos of sites possession exercise:

2) Scope of the works:

As per the signed contract, the work entailed the design of appropriate solar powered water systems, provision of materials, delivery, installation and commissioning the completed water system at all 6 sites.

The scope of the works at each site as per the Bill pf Quantities (BoQ) and other specifications stipulated in the Tender Document included:

- Transportation of equipments and structural parts to the sites.
- Installation of appropriate submersible pumps.
- Installation of solar modules, the control unit, cable connections, controller and all other parts. The design life of the system must be at least 15 years.
- Erection of the solar PV models support structure for solar panels and positioning of the solar modules on the structure with vandal proofing mechanism.
- Construction of concrete water tower structure
- Supply and provision of two (2) water storage tanks each with 10,000L storage capacity. The tanks must be of HDPE material, abrasion resistant and high tensile strength.
- Construction of water distribution point and connected to water tanks that are fed by the water system
- Full testing and commissioning of completed installation with water delivered to the tanks and including earth system check.
- Construction of a 15mX15mX2.5m Chain Link fence
- Conduct a 2 days training of pump attendants and other water committee members on the essential routine system checks, operation and maintenance of the solar powered water supply system

2.1). Proposed modifications on scope of works for site #6 (Ng'wandakw village):

Of all the six villages benefitting from this project, Ng'wandakw village was different from the rest. Ng'wandakw village" is actually mingled with and part Haydom "town". According to Ng'wandakw village chairman, approximately 65% of people who are running business and other livelihoods activities in Haydom centre are actually residing in Ng'wandakw village.

By then, there were two existing water distribution points located in Ng'wandakw village and water supply pipeline was already connected to Ng'wandakw primary school where a 5,000 litres capacity elevated water storage tank is connected to one water distribution point (DP) which located at school's premises. This water 5000L tank is fed directly from the main water storage tanks (*located approximately 600 meters from the newly drilled borehole in Ng'wandakw village*) that serve other parts of Haydom and Ng'wandakw village.

With the above background**,** Ng'wandakw village's leadership in agreement with Hang'wa water users' association requested NCA to slightly modify the initial plan of constructing water yard (kiosk) at Ng'wandakw. Since the school already has a water storage tank and is already connected to a piped water supply network, community would prefer to have this high yielding borehole to be connected directly to one of the three main water storage tanks and feed water back to school and other parts of Ng'wandakw village.

The village leaders confirmed that this modification is the most preferable to all community members and will have far-reaching impact to the community. This preference was also expressed during the communal mass meeting held at Ng'wandakw village as well as during the meeting with the leaders of Hang'wa Water Users Association. Hang'wa chairperson further committed that the association will bear all associated costs of electrical power connection to the borehole site if a hybrid solar pump capable to be powered by both solar power and electric power was installed. NCA eventually agreed to the proposed modification



3) Supervision and quality assurance

The Consultant supervised the construction works and ensured implementation were carried out according to sound engineering standards, specifications and BoQ as per the agreed contract. Several sites visits were conducted to oversee work progress, provide guidance and ensure activities are implemented as per plan and scope of works.


4) Completion Status

All six solar powered water schemes have been completed as per scope of works, handed over to the community and operational. Below are the pumps installation details for each water scheme

No	Village	Pump details	Installation depth	# of oriented water scheme operators
1	Labay	• Dayliff DSP3-21, 1.5kW pump end • Dayliff 1.5kW 1ph sub-mortar • Dayliff SV2, 2.2kW 1ph Sunverter • Dayliff 200W, 24VDC crystalline solar modules: 10pcs • Well probe sensor: 1pc	100 meters	2 operators
2	Garkawe	• Dayliff DSP3-21, 1.5kW pump end • Dayliff 1.5kW 1ph sub-mortar, • Dayliff SV2, 2.2kW 1ph Sunverter, • Dayliff 200W, 24VDC crystalline solar modules: 10pcs, • Well probe sensor: 1pc • Dayliff 1 1/4'' adaptor set	100 meters	2 operators
3	Dotina	• Pedrollo 4SR1/32, 1.1kW pump end • Dayliff 1.1kW 1ph sub-mortar • Dayliff SV2, 1.5kW 1ph Sunverter • 9 Dayliff 200W, 24VDC crystalline solar modules • Well probe sensor: 1pc • Dayliff 1 1/4'' adaptor set	100 meters	2 operators
4	Dang'aida	• Dayliff DSP 8-13, 2.2kW pump end • Dayliff 2.2kW 1ph sub-mortar • Dayliff SV2, 2.2kW 1ph Sunverter • 14 Dayliff 200W, 24VDC crystalline solar modules	50 meters	2 operators

		• Well probe sensor: 1pc • Dayliff 2'' adaptor set •		
5	Getanuwas	• Dayliff DSP 3-16, 1.1kW pump end • Dayliff DSM 1.1kW 1ph sub-mortar • Dayliff SV2, 1.5kW 1ph Sunverter • Dayliff 200W, 24VDC crystalline solar modules: 8pcs • Well probe sensor: 1pc	80 meters	2 operators
6	Ng'wandakw	• Dayliff DSP 5-32, 3kW pump end • Dayliff 3kW 3ph sub-mortar • Dayliff SV3/3.7 Sunverter • 14 Dayliff 200W, 24VDC crystalline solar modules • 2.5mm^2 4core armoured cable, • Well probe sensor: 1pc • Dayliff 1 1/4'' adaptor set • *Hybrid system – to be connected to electricity power supply and pump water during night hours*	50 meters	2 operators *(to be oriented week 22-25 June)*

Photos of completed solar-powered water yards


5) Hand-over processes

Completed water yards were handed over to the local community between 9th -11th June 2021. The handover processes involved representatives from Rural Water Supply and Sanitation (RUWASA) offices of both Mbulu and Hanang districts who went to all 6 sites.

At village level, village chairman, village executive officers (VEOs), chairman and members of water users' committees, village health officers, head teachers, ward councillors and other community members including 4CCP – Hayom's directors were part of the handover exercise.

Handover process at Dang'aida village with a representative from RUWASA

An Engineer from RUWASA's Mbulu district office measuring water flow entering into the Tank

6) Recommendations moving forward

- Community to closely monitor the performance of all completed water yards within the next 3 months and report back any anomalies that should be addressed by the Contractor during this "retention period"

- Organize and arrange to carry out intensive training to selected members of *Community Based Water Supply Organisation (CBWOs*) at each village and support registration processes. The training should be organised now to build the momentum, in close collaboration with respective RUWASA's district offices
- In preparation and before the training of CBWSOs, follow-up with village executive officers (VEOs) among other things to facilitate obtaining signed letters from people owning land within a radius of 70 meters where water facilities are installed.
    - The letters must clearly declare that they have given out the land, have been compensated and they won't demand ownership at later stages, as per RUWASA's guidance. These letters are to be accompanied by minutes of the village's mass meeting
- As part of water safety plans, liaise with RUWASA at district level and encourage them to conduct a follow-up water quality tests targeting a few parameters such as *Fluoride*, *Total hardness*, *Sulphate* and *Nitrate* specifically for Dang'aida and Getanuwas boreholes.
- Before issuing the final payment of the retention fee (3% of contract sum) ninety days after 1st June when completion report was submitted by contractor, it will be important to cross-check and confirm all water yards are performing well. This can be done by paying a field visit to all sites and/or cross-check with well-informed key informant personnel at village level.

7) Annexes

1) Progress report #2 (date 17th March 2021)
2) Progress report #3 (dated 21st April 2021)
3) Guidelines for selecting ang training CBWSOs

4) Tips on O&M of installed solar-powered water yards: http://shorturl.at/sGT02
5) pump rating curves: http://shorturl.at/csQW9
6) Warranty document for pumps and PV modules: https://shorturl.at/enxE8
7) Geophysical survey report: http://shorturl.at/azEIT
8) Boreholes drilling report: http://shorturl.at/azEIT
9) Water Quality testing report for all boreholes: http://shorturl.at/azEIT
10) Yield testing report for all boreholes: http://shorturl.at/azEIT

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