Master's thesis

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

Trine Ånestad Røer

Multiple-Use Water Services in Rural Sites in sub-Saharan Africa

Case study from the Hanang, Mbulu, and Mkalama districts in Tanzania

Master's thesis in MTBYGG
Supervisor: Sveinung Sægrov
June 2020

NTNU
Norwegian University of
Science and Technology

Trine Ånestad Røer

Multiple-Use Water Services in Rural Sites in sub-Saharan Africa

Case study from the Hanang, Mbulu, and Mkalama districts in Tanzania

Master's thesis in MTBYGG
Supervisor: Sveinung Sægrov
June 2020

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

NTNU
Norwegian University of
Science and Technology

Abstract

In Tanzania, 66 percent of the population live in rural areas where water is needed for a variety of essential uses ranging from drinking, hygiene and sanitation to food production and income generation. The approaches to supply water services consist of systems that are designed, managed, and financed for a single use such as drinking. Often, the populations in rural areas of Tanzania rely on such single-use services (SUS) to meet multiple water needs, which are not considered in the planning or management of the system. Overuse of SUS-systems can lead to conflict and breakage of equipment and thus reduce the sustainability of the water systems.

By 2019, the Norwegian Church Aid (NCA) in cooperation with Four Corners Cultural Program (4CCP), a local partner, have installed 29 solar powered pumping systems in the Mbulu, Hanang, and Mkalama districts in northern Tanzania. Six of them are constructed as multiple-use water services (MUS) systems designed to provide water for both domestic and productive activities. The MUS-systems are still in a pilot phase and thus, potential improvement measures regarding the systems are identified in this thesis as the NCA are planning on expanding the MUS-projects in the future.

This thesis is based on a case study from the Hanang, Mbulu, and Mkalama districts in northern Tanzania. The work has been conducted in cooperation with the NCA, 4CCP, and Engineers Without Borders Norway. During the fieldwork, three remote monitoring systems were successfully installed. The systems seem to work properly in measuring the groundwater levels and level in water storage tanks, but further testing would be beneficial to certify the systems. In addition, different measurements, a survey, and interviews have been carried out to identify benefits and challenges regarding the solar powered pumping systems, with a focus on those designed as MUS-systems.

The willingness to pay for MUS-systems was found to be higher than several types of SUS-systems with the main affecting factor being the reliability of the current water system. Thus, increasing the reliability of the systems may lead to more people using water for productive activities as reliable water systems also often facilitate multiple use.

After the installation of solar powered pumping systems, there has been a strong reduction of water related diseases. This has been confirmed by water committees and district engineers, and through measuring water quality during the fieldwork. However, the water from some of the solar powered pumping systems was found to contain high fluoride concentrations. The main challenge regarding the solar powered pumping systems is the insufficient water productions. None of the solar powered pumping systems produce enough water to cover the water demand assuming water is used for both domestic and productive activities. The study lists several advantages from using water for multiple activities, but these are considered unlikely to achieve since the water systems do not currently cover the water needs. Thus, different improvement measures have been identified and discussed to increase the water production from the wells. In addition, an updated design basis of future water systems is needed to prevent an underestimation of the total water demand.

Sammendrag

I Tanzania bor 66 prosent av befolkningen i landlige områder hvor folk trenger vann til en rekke viktige bruksområder, alt fra drikking, hygiene og sanitet til matproduksjon og inntektsgenerering. Nåværende vannforsyning består ofte av systemer som er dimensjonert, driftet og finansiert til enkeltbruk, for eksempel drikkevann. Innbyggerne i landlige områder i Tanzania er ofte avhengige av slike vannforsyningssystemer for enkeltbruk (SUS) for å dekke flere vannbehov som ikke er tatt i betraktning i planleggingen eller drift av systemet. Overforbruk av SUS-systemer kan føre til konflikter og ødeleggelser på utstyr, og dermed redusere vannsystemenes bærekraftighet.

I løpet av 2019 har Kirkens Nødhjelp (NCA) i samarbeid med en lokal partner kalt Four Corners Cultural Program (4CCP) installert 29 solcelledrevne pumpestasjoner i distriktene Hanang, Mbulu og Mkalama i Tanzania. Seks av dem er konstruert som vannforsynings-systemer for flerbruk (MUS) dimensjonert for å gi vann til både husholdningsaktiviteter og inntektsgenererende aktiviteter. MUS-systemene er fremdeles i en pilotfase, og potensielle forbedringstiltak angående systemene er derfor identifisert i denne oppgaven da NCA planlegger å utvide MUS-prosjektene i fremtiden.

Denne oppgaven er basert på en casestudie fra distriktene Hanang, Mbulu og Mkalama som ligger nord i Tanzania. Arbeidet er utført i samarbeid med NCA, 4CCP og Ingeniører Uten Grenser Norge. Under feltarbeidet ble det installert tre fjernovervåkingssystemer. Systemene ser ut til å fungere som de skal ved måling av grunnvannsnivåer og vannivået i vanntanker, men ytterligere testing vil være fordelaktig for å sertifisere systemene. I tillegg er det utført flere forskjellige målinger, undersøkelser og intervjuer for å identifisere fordeler og utfordringer angående de solcelledrevne pumpesystemene, med særlig fokus på de som er dimensjonert som MUS-systemer.

Det ble funnet en høyere betalingsvillighet for MUS-systemer enn flere typer av SUS-systemer, hvor den viktigste faktoren var påliteligheten til dagens vannsystem. Å øke vannsystemenes pålitelighet kan dermed føre til at flere bruker vann til inntektsgenererende aktiviteter, også fordi pålitelige vannsystemer ofte fasiliterer flerbruk.

Etter installasjonen av solcelledrevne pumpesystemer har det vært en kraftig reduskjon av vannrelaterte sykdommer. Dette er bekreftet av vannkomiteer og distriktingeniører, og gjennom måling av vannkvaliteten under feltarbeidet. Imidlertid ble det funnet høye fluorkonsentrasjoner i vannet fra noen av de solcelledrevne pumpesystemene. Hovedutfordringen med de solcelledrevne pumpesystemene, er at de ikke produserer tilstrekkelige nok mengder vann. Ingen av de solcelledrevne pumpesystemene produserer nok vann til å dekke vannbehovet når det antas at vannet brukes til både husholdningsaktiviteter og inntektsgenererende aktiviteter. Denne studien har identifisert en rekke fordeler ved å bruke vann til flere aktiviteter, men disse fordelene anses som lite sannsynlige å oppnå siden vannsystemene for øyeblikket ikke dekker vannbehovet. Ulike forbedringstiltak for å øke vannproduksjonen er derfor blitt identifisert og diskutert. I tillegg trengs det et oppdatert prosjekteringsgrunnlag for fremtidige vannsystemer for å forhindre at systemene blir underdimensjonert.

Preface

This Master's thesis and its research have been conducted at the Department of Hydraulic and Environmental Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim, in the spring of 2020. It equals 30 ECTS and marks the end of the five-year programme in Civil and Environmental Engineering, with a course specialization in Water and Wastewater Engineering. The research has been carried out in cooperation with Engineers Without Borders (EWB) Norway and Norwegian Church Aid (NCA) and their partner organization in Tanzania: Four Corners Cultural Program (4CCP).

First of all, I must express my profound and sincere gratitude to my supervisor, Sveinung Sægrov, for his genuine support and guidance throughout the project. Thank you for believing in me and for your inspirational enthusiasm and knowledge. A great thanks to Manfred Arlt (NCA) for providing valuable insight and for facilitating this research. Thank you both for enabling me to do what I have dreamt of since before I started at NTNU: to use my knowledge to help those who need it the most.

A special thanks to the team in Tanzania consisting of Zachayo Makobero (NCA Tanzania) and staff from 4CCP. Without you the research conducted would not have been possible. In particular, Eliminata Awet, Ahadi Mollel, James Makobero, and our exceptional driver and aspiring engineer Yacobo Awe have been of great importance during the fieldwork. You all made my time in Tanzania be more than only a research study. The time in Tanzania with you is an experience I will forever cherish and carry with me through my upcoming career. Thank you to employees and visitors at Haydom Lutheran Hospital that helped us with our fieldwork or that I have crossed paths and made unforgettable memories with. *Asanteni sana!*

Thank you EWB Norway, particularly Helene Svendsen and Federico Orioli, for your help with practical preparations ahead of, and for checking up on us during the fieldwork. Most importantly, thank you for providing us our mentor, Vibeke Brandvold. She has played an essential role in making the fieldwork successful. Your knowledge, work ethic, and persistence are truly inspiring and I have learned a lot from you during the two weeks in Tanzania. Thank you!

A sincere thanks to Endre Våland Bø (NTNU), Hallvard Helgetun and Gard Hansen (El-Watch) who have contributed with technological insight in remote monitoring systems. Thank you for your essential help both before, during, and after the fieldwork. I am also sending my gratitude to Trine Margrete Hårberg Ness (NTNU) for teaching us how to use the water quality testing equipment.

Furthermore, I express my thanks to my field-partner and friend, Maria Asklund. I am grateful for have been given this opportunity to work together. Thank you for five exceptional weeks in Tanzania and the subsequent help and beneficial discussions.

Lastly, thank you to family and friends who have always contributed with great support, not only during the time of writing this thesis. Thanks to all I have made invaluable memories with throughout my study period in Trondheim. You know who you are.

Trine Ånestad Røer

....

Trine Ånestad Røer — Trondheim , 24th of June 2020

Table of Contents

List of Figures

List of Tables

List of Abbreviations

4CCP	Four Corner Cultural Program
COWSO	Community Owned Water Supply Organizations
EWB Norway	Engineers Without Borders Norway
HLH	Haydom Lutheran Hospital
JMP	Joint Monitoring Program
lpcd	Litres per capita per day
MUS	Multiple-use water services
NAWAPO	National Water Policy
NCA	Norwegian Church Aid
NGI	Norwegian Geotechnical Institute
PETS	Public expenditure tracking system
RWH	Rainwater harvesting
RWSSP	Rural water supply and sanitation project
SDG	Sustainable development goal
SUS	Single-use water services
TCP	Telethon Campaign Program
WASH	Water, sanitation, and hygiene
WSDP	Water Sector Development Program

1 Introduction

This chapter describes the background and motivation for the work, presents the research questions, and provides the structure for this thesis.

1.1 Background and Motivation

Water is the essence of life. Safe drinking water and sanitation are requisites to sustain life and health. In 2010, the UN General Assembly and the Human Rights Council recognised access to safe drinking water and sanitation as a human right. The right to water entitle everyone to have access to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use. Yet, there are still more than 880 million people without a satisfactory water source (UN General Assembly, 2010). By 2025, more than three billion people could be living in water stressed countries, defined as less than 1700 cubic metres per person per year. The increase in water demand for both domestic activities and productive activities is a concern in many parts of the world due to limited water sources, especially in combination with climate change. The specific impacts of the climate change vary per context and are hard to predict, but there is a consensus that sub-Saharan regions are among the areas that will be the most affected ones. In addition, the world population will reach nine billion by 2050, with the highest increase in sub-Saharan Africa (United Nations, 2018). The climate change and population growth will hardest affect those with the poorest water quality and water availability today. Thus, the pressure on the water sources is increasing, and optimal resource management in making the water systems climate resilient and sustainable is particularly important in these areas.

In 2015, the Norwegian Church Aid (NCA) and other local partners implemented a water, sanitation and hygiene (WASH) program in Tanzania. The goal was to "expand access to safe water, sanitation and hygiene services and enhance sustainability of water supply infrastructure and services in vulnerable communities of Tanzania by 2019" (Norwegian Church Aid, 2015). Through Norway's national broadcaster's telethon campaign program (TCP) in 2014, the NCA gave tens of thousands of people in Tanzania permanent access to clean and safe water. The WASH program expired in 2019 and is followed by the NCA driven Tanzanian Climate Smart Economic Empowerment Program. A common concept within both programs is the multiple-use water services (MUS). MUS is a holistic approach to sustainable water delivery and includes water services for both domestic activities and productive activities (WI, 2012). Central within the EE project is "Micro Investment" that, amongst others, include installations of "veggie-gardens". As can be seen from Figure 1.1, a veggie-garden consists of multiple vegetable beds, each of which sizes 8 meter times 1 meter, and comprises different types of crops (Fagerland, 2020).

This thesis emphasises the importance of access to safe and clean water in rural development. During the research period, it has been inspiring and felt of great importance to continue the outstanding work by Martinsen (2018) and Misund and Møller (2019). In the autumn of 2019, a project thesis with focus on multiple-use water services in sub-Saharan Africa was written. The project thesis functioned as a preparatory literature review to the fieldwork conducted for this Master's thesis.

1.2 Problem Description

Rural populations in Tanzania need water for a variety of essential uses ranging from drinking, hygiene and sanitation to food production and income generation. The approaches to supply water services consist of systems that are designed, managed and financed for a single use such as drinking or irrigation (Renwick *et al.*, 2007). Often, the populations in rural areas of Tanzania rely on such single-use water services (SUS) to meet the multiple water needs, which are not considered in the planning or management of the system. They use water meant for domestic consumption in their gardens, for their livestock, or for other small-scale enterprises. These unplanned uses can create unintended consequences. Overuse of domestic systems may cause conflict and breakage of equipment. This lead to a more acute competition between alternative uses of water, a lack of water for some activities, and conflicts over water allocation.

By 2019, NCA in cooperation with a local partner called 4CCP (Four Corner Cultural Program) have installed 29 solar powered pumping systems in the Mbulu, Hanang and Mkalama districts in northern Tanzania with 6 of them constructed as MUS-systems. In the NCA's designing of the solar powered pumping systems, they categorize the water system as a MUS-system if cattle trough or irrigation system for veggie-garden is directly connected to the water system (see Figure 1.1). Most of the solar powered pumping systems are rehabilitated from hand pumps. A fieldwork has been conducted in the areas in cooperation with the NCA, 4CCP and Engineers Without Borders (EWB) Norway. During the five-weeks long fieldwork that was conducted for this thesis, 14 out of the 29 relatively new solar powered pumping systems have been visited and different measurements and other data collection have been carried out. Thus, the focus in this thesis concerns the solar powered pumping systems visited. The thesis aims to identify benefits and challenges regarding the water systems, to further suggest potential improvement measures. This can be taken into account in further development of solar powered pumping systems. Furthermore, this thesis and its issue are divided into two groups related to if water is solely used for domestic activities (SUS) or if water is used for both domestic and productive activities (MUS).

Figure 1.1: MUS-system installed by the NCA and 4CCP with cattle trough (left) and veggie-garden (middle and right) directly connected to the solar powered pumping systems.

The fieldwork and all associated data collection were done together with Maria Asklund, who also courses specialization in Water and Wastewater Engineering at NTNU Trondheim. Furthermore, parts of the data analysing are done in cooperation with Maria Asklund. There are therefore written two Master's theses based on the same fieldwork and the data collected. The Master's thesis written by Maria Asklund focuses on the operation of the solar powered pumping systems, whereas this Master's thesis focuses on the multiple use of water provided from the solar powered pumping systems. However, some of the content will be similar for both theses, particularly within the chapters regarding the water quality, the water situation, and the remote monitoring systems. The photos in this thesis are mainly taken by Maria Asklund.

1.3 Project Scope

1.3.1 Objectives

The aim of this case study is to systematically and rigorously evaluate a range of impacts associated with the implementation of new solar powered pumping systems, and to identify potential benefits and challenges with associated improvement measures. The goal is to answer the research questions defined in the following chapter.

1.3.2 Research Questions

In 1987, the United Nations Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, p. 15). The concept of sustainability is composed of three pillars: economic, environmental, and social (Purvis, Mao and Robinson, 2019). To achieve sustainability of a water project, there must be a balance between the three pillars. The water systems must be viable, equitable, and bearable. The sustainability of water systems is a challenge in low- and middle-income countries, particularly within the sub-Saharan Africa. It is estimated that 36 percent of the handpumps installed in sub-Saharan Africa are out of service at any given time (Harvey, 2011). In Tanzania, 40 percent of water points were reportedly non-functional in 2016 (World Bank, 2018). Since the solar powered pumping systems are relatively new, it is of interest to investigate their sustainability and to identify potential affecting factors.

The MUS-systems installed by the NCA and 4CCP in the Hanang, Mbulu, and Mkalama districts in Tanzania are still in a pilot phase. Thus, the potential improvement measures regarding the systems are beneficial to identify as the NCA is planning on expanding the MUS-projects in the near future. The veggie-garden and cattle trough connected to the solar powered pumping systems lead to a higher water demand. Thus, to investigate if the solar powered pumping systems are producing sufficient quantities of water to meet this water demand is essential in determining if the water systems can be used as a MUS-system. Additionally, to identify the specific water demand from people, cattle, and the veggie-garden are of interest and can be used in the designing of future MUS-systems. However, the NCA does not want to over-abstract the groundwater reservoir and sees monitoring of the groundwater source as important in the context of climate resilience and water delivery to MUS (Manfred Arlt, personal communication, 7th of October 2019). As many villagers in rural Tanzania use groundwater as their primary drinking water source, and the number of villagers connected to a borehole is increasing due to the increasing number of boreholes, sustainable abstraction and management of the groundwater resources are crucial. By monitoring the groundwater levels at the solar powered pumping systems one can also look at the possibilities of extracting larger quantities of water from the groundwater source to increase the water availability. Furthermore, the NCA wants to improve the sustainability of the solar powered pumping systems by exploring the possibilities within remote monitoring in rural sites to reduce the downtime of the water system. The downtime of the water system is in this thesis defined as when water is not being available due to an interruption in the water system.

Misund and Møller (2019) found several high fluoride concentrations within the Mbulu and Mkalama districts. The ingestion of high fluoride concentrations can have a negative effect on the consumer's health. Thus, a further investigation of the fluoride concentrations in the water provided from the solar powered pumping systems is needed to determine if there should be introduced methods to reduce the fluoride concentrations in the future. Other water quality parameters should also be addressed to determine if the solar powered pumping systems provide water safe for drinking.

Furthermore, there is a lack of data regarding the willing to pay for multiple-use water services. This is considered as important to identify as enough funding from the community to operate and maintain the water system is a prerequisite to ensure a sustainable water supply system. Based on all of the above, five main topics have been chosen to be further investigated in this thesis. They are:

- How can a remote monitoring system affect the sustainability of a solar powered pumping system?
- To what extent do the solar powered pumping systems provide sufficient drinking water quality?
- To what extent do the solar powered pumping systems meet the water demands, both for domestic uses and for productive uses, today and in the future?
- What is the willingness to pay for multiple-use water services compared to single-use water services, and what are the affecting factors?
- What are the benefits and challenges of multiple-use water services compared to single-use water services?

1.4 Project Structure

This thesis is divided into 9 main chapters. Firstly, a description of the study area is presented, including an overview of the climate, hydrology, socioeconomic characteristics, and rural water policies in Tanzania. In addition, the chapter provides detailed information regarding the fieldwork conducted for this thesis and the solar powered pumping systems within the study area. The 3rd chapter includes the methods used to collect and analyse the data, and identifies and discusses the limitations regarding the research. Chapter 4 to 8 contain the results from the research, each of which aims to address one of the research questions defined in the previous chapter. These chapters are further divided into three sub-chapters: background of the associating topic investigated, the results found from the study, and a discussion. Chapter 9 includes a general discussion of the results considered as most important in terms of addressing the research questions, and further summarises the main findings from these chapters into a conclusion. The conclusion provides the basis for future work, which is the final chapter in this thesis.

2 Study Area

This chapter briefly presents aspects of Tanzania’s climate, hydrogeology, socioeconomic characteristics and rural water supply policy that are considered as relevant for the study area. In addition, a description of the case villages, the solar powered pumping systems, and the associated fieldwork will be explained more detailed.

2.1 Tanzania

The United Republic of Tanzania is the largest country in the East Africa and covers 940.000 square kilometres, 60.000 of which are inland water. Tanzania borders the Democratic Republic of Congo, Rwanda and Burundi in the west, Uganda and Kenya in the north, and Mozambique and Zambia in the south. Kiswahili is the national language, with English as a second language. Tanzania possesses a complex landscape, formed by the westerns and eastern branches of the East African Rift, resulting in substantial spatial variety in landscape and climate within the country. Most of Tanzania is located 200 metres above sea level with the majority above 1000 metres above sea level (National Bureau of Statistics, 2019).

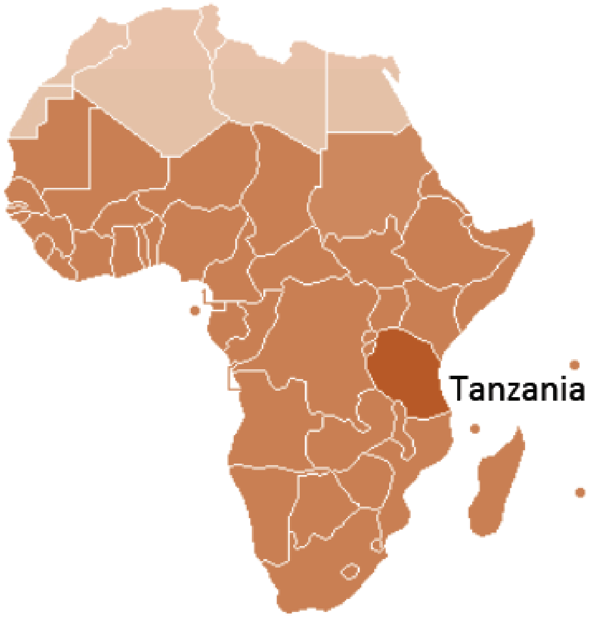


Figure 2.1: Map of Africa, showing countries defined as Sub-Saharan countries (orange) and the location of Tanzania (dark orange) (Jcherlet, 2010).

Tanzania, formerly known as Tanganyika, became independent of British colonial rule on 9th of December 1961 and became a republic one year later. The island of Zanzibar became independent on 12th of January 1964, and on 26th of April 1964 Tanganyika and Zanzibar merged and formed the United Republic of Tanzania.

Administratively, The United Republic of Tanzania is divided into 31 regions, 26 of which are located within the mainland of Tanzania (ibid). The regions are divided into districts, further divided into wards. Each district has a capital where the district councils often are located. The areas of interest, where the case villages are situated, are the Hanang, Mbulu, and Mkalama districts in northern Tanzania. As seen from Figure 2.2, Hanang and Mbulu are situated within the north-western part of the Manyara region, and Mkalama is situated within the northern part of the Singida region.

Figure 2.2: The administrative map of Tanzania with the regions visited during the fieldwork highlighted in dark orange. Modified from: (Sémhur, 2009).

2.1.1 Climate

The topographical diversity of Tanzania gives rise to four distinct climate zones: 1) hot and humid coastal belt (including Zanzibar archipelago) 2) hot and arid of the broad central plateau, 3) cooler semi-temperate high lakes region in the north and west, and 4) highlands of the northeast and southwest. The Tanzanian climate varies within the country due to its geographical location, altitude, relief, and vegetation cover. The region's climate is mainly influenced by its location close to the equator, the impact of the Indian Ocean, and the physiography in general (USAID, 2018).

Rainfall is highly seasonal, being influenced greatly by the annual migration of the intertropical convergence zone, a relatively narrow belt of very low pressure and heavy precipitation that forms near the earth's equator (McSweeney, New and Lizcano, 2010). The exact position of the intertropical convergence zone changes over the course of the year and causes two distinct wet periods in the north and east of Tanzania, whilst the southern, western and central parts of the country experience one wet season (ibid). The climate in central Tanzania is characterized by low rainfall patterns, punctuated by storms, droughts and floods. The regions within this area have an unimodal rainfall regime, concentrated in a period of six months from November to April and receive an annual rainfall of less than 400 mm (Lema and Majule, 2009). Other parts of Tanzania experience a bimodal rainfall pattern with a short dry season from the middle of January to late March followed by a rainy season from March to May. This long wet season is dominated by high humidity, temperatures between 30-35 degrees Celsius and heavy downpours in the afternoon. From June to October, there is a long dry season with hardly any rain and relatively low temperatures. Lastly, from November to the middle of January there is a short wet season with lighter precipitation and higher temperatures compared to the long wet season. The amount of rainfall falling in the rainy seasons is usually 50-200 mm per month but varies greatly between regions, and can be as much as 300 mm per month in the wettest regions and seasons (McSweeney, New and Lizcano, 2010).

According to Trust Engineering and IDBWO (2015), the climate in Hanang, Mbulu and Mkalama districts is characterized by a marked dry and wet season. The climate in these areas may be described as dry type savannah with a dry season of 6 to 7 months and a rainy season of 5 to 6 months. Generally, there is no rainfall after May. The following period to the end of November is characterized by an increase of sunshine hours and wind velocity. These two factors cause an increase of the evapotranspiration to more than 2000 mm per month. When the belt of equatorial calm moves southwards in December, the humidity increases rapidly causing an average rainfall of 1100 mm during December and January (ibid). Based on interviews with 4CCP and water committees from villages visited in these areas, the weather has typified the bimodal rainfall pattern in recent years, with a rainy season from March to May in addition to a rainy season from December to January.

Results from some of the latest available climate models suggest that, in contrast to rainfall, there is a strong consensus on rising temperatures in Tanzania with an averaging increased temperature of 1.8 degrees Celsius by 2040. The warming will lead to higher levels of evaporation and water demand everywhere, particularly in the inland. In addition, the number of days where the average temperature exceeds 30 degrees Celsius will increase from 10 days a year to 80 days a year by 2040 (TAWASANET, 2019). Matata, Bushesha and Msindai (2019) shows an increasing trend in average temperature and decreasing annual rainfall patterns from 1985 to 2016. Today, the temperatures in these areas are ranging from 20 to 22 degrees Celsius. The same trends are also identified by Noel (2012), who further states that there has been a decrease in rainfall of 5-15%, and that an increase in temperature of 4 degrees Celsius will occur in the central areas of Tanzania.

2.1.2 Hydrogeology

Hydrogeology is the study of groundwater and includes the study on how water gets into the ground (recharge), how it flows in the subsurface (through aquifers) and how groundwater interacts with the surrounding soil and rock (the geology) (International Association of Hydrogeologists, 2019). Thus, the hydrogeology is essential to study and analyse when planning and implementing a system for groundwater abstraction. It affects factors such as the water quality, the depth of the borehole, and the quantity of water that can be abstracted from the source. The science of hydrogeology is used to assess safe abstraction levels and is important in the planning of a pump system to ensure a sustainable and efficient pumping rate.

Groundwater is stored in the open spaces between rock and sand, soil, and gravel. It is found in two zones. The *unsaturated zone* contains water and air in the pores and is found nearest to the ground surface. The *saturated zone* is a zone in which all the pores and rock fractures are filled with water, and underlies the unsaturated zone. The top of the saturated zone is called the *water table* (Figure 2.3).

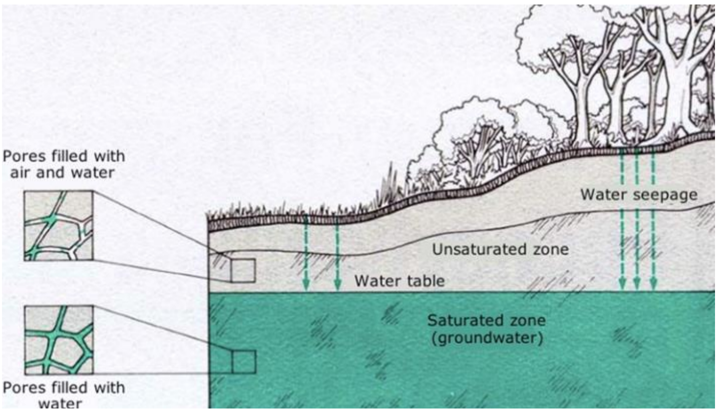


Figure 2.3: Storage of groundwater in different zones. Modified from (Stevens, N.A.).

Rock or soil layers within the zone that can readily store and transmit usable amounts of water are called aquifers (Chilton, 1996). An aquifer may be a few metres to several thousand metres thick. The amount of water an aquifer can hold depends on the volume of the underground rock materials and the size and number of pores and fractures that can be filled with water. According to Kruseman, De Ridder and Verweij (2000), there are three main types of aquifers: confined, unconfined, and leaky.

A confined aquifer is bounded above and below by impermeable geological unit called an aquiclude. The pressure of water is usually higher that of the atmosphere in a confined aquifer. If a well taps in a confined aquifer, the water in the well stands above the top of the aquifers, and sometimes even above the ground surface, called an artesian well (Figure 2.4).

An unconfined aquifer is bounded below by an aquiclude, but is not restricted by any confining layer above it. If a well taps in an unconfined aquifer, the water is at atmospheric pressure and does not rise above the water table (Figure 2.4).

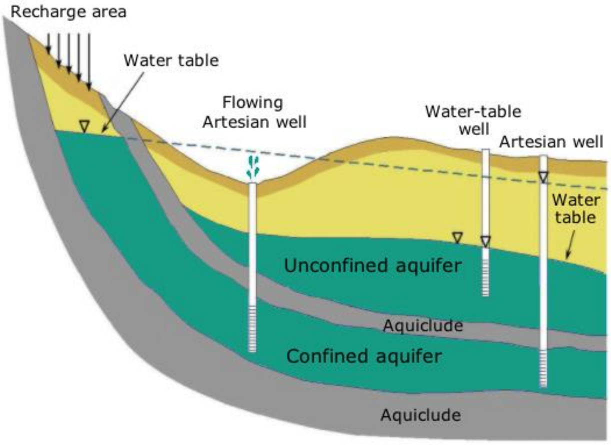


Figure 2.4: Illustration of observation wells in unconfined and confined aquifers. Observation wells in unconfined aquifers are called water-table wells, whereas in confined aquifers they are called artesian wells. Modified from (Andriyani et al., 2017).

A leaky aquifer, also known as a semi-confined aquifer, is an aquifer with upper or lower boundary as an aquitard. An aquitard is a geological unit that is permeable enough to transmit water in significant quantities, but its permeability is not sufficient to justify production wells being placed in it. If a well taps in a leaky aquifer, the water in the well may coincide with the water table. The water level may also stand above or below the water table, depending on the recharge and discharge conditions (ibid).

The most likely types of aquifers that wells tap from in rural areas of Tanzania are either confined or unconfined. A confined aquifer with thick overlying impermeable layer is likely to be less vulnerable to pollution than an unconfined aquifer, which is preferable in the rural areas of Tanzania where there is little or no purification of the groundwater used for drinking. However, the confined aquifers are likely to be located deeper than unconfined aquifers. Thus, the distance from source to surface will be greater for confined aquifers than unconfined aquifers. This affects the cost, performance and efficiency of the water pump and must be considered in the designing of a system for groundwater abstraction.

The occurrence of groundwater is largely influenced by geological conditions. Hanang, Mbulu and Mkalama districts are situated within two geological formations, known as the Central Plateau and the East African Rift System. The central plateau is composed of ancient crystalline basement rocks. These are predominantly faulted and fractured metamorphic rocks with some granites (BGS, 2000). The East African Rift System runs through Tanzania and has shaped much of its geology and aquifer characteristics. The northern and southern highland regions are parts of this major rift system. The East African rift is a developing divergent plate boundary in East Africa, and currently extends for 3500 km from the Red Sea to Mozambique. It is formed from two broadly parallel main rift branches: the eastern rift and the western rift (The Geological Society of London, 2012). The eastern rift, also known as the Gregory Rift, extends through north-west parts of Tanzania whereas the western rift extends along the south-western margin of Tanzania. The villages studied located within the Rift Valley are parts of the Gregory Rift. The geology of the Rift zones comprise volcanic and intrusive rocks, largely of basaltic composition and some sodic alkaline rocks (BGS, 2000). According to The Geological Survey of Tanzania (2020), the aquifers in the villages visited consist of following sediment types: predominantly alluvial and eluvial sediments, migmatite-granitoid-meta-sediment complex, volcano-sediment complex-Greenstone Belt with banded iron formation.

The groundwater potential of the aquifer types differs from place to place due to variability in aquifer formations and recharge mechanisms. In the crystalline basement of the central plateau and in the granitoid, groundwater flow is restricted to joints and fractures and is therefore limited. For both the greenstone belt and the eluvial and alluvial sediments, water will be within the pores and the groundwater may be easier to access (Misund and Møller, 2019).

The groundwater levels measured during the fieldwork and associating pump depths are presented in Figure 2.5. The lowest groundwater level was found to be 85 metres in Diling’ang village whereas the highest groundwater level was found to be 1.6 metres in Isene village.

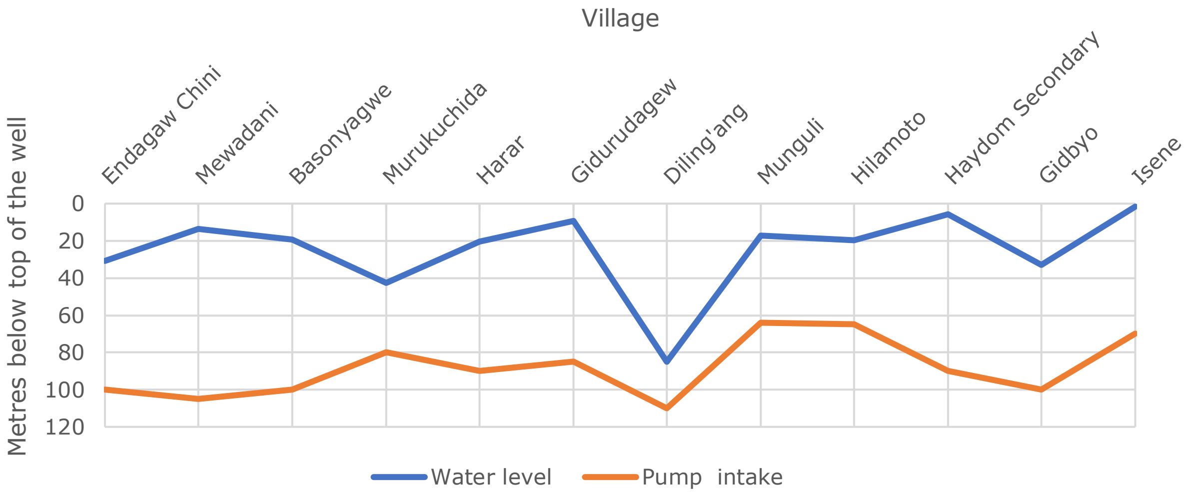


Figure 2.5: Groundwater levels within the study area with associating pump depths.

Borehole Definitions

Appendix 2 shows technical details of the installed solar powered pumping system installed through WASH TCP from 2015 to 2019. The borehole definitions considered as highly relevant to this thesis are presented in Figure 2.6 and are defined as follows:

The *static water level (SWL)* is the distance from the ground level, or other measuring point being the top of the well during the fieldwork, to the water table under non-pumping conditions. SWLs can be influenced by climatic conditions (GWIC, 2020).

The *dynamic water level (DWL)* is the distance from the measuring point to the level of water in the well during pumping, or the distance after *drawdown.*

The *drawdown* is the difference between SWL and DWL. The drawdown begins when the pump is turned on and increases until the well reaches "steady state" when the withdrawal is compensated for by inflow of groundwater from the surrounding area (ibid).

The *yield* of a well is the amount of water produced by the well when the pump is on (ibid). The water production from the wells is in this thesis referred to as *flow rate.* The flow rate varies with the speed of the pump, which in turn varies with electricity available, and drawdown. This will be further discussed in chapter 6.

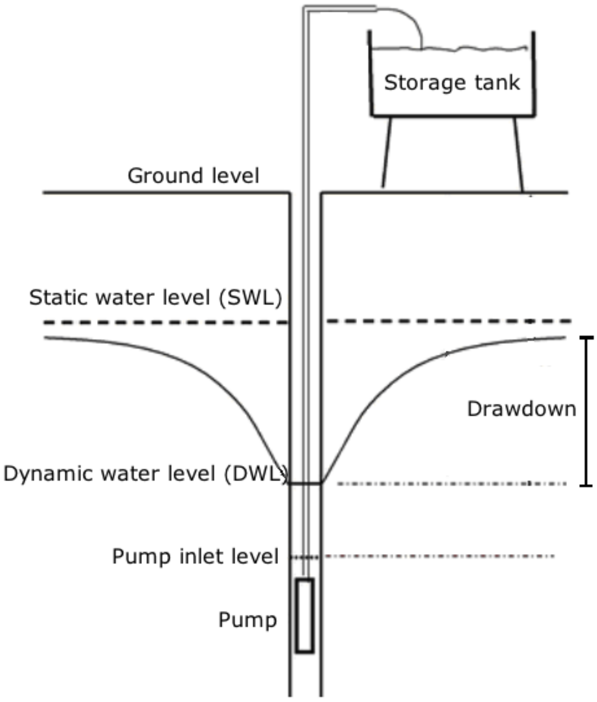


Figure 2.6: Borehole definitions. Modified from (GWIC, 2020).

2.1.3 Socioeconomic Characteristics

Water is a basic natural resource for socioeconomic development. It is fundamental for various development activities such as industrial production, irrigated agriculture, livestock keeping, mineral processing, hydropower production, and tourism.

According to The World Bank (2020c), Tanzania's overall population is about 56 million, making it the fifth-most populous country in Sub-Saharan Africa. The majority of the population lives inland, far away from the coastline. Over 66 percent of the population live in rural areas, where the poor often live. The poverty rate in the country (earning less than 16 USD per month) has declined from 28.2 percent in 2011 to 26.4 percent in 2018, but the absolute number of poor citizens has not because of the high population growth (The World Bank, 2020b). The population projections show that Tanzania is expected to reach 63.5 million in 2025. The main components of this population growth are fertility and mortality. The total fertility rate is 3.8 and 6.0 children per woman for urban and rural areas respectively. The under-five mortality has declined from 112 per 1000 live births in 2005 to 67 per 1000 live births in 2016 (National Bureau of Statistics, 2019). Rapid population growth impacts on the water resources coverage and because of that, the per capita water use has been decreasing over time. Government efforts to expand access to other social services such as education and health have been undermined by their declining quality as the population rises faster than the supply of the services (The World Bank, 2019).

The annual GDP in Tanzania Mainland was 49 184 million USD in 2014 and has been growing at an average rate of 6.7 percent from 2013 to 2018. The Tanzanian economy largely depends on agriculture which comprises 31 percent of the GDP (FAO, 2016). The sector employs 65 percent of the total employment in 2019 (The World Bank, 2020a), and thus continues to drive the economic growth of the country. The government has an ambition of becoming a middle income country and aid independent by 2025 (Norwegian Church Aid, 2015).

2.1.4 Rural Water Supply Policies

The Government of Tanzania has changed the structure of rural water supply substantially during the last 15 years, first with the National Water Policy (NAWAPO) and later with the Water Sector Development Program (WSDP). Improving access to sustainable water service in rural areas of Tanzania is a priority goal for the Tanzanian government. There are three strategic actions for improving this access:

- Increasing water supply coverage through new projects and rehabilitations of old ones;
- Improving water management systems;
- Strengthening supervision and monitoring of the sector (Fierro *et al.*, 2019).

Under NAWAPO, a new village institution was formed known as Community Owned Water Supply Organizations (COWSO) having the responsibility of operating, maintaining, and sustaining water points at the village level (URT, 2002). These organizations corresponds to what is referred to as water committees within the study area. The water committees are elected at each water point, and the management board is composed of a chairperson, secretary, treasurer, and members. Within the study area, the NCA and 4CCP aim to have an equal number of men and women in the water committees. The WSDP consolidates three sub-sector programs including water resources management, rural water supply, and urban water supply and sewage, and provides a nation-wide vision and funding (Fierro *et al.*, 2019). The water committees should bear the full cost of operation and maintenance and contribute 5 percent of the capital investment in rural water schemes (URT, 2006). This is a strategy aiming at making the consumers and water committees of the water scheme feel a greater sense of ownership to the systems. According to the WSDP, the Ministry of Water will take the lead role in implementing the plan for rural water supply and sanitation project (RWSSP) (URT, 2006). The RWSSP includes both rural and small town populations in Tanzania. One of the main goals in RWSSP is to increase the water coverage from 54 percent in 2005 to 90 percent by 2025. The objective of RWSSP is to provide water supply and sanitation services that are sustainable and equitable. As such, a "significant proportion of the planned investments is allocated to planning support, stakeholder consultation, the establishment of District Water and Sanitation Teams, support to the private sector, general capacity building, and other key areas" (URT, 2006, pp. 3-3).

2.2 The Case Villages

The case villages are situated in the rural areas within the districts of Hanang, Mbulu and Mkalama in Tanzania (see Figure 2.2). The villages studied were surrounding Haydom Lutheran Hospital in Haydom Village, which was conveniently used as accommodation and base during the fieldwork.

2.2.1 Fieldwork

The fieldwork was conducted from the 28th of January 2020 to the 24th of February 2020. It was done in collaboration with the NCA, 4CCP, and EWB Norway. Manfred Arlt, NCA's Senior WASH Advisor, has helped with the preparation of the fieldwork beforehand including development of the frames of this thesis, providing different water quality measuring equipment used during the fieldwork, and answering questions regarding the thesis both before and after the fieldwork was conducted. Zachayo Makobero, WASH

Program officer and engineer from the NCA Tanzania, helped with the installations of the remote monitoring systems during the first week of the fieldwork. Zachayo Makobero has also been answering technical questions regarding the solar powered pumping systems before, during, and after the fieldwork was conducted. EWB Norway has helped with the financing of the fieldtrip and provided a mentor, Vibeke Brandvold, to ensure that all technical assessments and implementations were done correctly during the fieldwork. Vibeke Brandvold is an engineer within hydrogeology and was involved in all of the work executed during the two first weeks of the fieldwork. After Vibeke left Tanzania, Sveinung Sægrov and Randi Sægrov participated in the fieldwork for one week. 4CCP provided the program for the fieldwork, suggested which villages to visit, arranged meetings with different stakeholders, provided translation, and was responsible for all associated logistics. The fieldwork included interviews with different stakeholders, survey, installment of remote monitoring systems, and measurements.

The day before the fieldwork officially started, a meeting with 4CCP and Zachayo Makobero was held to complete the final fieldwork program. Both 4CCP and Zachayo Makobero were very accommodating in adapting to new suggestions, both during the meeting and during the entire fieldwork when unexpected situations caused new itinerary planning. The updated program for the fieldwork is found in Appendix 1. As can be seen from the updated program, some of the villages were visited multiple times. In three of them, (Basonyagwe, Endagaw Chini, and Mewadani) remote monitoring systems were installed, further presented and discussed in Chapter 4. The installation was time-consuming and thus the villages were visited multiple times in order to complete the installment. All villages visited can be seen in Figure 2.7. As can be seen from Figure 2.7, the distances to the villages from Haydom vary. A significant amount of time was used on transport because of long distances in combination with limited infrastructural access, particularly the first two weeks when the presence of heavy rain lead to longer detours due to floods and broken roads and bridges.

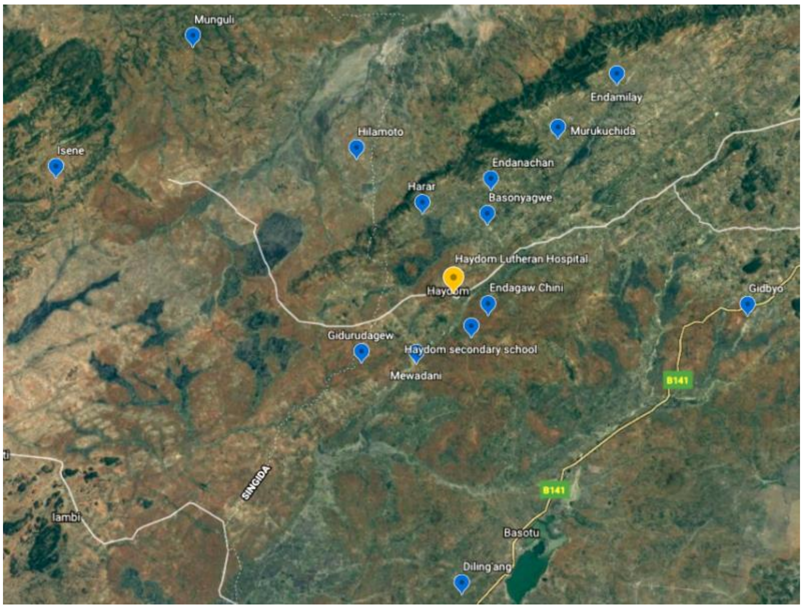


Figure 2.7: Villages visited during the fieldwork, with Haydom Lutheran Hospital used as accommodation during the fieldtrip highlighted in orange, and the rest of the villages visited highlighted in blue (Made with Google Maps).

Haydom is located in Manyara region, 300 km from the nearest urban area, Arusha. Haydom is build up around Haydom Lutheran Hospital (HLH). The hospital serves 7 districts in 4 regions. HLH was set up by a Norwegian missionary in 1955 and quite rapidly Haydom town grew around it. Today Haydom town has 23 000 inhabitants, and is still growing. Every year, missionaries, students, volunteers working at the hospital, and other external actors visit HLH.

4CCP was funded in 2006 as a sister organization to HLH, stands for Four Corners Cultural Program and represents the four ethno linguistic groups of Africa; Bantu, Iramba, Hadzabe, and Datoga. 4CCP is described as "a community empowerment project and a cultural program which aims at promoting development and social welfare among the indigenous community through various cultural programs and community empowerment projects such as entrepreneurship, agriculture, water projects, leadership skills and accountability" (4CCP, 2020). Currently, they are solely sponsored by NCA-Tanzania, except for the Youth Communication for change which is supported by FK/NCA Norway (ibid). In the installation of the solar powered pumping systems, the roles of 4CCP as a partner to NCA, were to supervise the drilling, establish and train the water committees and public expenditure tracking system (PETS) committees, mobilize the communities to contribute to the project in order for them to feel ownership to the project, have meetings with different stakeholders on how to ensure and increase the sustainability of the projects, and to overlook the projects after installation (Interview with 4CCP, February 2020). Hence, 4CCP is an important partner for the NCA both in the implementation of the solar powered pumping systems and in ensuring the sustainability of the systems upon completion.

2.2.2 Solar Powered Pumping Systems

The focus during the fieldwork was to investigate the solar powered pumping systems within the study area to identify potential benefits and challenges, and based on the findings present possible improvement measures.

As previously mentioned, the NCA has installed at least 29 solar powered pumping systems within the study area. The majority of the solar water powered systems are designed to provide water solely for domestic uses. Some of the systems are also designed to provide water for productive uses such as irrigation and cattle watering. Solar powered pumping systems have proven to be a reliable and cost effective solution in areas where there is widely spread water resources, no electricity grid is near, and the fuel and maintenance costs are considerable. These systems require adequate sunshine and a source of water. The use of the solar systems is appropriate, as there is often a natural relationship between the availability of solar power and the water requirement. The reliability is high compared to handpumps because the water can be pumped during the day and stored in tanks, making water available at night or when it is cloudy (Ghoneim, 2006). In sub-Saharan Africa the typical storage is about 3 to 5 days of water demand and thus it is not necessary to use batteries (Baumann *et al.*, 2010). However, a general problem regarding the solar powered pumping systems mentioned by villagers within the study area is that there is no water when there is no sun. They further state that this problem happens up to three times per week in the dry seasons. This will be further discussed in chapter 6.

The most common type of solar pump for village water supply in rural areas is systems with pumps using alternating current (AC) where the direct current (DC) has to be fed through an inverter (Mudzingwa, Nyakutsikwa and Ngogodo, 2016). The solar powered pumping systems within the study area use this type of system and are constructed with an AC/DC inverter and pump provided by Dayliff. The AC/DC inverter is specially designed for solar powering AC motors in various pumping applications (Davis and Shirtliff, 2018). The solar powered pumping systems are similarly constructed and contain components such as tank tower, water tanks, domestic point(s), submersible pump, DC disconnect switch, AC/DC converter, solar panels, and a well probe sensor (Zachayo Makobero, personal communication, 29th of November 2019). The number of solar panels, size of water storage tanks, type of pump, and type of inverter used in the systems vary and can be seen in Appendix 3. Figure 2.8 shows some of the components in a typical solar powered pumping system within the study area. The systems designed to provide water for productive activities are installed with cattle through or irrigation pipes for vegetable garden, so-called "veggie-garden", or both. The cattle through and irrigation pipes in the veggie-garden are directly connected to the water tanks (see Figure 1.1).

Figure 2.8: Solar powered pumping system in Endagaw Chini village with storage tanks, borehole (blue box in the middle) and solar panels.

The pumps used in the villages visited are mostly DS, DSP, and DSD submersible multistage centrifugal pumps provided from Dayliff. These types of pumps are chosen because they are relatively cheap (Zachayo Makobero, personal communication, 14th of February 2020). Additionally, these pumps provided by Dayliff feature a floating type impeller that gives superior sand handling capabilities. However, the budget is the major limiting factor as the turbidity levels and sand levels in the groundwater sources within the study area are quite low, as can be seen from Table 5.2 (ibid). The DS pumps feature stainless steel construction throughout whereas the DSP pumps use engineering plastics for the hydraulic components. The maximum allowable water temperature is 30 degrees Celsius and the maximum sand content is 50 g/m^3 (Davis and Shirtliff, 2014). The material of construction for the DSD pump include plastic impellers and diffusers, cast iron delivery and suction chambers and AISI 304 stainless steel pump housing, shaft and shaft coupling. The maximum allowable temperature is 35 degrees Celsius and sand content of 0.25 percent (Davis and Shirtliff, 2017). The submersible pump will not work unless it is completely submerged and is designed to push water to the surface. These pumps use a spinning impeller that adds energy to the water and pushes into the system, similar to a water wheel. The motor is hermetically sealed and closed-coupled to the body of the water pump. In the pumps used within the study area, the pump is coupled to a sealed liquid cooled 2-pole asynchronous squirrel-cage motor constructed of stainless steel (Davis and Shirtliff, 2014; 2017). The rest of the unit consists of a cable connected to the motor and a pipe that transports the water to the surface and into the water storage tanks. Other advantages of this configuration are that it is easily installed, with a lay-flat flexible pipe work and the motor pump set is submerged away from potential damage (Sontake and Kalamkar, 2016). The systems also include a well probe sensor which automatically turns the pump off when the groundwater level drops under the level of the water pump to prevent damages of the pump. Maximum pump immersion depth for the pumps used within the study area is 150 meter for DSD, 200 meter for DSP, and 250 meter for DS. The motor speed of the pumps is 2850 rpm for DSD and 2900 rpm for DSP and DS (Davis and Shirtliff, 2014; 2017). A robust sealed wellhead plate is also installed on the borehole top to prevent borehole contamination (Figure 2.9).

Figure 2.9: Borehole top of a solar powered pumping system.

Figure 2.10: Water tap connected to the solar powered pumping system in Endagaw Chini.

Water Yard Organization

The solar powered pumping systems within the study area also have a caretaker, a water committee, a PETS committee, and a security guard. According to the interviews in the villages visited, the tasks of the caretaker are to open and close the water system. There is a valve inside the fence that needs to be open in order to get water from the taps. The caretaker also collects fees from the water users where the users are paying an amount per bucket of 20 litres, registers the amount of buckets sold in a day, reads off and registers the number of the water meter in the morning and in the evening, and provide the money collected to the water committee approximately once a month. The main tasks for the water committee are to control and supervise all activities within the water projects, collect revenue from the water project, and to provide feedback to the village government. The PETS committee has follow-ups on the water projects within the village to avoid misuse of public or private funds and thus functions an anti-corruption measure through budget monitoring. The security guard surveils the solar powered pumping systems during the night to prevent vandalism.

3 Methodology

The methods, tools, and other equipment used to collect data are presented within this chapter with their associating purpose(s). Furthermore, the main limitations encountered during the research are discussed.

3.1 General Methodology

There are established different methods that can be applied to explore and illustrate the themes of interest. The choice of method affects the data generated, which in turn provides the foundation of the study. Thus, the method is strongly connected to what the study aims to present. Research is largely divided into two overarching categories; quantitative and qualitative (Dalland, 2012). Quantitative research defines specific variables and categories and link them together. An inflexible view and the use of statistical practice is characteristic (Brannen, 1992). The qualitative methods aim to capture meaning and experience that cannot be quantified or measured (Dalland, 2012). Qualitative and quantitative research can facilitate each other. Quantitative research allows relationships between variables where the data are collected using methods such as survey, structured observation, and statistical analysis. However, quantitative research is weak in identifying reasons of the relationships. Thus, qualitative methods are often used in combination with quantitative methods. The qualitative interviews may be appropriate to use when results based on quantitative results are complex (Brannen, 1992).

In order for data collected to be used safely to draw conclusions, it is important that the data and results have a high degree of reliability and validity. These factors affect the trustworthiness of the research findings. Reliability refers to the extent to which the same results can be obtained using the same instruments multiple times under constant conditions (Dalland, 2012). According to Wilson (2014) there are several potential threats to the reliability which include time error, subject error, and observer influence. In order to reduce the likelihood of time error, it is favorable to examine the population and measurements within the study at different times of day, week, and year. Both the subject error and observer influence relate to bias on the part of the researcher (ibid). An improvement measure to minimize the bias and increase the reliability of the research is to use multiple sources of evidence to strengthen any finding or conclusion (Yin, 2017). Additionally, the parameters used for measurements with associating methods should be clear in order for the observer to understand how and why the measurements have been executed (Wilson, 2014). Furthermore, Wilson (2014) argues that for a test to be reliable, it also needs to be valid. Content validity includes the extent to which an instrument measures what is supposed to measure, and the extent to which the measure includes all areas within the nature of the study. Improvement measures to increase the validity of the results are to fully engage research stakeholders, ensure that measures are related to the research questions, and to compare the measures with those of previous research (ibid).

3.2 Data Collection

This thesis continues the projects done by Martinsen (2018) and Misund and Møller (2019). Thus, the same framework for methodology used in these previous Master's theses is also used in this thesis as it is considered as favorable because it will make it easier to compare results found in this study with the results found in both previous theses. Additionally, the results from the theses by Martinsen (2018) and Misund and Møller (2019) have shown that this methodology framework has been successful in this type of research. The methodology consists of seven common methods used to collect data (Olsson, 2011):

- Literature review
- Use of existing data from system, reports and similar sources
- Interviews with different key stakeholders
- Participating observation
- Direct observation/measurements
- Surveys or questionnaires
- Case studies

All of the seven mentioned data collection methods are used in this thesis. The data collection methods and how to execute them were suggested in the preparatory project thesis and further discussed and determined with Sveinung Sægrov from NTNU, and Alexander Klein and Manfred Arlt from the NCA before the fieldwork was conducted. Their experience and knowledge were valuable in optimizing the data collection methods to gather data of good quality during the fieldwork. They will further be presented with their associated purpose(s). Additionally, the installations of remote monitoring systems within the study area and the preparatory workshop are presented in a separate chapter.

3.3 Literature Review

A literature review is a critical analysis of a selection of literature within a given field. This type of study typically include a summary, classification, evaluation, and comparison of the literature examined (Dalland, 2012). The literature review was mainly carried out in the preparatory project thesis using secondary literature. This thesis is based on the literature review considered as relevant to the research questions combined with the research results from the fieldwork in Tanzania.

The theory presented in the background chapters, both in the introduction chapter, study area chapter, and in the results chapters, is mainly retrieved from the WHO, UNICEF, UN, the World Bank, and publications by different bodies in the Tanzanian government. There are also used different reports and journal articles on the specific topics to investigate knowledge gaps previous to the fieldwork, and to validate or question results found in this thesis after the fieldwork was conducted. The literature has been found using both systematic searches and chain searches. Systematic search means search of literature in databases through subject-specific words, whereas chain search is to find new sources in the reference list of the primary source (Rienecker and Jørgensen, 2006). The databases used were Google Scholar, Oria, and Web of Knowledge. The most relevant keywords were: rural water supply, multiple-use water services, sustainability, groundwater, sub-Saharan Africa, and solar water pump. After trying different keywords with different search engines, a method for prequalifying literature was devised:

1. Assessment of title
2. Assessment of publication date
3. Assessment of the number of citations
4. Whether the publication is peer-reviewed
5. Reading abstract
6. Reading the conclusion
7. Assessment of the publication’s research method

Additionally, the previous Master's theses by Martinsen (2018) and Misund and Møller (2019) have been of great value both before and after the fieldwork was conducted. Their research was used in advance to the fieldwork to identify knowledge gaps and to prepare the fieldwork in terms of villages to visit and data collection methods to use. Furthermore, their research has been important in discussing the results found in this thesis.

Purpose: To provide foundation of knowledge on different topics, to identify knowledge gaps within existing research in order to justify the research within this thesis, to compare the research in this thesis with existing research to validate or question the results found, and to place the research in this thesis within the context of existing literature to identify areas of interest to be further investigated in future work.

3.4 Case Study

The case study method enables to closely examine the data within a specific context. A case study method often selects a small geographical area or a limited number of individuals as the subjects of study (Zainal, 2007). In this case, 15 villages within the Hanang, Mbulu and Mkalama districts in Tanzania are defined as the study area. The fieldwork was conducted from 28th of January 2020 to 24th of February 2020.

The case study method embraces the full set of procedures needed to do case study research. These procedures include designing the case study, collecting data during the case study, analysing the data, and presenting and reporting the results (Yin, 2011). The procedures used in this thesis are presented in Figure 3.1. As can be seen from the Figure 3.1, both qualitative and quantitative research are included in the case study.

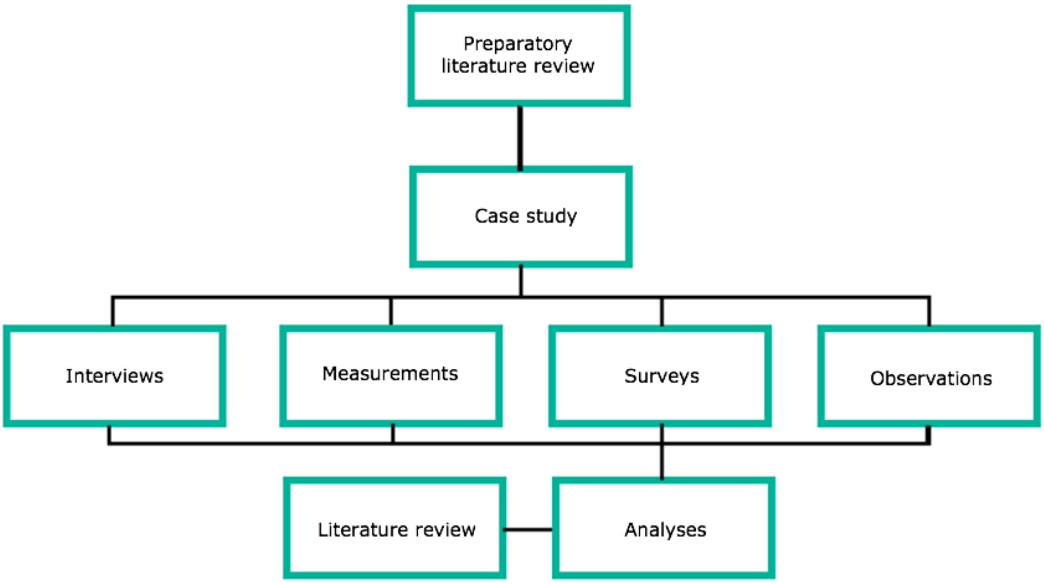


Figure 3.1: Framework of the Master's thesis, with procedures included in the case study.

Additionally, a "fieldwork diary" and logging of different measurements were written during the fieldwork which also can be seen as a procedure included in the case study. The research diary includes different parts of a fieldwork such as observations, thoughts and reflections, notes on methodology, unresolved problems, and plans for action. The different measurements were first logged in the field either in a notebook or on the cell phone and then logged in a clearly structured system at the computer at the end of the day as to allow for easy access to relevant data later on in the research period.

Purpose: To investigate different topics within the study area, address the reasons for the results, and to compare the results to preexisting theory.

3.5 Interviews with Key Stakeholders

The research interview is one of the most important qualitative data collection methods (Qu and Dumay, 2011). Interviews can take place in an individual or a group setting, called focus groups. In focus group interviews several people are utilizing for respondents interaction between participants which may create a chain of thoughts and ideas without the interviewer taking an active role in guiding the discussion. This type of interview has several advantages such as less bias is introduced by the researcher, convenience, and time savings (ibid). Another type of interview used in this thesis in the individual interview to get a deeper understanding on a specific topic. The type of structure used in the interview is considered as a mix of structured and semi-structured. Questions were pre-established and discussed with Sveinung Sægrov from NTNU and Manfred Arlt from the NCA before the fieldwork was conducted. Additionally, the questions were presented to 4CCP before the interviews were executed to avoid sensitive questions which can be a problem when conducting cross-cultural research (Wilson, 2014). However, the questions were updated during the fieldwork as the focus group interactions and input from 4CCP staff, Vibeke Brandvold, and Sveinung Sægrov led to new questions considered as valuable to the research.

We were at least three persons doing the interviews during the first three weeks of the fieldwork, in addition to a translator from 4CCP. The last week of the fieldwork, the number of interviewers were reduced to two persons. Due to the challenge of bringing the laptop in the field, the interviews were handwritten in a notebook and later transcribed. Additionally, the interviews were recorded on a cell phone application with the consent of the respondents. Having two sources of logging were considered as beneficial to minimize the data losses and to make the transcription of interviews easier and more complete. One of us had the responsibility of asking questions, whereas the other had the responsibility of logging the interview, as seen from Figure 3.2. In every interview conducted, inputs and follow-up questions from other than the one having the responsibility of asking questions occurred. This often clarified answers from the respondents and thus led to a more complete and detailed interview. See Appendices 4-8 for the updated interview questions. In total, 21 interviews have been conducted and transcribed in this study; 16 group interviews and 5 individual interviews.

Figure 3.2: Interview with water committee where one of us is having the responsibility of asking questions, and one recording the interview both in a notebook and on a cell phone application. Photo: Randi Sægrov.

3.5.1 Focus Group Interviews

The focus group interviews within this study include interviews with water committees, PETS committees, and 4CCP. The interviews with the water committees and the PETS committees were executed at the solar powered pumping systems (see Figure 3.2), whereas the interview with 4CCP was conducted at the last day of the fieldwork at their office in Haydom. The groups interviewed varied in size due to the availability of the members within the different groups. In general, the water committees consist of 11 to 14 members whereas the PETS committees consist of 8 to 12 members (Interviews with water committees and PETS committees, February 2020). 4CCP has 9 employees (Interview with 4CCP, February 2020). In some of the villages visited, approximately half of the members of the water committees and PETS committees were present, whereas in some villages almost all of the members were present. Often the chair-person, secretary, and treasurer of the committees were present. Additionally, the village executive officer and the caretaker and security guard of the water system often participated in the interviews. Two from the staff participated when conducting the interview with 4CCP; Eliminata Awet, the project coordinator at 4CCP, and Ahadi Mollel, a program manager at 4CCP.

The group interviews were designed to open up for a conversation and to utilize a flexible and exploratory discussion. Most often, the interviews with the water committees and PETS committees were combined, and in some villages the interviews were held separately. First, we introduced ourselves and the research study to the respondents to make the participants feel less apprehensive about what was to follow. The interviews were started with short and simple introduction questions and transitioned to more open questions at the end of the interview. It was observed during the interviews that men often were the ones answering the questions asked to the group. Women often had to be asked directly to answer in front of the rest of the respondents. According to 4CCP, this is due to cultural habits. Lastly, we showed our gratitude for the respondents' use of time and contribution, and the respondents were asked if they had any questions regarding the research study.

Purpose: To collect data and information from the users and other stakeholders of the water system. This is further used in analyses to get an overview of the water supply situation in the study area and to identify benefits, challenges, and improvement areas of the water systems. The feedback from both 4CCP and the different communities are considered as an important source of information to this thesis.

3.5.2 Individual Interviews

There were also conducted individual interviews during the fieldwork. The individuals interviewed include DWEs, DEDs, District Commissioners (DC), and principals or teachers at Munguli, Mewadani and Haydom schools in Hanang, Mbulu and Mkalama districts. The meetings with the DWE, DED and DC in Mbulu where held at their offices before the installations of the remote monitoring systems as the systems were to be installed within Mbulu district. The meetings at the offices of DED in Mbulu and Hanang and DC in Mbulu were more an introduction to the research study and associated fieldwork rather than an interview due to that the DC and DED were unavailable and meetings were held with people representing them. However, the meeting with the DWE in Mbulu was valuable and inspiring to both the fieldwork and rest of the study because of his positive attitude towards the project. Additionally, in-depth interviews were held with the DWE in Hanang and Mkalama districts and the DED in Mkalama district.

As for the groups interviews, the individual interviews started as a structured interview. However, the interview transitioned to a semi-structured interview as discussion or conversation between DED or DWE and 4CCP occurred several times during an interview. Most of the times the discussions were in English, but also discussions in Swahili arose. In addition, teachers and principals at Haydom Secondary school, Mewadani Primary school, and Munguli Primary school were interviewed. The same questions as for the water committees were used (Appendix 4).

Purpose: To gather specific information on a given topic and to introduce the project and associated fieldwork to stakeholders.

3.6 Participating Observation

Both Zachayo Makobero and Vibeke Brandvold were involved in the activities executed in the first week of the fieldwork. This was very instructive as one was able to observe how various measurements and installations should be carried out correctly. Additionally, Vibeke Brandvold has been doing a lot of fieldwork during her working career and her solution-oriented way of thinking when unforeseen things happened during the fieldwork was inspiring and also influenced the last weeks of the fieldwork as one had learned new ways of thinking. Furthermore, observing how staff from 4CCP met with different stakeholders was educational, and some polite and useful phrases in Swahili were learned and used further in the fieldwork when meeting with different stakeholders.

The last day of the fieldwork, a meeting with villagers in Dangayda village and 4CCP was held in Dangayda. In December 2019, representative members from the Dangayda village visited 4CCP offices and asked for help to access clean water in their village as their village is located 15 km from the nearest water source and thus people in the village are suffering. The meeting in Dangayda was held to identify the water situation in the village and to inform the villagers in Dangayda on what 4CCP expect from the villagers if a solar powered pumping system is installed in the area. This observation truly made a personal impression by experiencing how important access to clean and safe water is. Additionally, one got a holistic understanding on the implementation of the solar powered pumping systems and an insight on how the work is carried out by 4CCP in advance of the installations of the water systems.

Purpose: To gather information and attain a better understanding of the situation within the study area. The method is considered to have been an important source of insight and understanding.

3.7 Direct Observation and Measurements

Two kinds of direct observation and measurements were executed and are further presented: measurements in the borehole including bucket testing and groundwater level measures, and water quality measurements including the testing of pH, alkalinity, fluoride concentrations, conductivity, turbidity, and hydrogen sulphide producing bacteria.

3.7.1 Water Borehole Measurements

Bucket Test

Bucket tests were conducted at the majority of the solar powered pumping systems (Table 6.6) using a bucket of either 10 litres or 20 litres and a stop watch. Most often, the latter bucket size was used. The time to fill the bucket were logged in seconds to further calculate the water production provided by the well per day (Figure 3.3). Two or three bucket tests were conducted in every well tested. The bucket tests were executed just over the top of the well as seen from Figure 3.3.

Figure 3.3: Bucket testing to measure flow rate from the wells.

Purpose: To measure the flow rate provided by the well.

Groundwater Level – Pocket Dipper

The pocket dipper was used to measure the groundwater level and was provided by the NCA (Figure 3.4). This is a low cost, light weight, and portable tool and is designed and manufactured by a company called Groundwater Relief. One turns on the buzzer on the pocket dipper and lowers the pocket dipper down into the well using surveyor tape. When the buzzer reaches the water table, the sound is attenuated which allows the user to measure the depth of water table. It is a simple and smart concept, but the method was not optimal to use within the study area as the groundwater levels are general located quite deep, making it hard to hear when the pocket dipper reached the water table because the sound was already quite low even before it was attenuated by the water. On the January 31st, the pocket dipper was broken and measuring tape was further used to measure the groundwater level after Sveinung Sægrov brought it from Norway the 10th of February.

Figure 3.4: Pocket dipper to measure groundwater levels in the wells (Groundwater Relief, 2020).

Purpose: Measuring groundwater level in the wells manually at a given time.

Groundwater Level – Measuring Tape

The measuring tape used in the fieldwork was a KLL-light with 50 metres strip from SEBA Hydrometrie (Germany). The measuring tape is instrumented with a connected probe at the end that is lowered into the well. When the probe reaches the water, the electric circuit switches are sending back a signal which turns on the light and gives a sound signal from the casing of the measuring tape. The water level is then determined by reading the cable/measuring tape from the top of the well. This

Figure 3.5: Measuring tape with the light signal on the other side of the black casing.

method was considered as more accurate than the pocket dipper, particularly at deeper groundwater levels, as the sound signal came from the casing of measuring tape and not from the sensor lowered into the well (see Figure 3.5).

Purpose: Measuring groundwater level in the wells manually at a given time.

3.7.2 Water Quality Measurements

The equipment to measure fluoride concentrations, alkalinity, and hydrogen-sulfide producing bacteria were provided by the NCA. The equipment to measure pH, turbidity, and conductivity were borrowed from NTNU. The villages tested with associated measurements are presented in Table 5.1, Table 5.2, and Table 5.3. The tests in the wells, rainwater harvesting systems, and one from Endagulda spring (tap) were taken from the tapping point after the water had been running for approximately 30 seconds to 1 minute. The majority of the testing were done in the field, and some samples were stored in bottles and tested later the same day.

Purpose: To check if the water is of sufficient quality for drinking.

pH

From the 29th of January to 17th of February, a Multi 3630 IDS was used to measure the pH value. However, this tool was broken after a calibration and pH-paper was further used. To measure the pH using the Multi 3630 IDS, an IDS-pH sensor is connected to the meter and the pH measuring window is displayed. The IDS-pH sensor was immersed directly in the test sample, and the pH value was displayed. The IDS-pH sensor was cleaned with distilled water both before and after testing.

After the 17th of February, pH-paper was used to measure the pH value. The pH-paper is dipped in the water sample until the reactive part of the paper is saturated. The pH-paper is then compared by the colour change with the set of colours for specific pH-values (see Figure 3.6). The pH can only be measured in approximate whole numbers and thus this type of pH-test is less accurate than the IDS-pH sensor.

Figure 3.6: pH measurement using pH-paper.

Conductivity

The Multi 3630 IDS was also used to measure the conductivity, and the procedure is the same as for the pH test, using a IDS-conductivity sensor directly in the test sample. This sensor also measured the water temperature which was logged. The conductivity was measured in μS/cm and the IDS-conductivity sensor was calibrated once during the fieldwork.

Turbidity

The Hach2100Q IS Portable Turbidity meter was used to measure the turbidity values in the water sources within the study area. The representative sample was collected in a clean container which was used to fill sample cells to the line of about 15 mL. Further, the cell was capped, wiped with lens paper to remove water spots and fingerprints, and inverted in the cell compartment. The cell was turned so that a diamond mark was oriented with raised orientation mark in front of the cell compartment instrument. When the orientation of the cell was done and the lid was closed, the "read" button on the instrument was pushed to display the turbidity value. After use, the cells were cleaned with distilled water. The turbidity meter was calibrated once during the fieldwork.

Fluoride Concentrations

The Palintest Colour System was used to measure the fluoride concentrations. This is a colour matching and printing system using a manufactured Palintest disc and Palintest colour standards. Zicronyl Chloride and Eriochrome Cyanine R are reacted in acid solution to form a red colour complex. This colour is destroyed by fluoride ions and gives the sample a more yellow colour. Thus, different amount of fluoride concentrations show different shades of colour ranging from red to yellow, where red colour shows a low concentrations of fluoride whereas yellow colour shows a high fluoride concentration.

Two tablet reagents are used and mixed with the sample. First, a square test tube were filled with water from the water source to a 10 ml mark after "cleaning" the tube with water from the water source. Then the first tablet was crushed and mixed to dissolve, followed by the same procedure for tablet number 2. The colour produced after five minutes is measured by comparison against colour standards using a Palintest Comparator and Disc (see Figure 3.7). This is done by placing the treated sample in the right-hand side of the tube holder, and the colour from the disc on the left-hand side of the tube holder. The disc is hold against a source of light and turned until the two colours showing in the tube holder are equal. The fluoride concentration, measured in milligrams per litre F, is directly read from the colour disc (see Figure 3.7). After use, the tubes used for testing were cleaned with distilled water.

Since some of the tests exceeded the highest fluoride concentration on the coloured disc, being 1.5 mg/L, some of the samples were diluted. The samples were diluted with a factor of 2. A clean container, a squared test tube, and distilled water were used to dilute the samples. The clean container was first filled with 10 ml of water from the water source using the squared test tube. Then the squared tube was cleaned with distilled water to be further filled with 10 ml of distilled water. The distilled water was mixed with the water from the water source in the container. After mixing, the same procedure as described in the previous section was followed after the tube had been "cleaned" with the diluted sample water. Lastly, the fluoride concentration read from the colour disc was multiplied with the factor of 2.

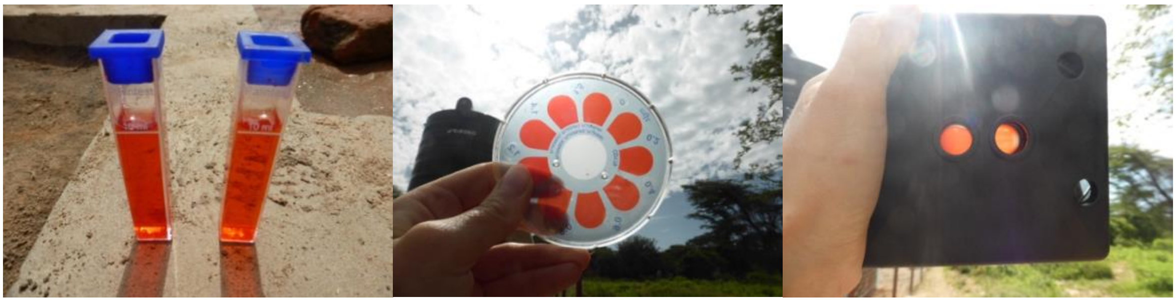


Figure 3.7: Measurement of fluoride concentrations showing the mixed samples (left), the coloured disc (middle), and the comparison of sample and disc (right).

Alkalinity

The alkalinity is measured by Palintest Colour System and the procedure is similar as for fluoride concentration measurements, but only using one tablet reagent. Under the conditions of the test a distinctive range of colours from yellow, through green, to blue are produced over the alkalinity range 0-250 mg/l $CaCO_3$.

A square test is filled with sample water to the 10 ml mark and added a tablet reagent which is crushed and mixed to dissolve. The sample can be compared with the coloured disc immediately. Some of the values exceeded the upper limit of the test (250 mg/l $CaCO_3$) and thus the same dilution procedure as for fluoride was conducted.

Hydrogen-sulfide Producing Bacteria

Nine water sources were tested for hydrogen-sulphide producing bacteria using the PathoScreen Field Test Kit from Hach. The test is for detection of Salmonella, Citrobacter, Proteus, Edwardsiella, and some species of Klebsiella in drinking water. The method in this thesis has been applied as in presence/absence with a 20 mL sample.

A clean tube is filled with 20 mL sample water. Then the PathoScreen Medium is added to the test and mixed by swirling the tube thoroughly. The PathoScreen medium has a detection sensitivity of 1 CFU/100 mL. If the colour changes from yellow to black or if black precipitate forms after 24 hours, the sample is positive for hydrogen-sulphide producing bacteria. If there is no change, the test is incubated for an additional 12-24 hours and examined again. If there is no colour change, the sample is negative for hydrogen-sulphide producing bacteria (see Figure 3.8). After the tests were done, the tubes were cleaned with a dilute bleach solution. All of the hydrogen-sulphide producing bacteria tests were done back at the HLH and not at the solar powered pumping systems. The tests were stored in room temperature.

Figure 3.8: Measurements of hydrogen-sulphide producing bacteria showing both positive tests (black colour or black precipitate) and negative samples (yellow colour).

3.8 Installment of Remote Monitoring Systems

A remote monitoring system consisting of different types of components was installed in Basonyagwe village, Endagaw Chini village, and Mewadani village during the fieldwork. The villages with their associating installed components are presented after a general description of the installments procedure, different components tested in the field and their purpose. All of the components are manufactured and provided by El-Watch, except from the pressure sensor in the well which is manufactured by GE Druck and provided by the Norwegian Geotechnical Institute (NGI), and the regulator and motorcycle battery which were bought in Haydom town in Tanzania. All of the sensors provided by El-Watch, called Neuron sensors, are small, robust, and energy efficient with a battery life up to 15 years. The sensors are connected to the Neuron Gateway which further communicates with Neuron’s cloud solution. The sensors and the gateways are quickly and easy connected to this system using a QR code on the components (see Figure 3.9) and an application on the cell phone (El-Watch, 2020).

3.8.1 Preparatory Workshop

There were in total three workshops before the fieldwork was conducted. Workshop as a research method aim to produce reliable and valid data about the topic in question regarding forward-oriented processes. The workshop is a qualitative research method where stakeholders of different organisations with the opportunities to collaborate with one another in learning about a particular topic (Ahmed and Asraf, 2018). The workshops were done in collaboration with Hallvard Helgetun and Gard Hansen from El-Watch, and Sveinung Sægrov and Endre Våland Bø from NTNU. The first workshop was held in November where the aim was to identify and determine possible sensors to install, learn how the sensors worked, and how to install them during the fieldwork. The second workshop was held in January, where the sensors and other components that were to be installed in Tanzania mostly were determined. The aim was then to learn how to install the different components together. In the last workshop, held the day before the fieldwork started, Endre Våland Bø gave a briefing on how the components should be correctly connected.

Purpose: To determine possible components to install during the fieldwork, learn how they work, and learn how to correctly install and connect them together to further install a successful remote monitoring system within the study area.

3.8.2 Components

Gateway

The Neuron Cellular Gateway (Figure 3.9) is a data transmission unit which receives and sends data wirelessly via an encrypted link to the cloud. Measurements are transmitted from the Neuron sensor to gateway at 868 MHz and uploaded online via mobile network. The gateway selects the mobile network provider with the best signal in the particular area where it is located, and thus ensures more uptime. No SIM card or custom configuration is required since the gateway comes fully configured and is equipped with eSIM. The gateway connects automatically to Neuron's servers. The range between sensors and gateway varies and is influenced by walls and type of materials (El-Watch, n.a.).

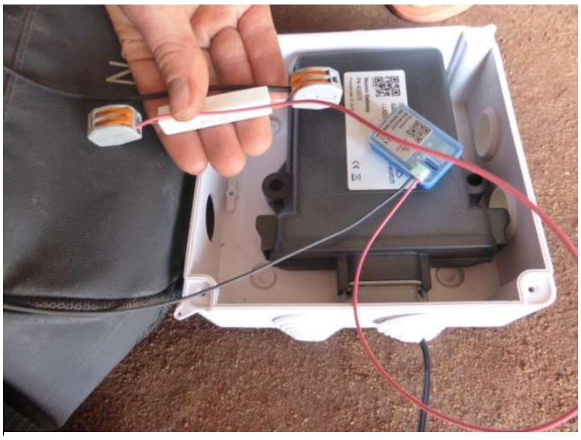


Figure 3.9: Gateway (black component), current digitizer (blue component), and cable with resistance.

Purpose: Transmit the measured data from the Neuron sensors to the cloud.

Pressure Sensor in the Well

The pressure sensor used in the well is from the UNIK 5000 series. The sensor model is PTX5032 and is a submersible pressure sensor transmitter, with a 100 metres long polyurethane ventilated cable, 4-20 mA pressure transmitter, and has two conductors (Tormatic AS, 2020). The pressure range is from 0-100 metres with a 7-32 volt supply. The sensors draw little power due to a setting made by the NGI making the sensors go into hibernation between each measurement and are only turned on to make a registration (Vibeke Brandvold, personal communication, 23rd of January 2020).

The pressure sensor in the well senses the pressure in terms of water column over the pressure sensor and converts it into an electrical signal where the magnitude depends upon the pressure applied (Figure 3.10). The sensor was installed at 69 metres below the top of the well in Mewadani village and 70 metres below the top of the well in Basonyagwe village.

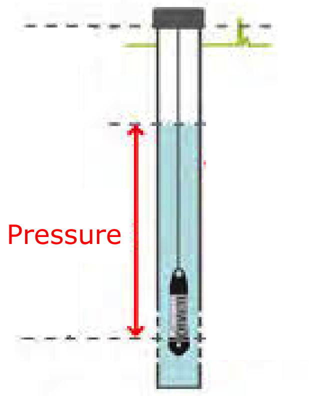


Figure 3.10: Groundwater level measurement by the pressure sensor in the well. Modified from (Schlumberger, 2007).

Purpose: To measure the groundwater levels in the well.

Pressure Sensor in the Water Tank

Neuron Pressure Sensor measures the pressure similarly as the pressure sensor in the well, but the measurement unit is Bar. The measuring range is 0-2 Bar and the resolution is 0.13 Bar. The absolute accuracy is ±2.5 mBar depending on the temperature (El-Watch, n.a.). The sensors were installed 1.4 metres, 1.2 metres, and 1.5 metres below the water tank in Basonyagwe village, Endagaw Chini village, and Mewadani village respectively (see Appendix 9-11). The pressure sensor is installed directly in the outlet pipe under the valve between the water tank and tapping point in all three of the villages due to operational issues.

Purpose: To measure and monitor the volume of water in the water storage tanks remotely.

Digitizer – Current

The Neuron Wireless mA Digitizer digitizes existing measurement data to the Neuron's cloud. The sensor comes with a 40 cm long cord and connects to existing or new sensors with that have an output of 4-20 mA (ibid). In this case, the digitizer is connected in series to the output signal from the pressure sensor in well. The digitizer sends the output signal ranging from 4-20 mA from the pressure sensor to the cloud, where the corresponding maximum and minimum values are set. The minimum output of 4 mA corresponds to 0 water column above the pressure sensor, and the values are converted using linear interpolation to the maximum output from the sensor of 20 mA which corresponds to 100 water column above the pressure sensor in the well.

Purpose: To digitize the signals from the pressure sensor in the well in order to monitor the groundwater levels remotely.

Digitizer – Voltage

Neuron VDC Digitizer is similar to the Neuron mA Digitizer, but receives and sends data in voltage instead of current. The sensor also comes with a 40 cm long cord and connects to existing or new sensors that have an output of -30 VDC to +30 VDC (ibid). In this case, the VDC Digitizer is directly connected to the battery, further presented below, and thus sends the voltage available on the battery to the cloud. When the voltage available on the battery is known, the approximate amount of power available is known, and thus one can check if the regulator and solar panels are working properly (Endre Våland Bø, personal communication, 20th of February 2020).

Purpose: To digitize the signals from the battery to check remotely if components such as battery, solar panels, and regulator are working properly.

Vibration Sensor
Neuron Vibration Basic is a wireless sensor that detects vibration, change in vibration and measures temperature of the object measured. The sensor is attached to the object to be measured using the embedded magnet. The measuring range for vibration is 0-12 g rms acceleration (sum of X, Y, and Z axis) and the resolution is 0.001 g. Regarding the temperature, the measuring range is -40 to 85 degrees Celsius and the resolution is 0.1 degrees Celsius (El-Watch, n.a.).

Purpose: To remotely monitor the condition of the pump and uptime of the system.

Surface Temperature Sensor
Neuron Temp Surface Sensor is a wireless sensor measuring surface temperatures of desired components. In this case, the sensor was installed to measure the surface temperature of the outlet water pipe to detect when water was running through the pipe. The measuring range is -40 to 85 degrees Celsius and the accuracy is 0.5 degrees Celsius. The measuring frequency is every 3 seconds and the transmitting frequency is every 2 minutes (ibid). The sensor was attached to the water pipe using plastic strips.

Purpose: To detect when water was running though the outlet water pipe.

Power Supply
The gateway requires electricity to work. Thus, a small solar panel and a battery has been installed in each of the pumping stations. The battery is a 12V motorcycle battery with 9AH. The 4 Watt solar panels are provided by El-Watch. The sensors installed have internal batteries which last up to 15 years, and therefore they do not require power supply.

Purpose: To supply the remote monitoring system with power to transmit data continuously.

Regulator
The regulator connects the solar panel, the battery, and the gateway. It makes sure that the battery is not over charged by the solar panel during the day, and that power does not run backwards from the battery to the solar panel during the night.

Purpose: To ensure a stable energy transfer within the system.

3.8.3 Installment Procedure

The installment of the remote monitoring systems in the three villages within the study area were done in collaboration with Zachayo Makobero, staff from 4CCP, members of the water committees, and other villagers. Klas Brodtkorb, a plumber from Norway also visiting HLH, helped with the installations of the pressure sensors in the water tank. Hallvard Helgetun from El-Watch and Endre Våland Bø from NTNU, located in Norway at the time of installations, were also very helpful and accessible. Most parts of the remote monitoring systems were installed during the first two weeks of the fieldwork. An overview on how the remote monitoring systems are installed and connected are shown in Figure 3.11. All three of the systems are installed similarly. The only exception is Endagaw Chini village. The remote monitoring system in Endagaw Chini does not have a pressure sensor in the well or current digitizer sensor. Only the gateway is installed on the right side of the regulator in Endagaw Chini village.

The pressure sensor in the well was disinfected using chlorine the day before installation. Before it was installed in the well, the sensor and cable were cleaned in the water from the tap at the solar powered pumping system.

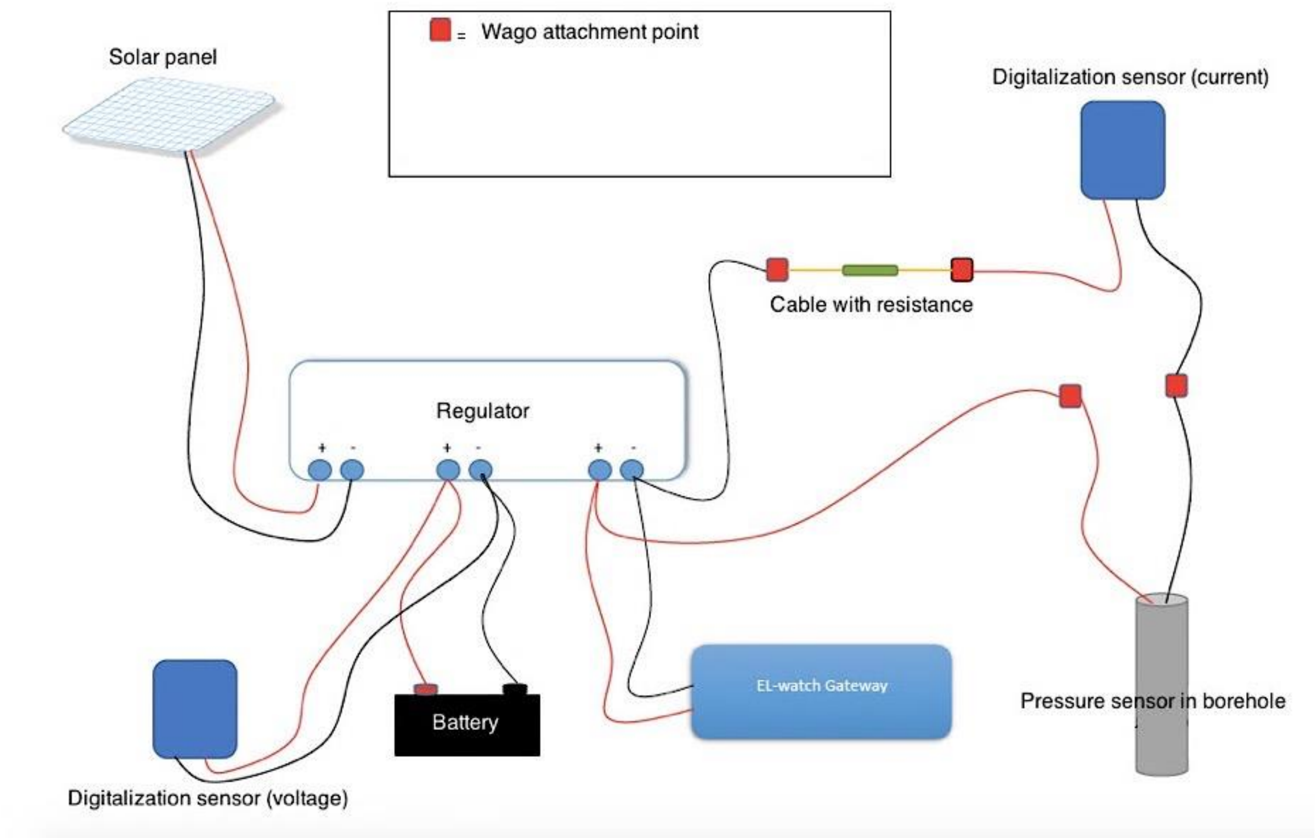


Figure 3.11: Overview on how the remote monitoring systems are installed and connected. Made by Endre Våland Bø (NTNU).

All of the sensors and other components were placed out of reach to prevent vandalism. The gateway, digitizers, battery, and cable with resistance were locked in a wooden box installed under the solar panels. This was to protect the equipment from the sun and rain. The box material was chosen to minimize the risk of disruption of the mobile signal. This has previously proved to cause problems if metal boxes are used (Martinsen, 2018). The gateway and the current digitizer were further placed in a plastic box inside the wooden box for extra protection (see Figure 3.9 and Figure 3.12). An overview over the three villages with associated components installed and pictures of the system are shown in Appendix 9-11.

The pressure sensor in the water tank is protected by either a wooden box or a plastic tub (see Appendix 9-11). There are two sets of keys to the wooden box; 4CCP has one set of keys, and the water committee has the other set of keys.

Figure 3.12: Inside of the wooden box (left). The wooden box was locked and installed under the solar panels in protection from sun and rain (right).

3.9 Survey

A survey using questionnaires is a method of data collection that comprises a set of questions designed to generate data for achieving the objectives of a research project. Surveys can be used to gather both qualitative and quantitative data (Wilson, 2014). The surveys have been an important source of information in this thesis. The data collected from the surveys are mainly used to identify several factors regarding the water situation within the study area, to investigate benefits and challenges regarding multiple-use water services, and in the analysing of the willingness to pay for water services.

The method for data collection was a direct customer survey using a structured questionnaire. The questions are similar as in the survey designed by Misund and Møller (2019) as one of the main purposes of the surveys is to compare the results in this thesis with the results found by Misund and Møller (2019). Further questions regarding multiple-use water services are added. See Appendix 12 for the updated version of the questions included in the survey.

The surveys were conducted at the solar powered pumping systems. Thus, the respondents are members of the water committees, PETS committees, workers at the water systems, and other villagers that were present. Due to time-related issues, the surveys were conducted by either Ahadi Mollel or James Mmbando from 4CCP. Since the surveys were in English, Ahadi Mollel and James Mmbando had to translate the questions to Swahili. In total, 87 surveys were conducted within the study area.

After the fieldwork was completed, the surveys were transferred manually to a digital tool called easyQuest. Thus, the data from the surveys are stored in a structured system and one can choose to make reports using a tool in easyQuest that are automatically generated online, or the data can be exported to Microsoft Excel. Both methods were used in this thesis.

3.10 Calculation of Flow Rates

The calculations of water productions are found by using flow rate calculations and mainly done by Maria Asklund. To find the flow rate a pump will deliver, it is necessary to plot both the pump characteristic and system characteristic in the same graph. The intersection of the system curve and the pump curve is called the operating point and is the point at which the pump must be operated. The operating point with associated flow rate and pump head is shown in Figure 3.13.

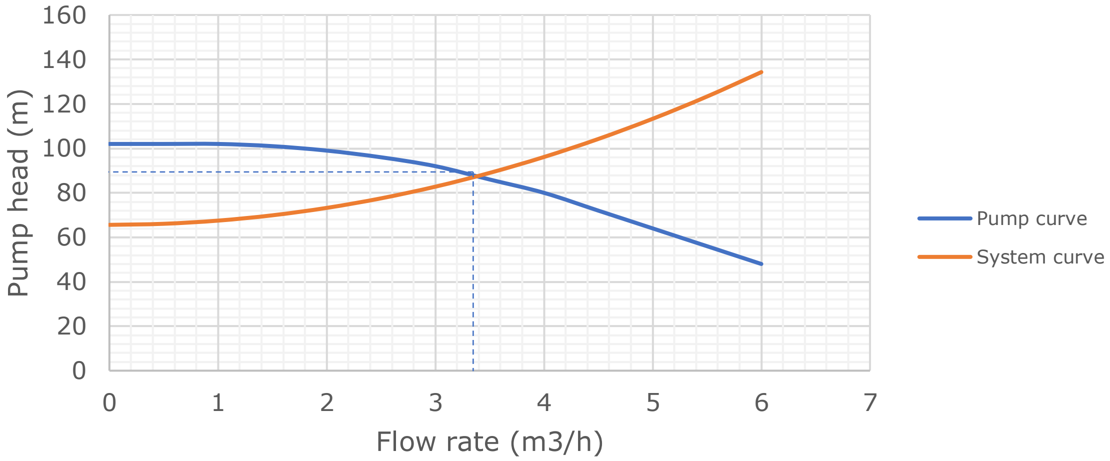


Figure 3.13: Pump curve and system curve of a water system within the study area, with associated operating point (intersection of the curves).

The pump curve is given from the manufacturer of the pump, which in this case is Dayliff. The pump curves vary with pump types. An overview on different pump types within the study area is given in Table 6.5 and Appendix 3.

The system curve must be calculated in each of the water systems using the formula for total head loss (H_T). Total head loss will be the sum of static height (h_h), singular head losses (h_s) and friction head losses (h_f).

Equation 3.1: Total head loss

$$H_T = h_h + h_s + h_f \tag{3.1}$$

The static height is the distance from the level of water in the well during pumping, or the dynamic water level (DWL), to the inflow of the water storage tank (see Figure 2.6). The singular head losses must include all losses in bends, valves, and water metres. The friction head losses in the pipes are calculated with the Darcy-Weisbach formula.

Equation 3.2: Singular head loss

$$h_s = k_s * \frac{v^2}{2g} \tag{3.2}$$

The singular losses increase with higher water velocities (v) and singular head loss coefficients (k_s). The singular head loss coefficients can be found in Appendix 13 and are determined from Engineering Toolbox (2004).

Equation 3.3: Darcy-Weisbach

$$h_f = f * \frac{L}{D} * \frac{v^2}{2g} \tag{3.3}$$

The different values for the friction head loss coefficients and lengths and diametres of water pipes can be found in Appendix 13. Additionally, Appendix 13 shows the calculated flow rates and associated system curves and pump curves.

3.11 Limitations

One of the main limitations during the fieldwork was the need of translation and the associated language barrier. Since all of the translation were done by 4CCP from English to Swahili and vice versa, some of the information may have been slightly altered or even lost during the translation process. Especially when a discussion amongst respondents in Swahili during interviews occurred, valuable data may have been lost even though the staff from 4CCP summarised the discussion afterwards. Additionally, different language and culture may give different associations and meanings to different words or ways of expression. The language barrier was also observed during the execution of the survey. The time used to conduct the survey was prolonged which resulted in 4CCP having the whole responsibility of the survey as other measurements at the solar powered pumping systems needed to be done within a given timeframe. However, the staff from 4CCP asked us for clarification several times. Furthermore, the translation of every question led to the survey often being completed in a group rather than individually which may have affected the results. Another challenge regarding the survey occurred when the questions in the survey were not a multiple choice type of question, but required a short written answer.

As previously mentioned, it was observed that men often were the ones answering the questions asked to the group during interviews. Women often had to be asked directly to answer in front of the rest of the respondents. This was not discovered until the end of the fieldwork, when Ahadi Mollel pointed it out during an interview and suggested to ask the women questions directly. This could have been considered from the beginning of the fieldwork, and valuable information may have been unintentionally let out.

There were some limitations regarding the water quality measurements. Due to limited time and weather conditions, some of the water samples had to be stored in a water bottle and brought back to HLH to be measured in the evening. It would have been optimal to measure the water quality parameters right after tapping due to that the water bottle was stored at relatively high temperatures before testing which may have led to some uncertainties. Additionally, the hydrogen-sulphide producing bacteria tests should be stored at constant temperature which was not always possible to obtain due to the rooms at HLH being easy equipped with no air condition. The day and night room temperatures varied significantly. However, the tests were stored for an additional 12-24 hours to compensate for the temperature variations. To clean the tubes after testing was also a challenge because of the limited access to distilled water. The tubes were first cleaned by using water from the tap and soap and then disinfected with diluted bleach. Nevertheless, the cleaning procedure may have led to some false positive results.

The Palintest Colour system to measure the alkalinity and fluoride concentration was not optimal as it is largely based on subjective assessments. Thus, the tests can be affected by human interpretation and potential errors, particularly in the measurements of the fluoride concentrations as the colour shades representing different fluoride concentrations are quite similar (see Figure 3.7). At least two persons executed the comparison of colour disc and water test colour to reduce the risk of human interpretation and potential errors.

Furthermore, the timeframe and the fact that the measurements and other data collection were executed in a different continent are considered as one of the main limitations of the study. While analysing the collected data, it has been revealed that some data advantageously should have been collected during the previous fieldwork. This is both to fill in for missing data, and to validate results. For example, the remote monitoring system has shown an increase in groundwater levels in Basonyagwe village and Mewadani village due to seasonal variations. This could easily been measured, but was of course not possible.

At the time when the fieldwork was conducted, there was a relatively high access of water. Thus, measurements at the most critical time of year, being during the dry season, would have been preferred. Additionally, the validity of the collected data and whether is it sensible to draw conclusions due to the number of villages visited with associating respondents in the study is limited. As stated by Misund and Møller (2019, p. 34); "*this should however not be read as a way of downplaying our work and findings, but rather as a call for and encouragement to conduct further research*".

4 Remote Monitoring

This chapter shows and discusses the results from the remote monitoring systems installed during the fieldwork. First, background information and a short summary of previously installed remote monitoring systems within the study area are presented.

4.1 Background

Remote monitoring systems allow manufacturers and service providers to remotely manage, service, and analyze solar water pumping systems in isolated and remote locations (Khare and Economu, 2019). Remote monitoring systems may help address challenges in reliability of water supplies through enabling greater accountability and responsiveness of cognizant service providers (Nagel *et al.*, 2015). The use of these types of systems to monitor rural water supply is on the increase and is driven by several factors. Firstly, during the last years there has been an expansion of mobile networks into rural areas which has made remote monitoring more viable. The Internet penetration rate in Tanzania has more than doubled from 21 percent in 2013 to 46 percent in 2019 (O'Dea, 2020). Second, advances in the Internet of Things are leading to both faster and cheaper data, and new ways of thinking. Lastly, the general reduction in the cost of electronics is enabling the development of low-cost devices, and improvements in performance particularly regarding the power consumption (Thomson, 2018).

A typical remote monitoring system consists of field sensors and controllers, basic hardware consisting of relays, integrated circuits, and power electronic components, and a communication module that communicates with a host machine, or back-end applications. The systems can provide useful information to stakeholders such as solar system voltage, current, usage, and total water output (Khare and Economu, 2019).

As of 2005, the Ministry of Water had a database of 9242 drilled boreholes (Baumann, Ball and Beyene, 2005). It is estimated that at least 26406 boreholes are available in Tanzania in 2018 (Lufingo, 2019). Thus, groundwater is an important water source in Tanzania supplying more than 25 percent of the domestic water consumption and is the main source of water for most rural water systems and municipalities (Kashaigili, 2010). Increased groundwater abstractions are causing increasing problems, both from a quantitative and qualitative point of view. In Mbulu district, there have been problems with increase in the salinity of groundwater due to over-abstractions from the source (Interview with DWE at his office, February 2020). Kashaigili (2010) mentions the lack of data, the lack of groundwater monitoring networks, and the lack of groundwater/resource management plans as problems related to the groundwater abstraction in Tanzania. He further states that increased climate variability and change, bringing about certainty in terms of rates of replenishment, may be a future problem (ibid). In rural areas, where only limited surface water supplies are available for villages, groundwater plays a critical role in meeting water requirements. Thus, there is an increasing need for sustainable development of groundwater sources. Having a monitoring system of groundwater levels in rural areas that can be accessed remotely can potentially increase the sustainability of the water system.

4.1.1 Remote Monitoring Systems Developed by NCA

The NCA wants to better the sustainability of the rural water schemes through remote monitoring. The availability of standardized remote monitoring products on the market has been limited. Thus, the NCA tried to develop their own system. Field tests have been carried out by Alexander Klein and Håvard Aagesen in Tanzania to evaluate the feasibility of the system. The system includes a Ardiuno microcontroller that uses electricity. The microcontroller is able to read, store locally and send the signals measured in the water flow sensor. A power bank or battery receives power from a solar panel and provides power to the system when there is no sun. A SIM card can be added to the system to transfer data over the mobile network. In addition, the system has a screen that displays the measured values. The idea is that the device should be connected to different sensors depending on what is favorable to measure. A code is programmed depending on the parameter to be measured (Alexander Klein, personal communication, 15th of October 2019).

In 2018, Rebecca Martinsen and the NCA installed this type of system at a solar powered pumping system in Munguli and on a handpump in Gidurudagew in Tanzania to remotely measure and monitor the water flow through a pipe to further calculate the consumption of water per person per day (Martinsen, 2018). The solar panel was installed on an elevated spot with a favorable tilt angle in accordance to the sun. The reading and transmitting system was placed in a locked metal box. The system installed in Munguli logged and transferred water flow data, but with incorrect values. Martinsen (2018) argues that this was due to failure with the sensor itself or with the connection between the sensor and the reading and transfer system. The system in Gidurudagew only delivered values locally, and with wrong date and time of measurements. A possible reason mentioned for the non-transferal of data was that the system was placed inside a metal box which disrupted the mobile signal (ibid).

In May 2018, Alexander Klein from the NCA implemented a new version of the system. The new version had a built-in GSM module and the possibility of having an external antenna outside the box. However, the transferal of data remained a problem, even with the box containing the reading and transfer system left open (ibid). Martinsen (2018) argues that this may be due to the combination of hardware and software which caused lagging of the system. Thus, further work needs to be done to install and implement a system that successfully transmits measured data online from water schemes in the rural areas of Tanzania.

4.1.2 Remote Monitoring Systems Installed During the Fieldwork

The majority of the components included in the remote monitoring systems were installed during the first week of the fieldwork. Three villages within the study area were chosen based on the relatively good mobile network connection; Basonyagwe village, Endagaw Chini village, and Mewadani village. Components installed in the remote monitoring systems during the fieldwork and provided from El-Watch are pressure sensors in the water tanks, digitizers, temperature sensors, vibration sensors, and gateways. In addition, UNIK 5000 pressure sensors provided by NGI and manufactured by GE Druck were installed in two of the wells. A detailed operating procedure of the installment of the remote monitoring systems and the components of the systems are presented in chapter 3.8.

4.2 Results

4.2.1 Pressure Sensor in the Well

The user interface provided by El-Watch shows the converted data received from the current-digitizer as water column above pressure sensor in the well. In the figures presented in this chapter, the groundwater level data are converted to metres below top of the well to visualize the groundwater levels in the two wells. In addition, the neuron sensor user interface shows a minimum value, a maximum value, and a middle value for each measurement. The figures presented in this chapter show the middle values.

Basonyagwe Village

Figure 4.1 shows the groundwater level fluctuations during a month, whereas Figure 4.2 shows the groundwater level variation during a week.

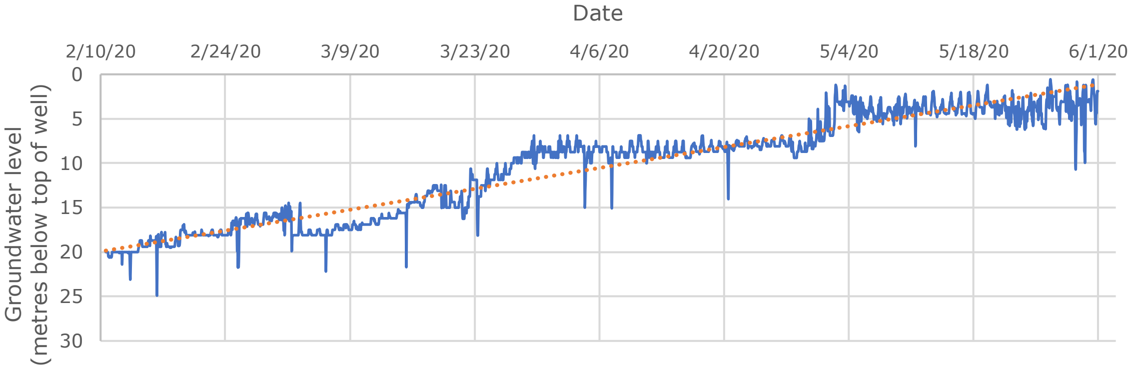


Figure 4.1: Groundwater level fluctuations from the middle of February to the beginning of June in Basonyagwe village.

Figure 4.1 shows large variations in groundwater level from the middle of February to the beginning of June 2020. The groundwater level falls to a level of 24.9 metres below the top of the well at the lowest on 16th of February 08:00. The highest groundwater level is found to be 60 cm below top of the well the 31st of May. In addition, Figure 4.1 shows a general increase of the groundwater level from the middle of February to the begging of June.

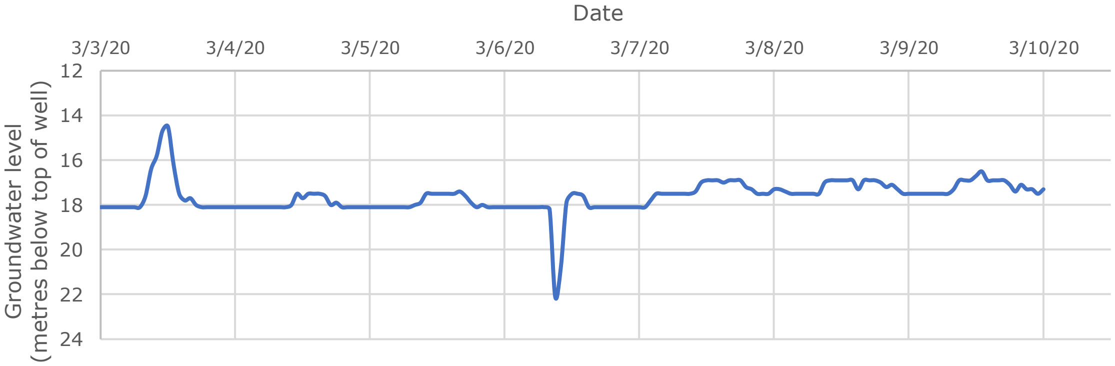


Figure 4.2: Groundwater level fluctuations during a week in Basonyagwe village.

Figure 4.2 shows a relatively stable groundwater level of 18 metres below top of the well from 3rd of March to 7th of March. On the 7th of March, the groundwater level varies between 17.5 and 17 metres below the top of the well and there is no clear level where the groundwater stabilises. During the week, the groundwater level peaks with a value of approximately 14.5 metres below top of the well around 12:00 the 3rd of March and falls to a stable level after three hours. In addition, there is a lowering of the groundwater level at 08:00 on the 6th of March to approximately 22 metres below top of the well. After one hour, the groundwater rises to a level higher than the level before the lowering and stabilises at 16:00.

Mewadani Village

Figure 4.4 shows the groundwater level variations during a week, whereas Figure 4.3 shows the groundwater level variation during a month.

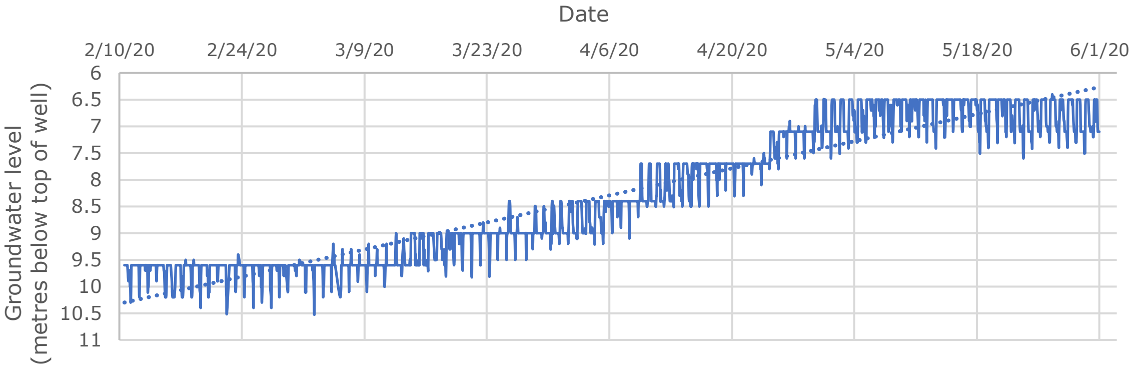


Figure 4.3: Groundwater level fluctuations from the middle of February to the beginning of June in Mewadani village.

Similarly to the well in Basonyagwe (Figure 4.1), the groundwater level rises from the middle of February to the beginning of June. There is a relatively stable groundwater level of 9.6 metres below the top of the well from the middle of February to the beginning of March, whereas at the end of April to the beginning of June the groundwater level is stabilized around 6.5 metres below top of the well. The lowest groundwater level is found at 10.5 metres below the top of the well on the 3rd of March at 09:00. The highest groundwater level is found at 6.4 metres below the top of the well on 26th of May at 17:00.

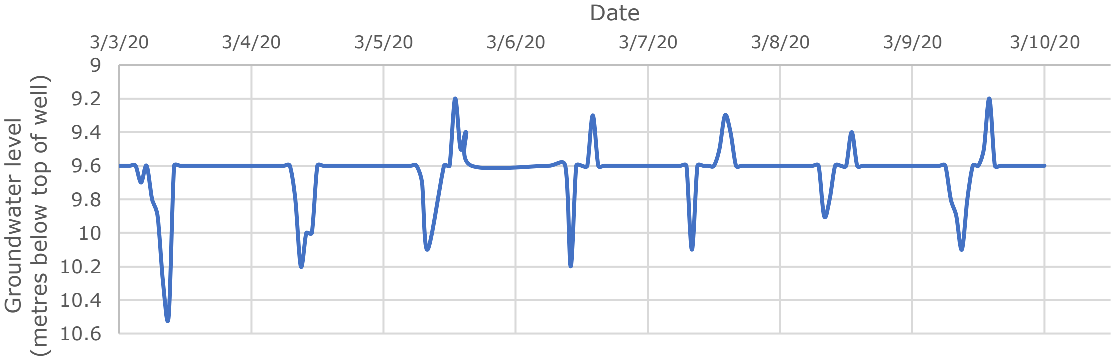


Figure 4.4: Groundwater level fluctuations during three days in Mewadani village.

Figure 4.4 shows a more repetitive pattern in the variations of groundwater level in Mewadani village compared to in Basonyagwe village (Figure 4.2). There are minimum values every day between 08:00 to 10:00. From the 5th of March, the minimum values are followed by a peak value. The highest groundwater level during the week is on the 9th of March at 14:00, located at 9.2 metres below top of the well. The lowest groundwater level is found at 10.5 metres below the top of the well on the 3rd of March at 09:00, similarly as in Figure 4.3.

4.2.2 Pressure Sensor in the Water Tank

In Basonyagwe, both of the water storage tanks are in use, whereas in Endagaw Chini and Mewadani only one of the tanks is in use. The figures presented in this chapter represent one water storage tank. Since the pressure sensor is installed under the valve between the water tank and tapping point in all three of the villages, the pressure will be equal to the air pressure when the valve is closed and the pipe from the valve to the tap is empty. When the valve opens, the water pressure depends on whether water has been pumped into the storage tank during the time the valve has been closed. If no water has been pumped, the water pressure is the same as it was before the valve was closed. If water has been pumped, the water pressure is higher than it was before the valve was closed. This can be seen from Figure 4.5, Figure 4.6, and Figure 4.7 and will be further discussed. Similarly as in the previous chapter, the middle values are used in the figures presented within this chapter.

Basonyagwe Village

The maximum water level for one water storage tank in Basonyagwe village is 2.4 metres which is equal to 9.1 cubic metres. As seen from Figure 4.5, this maximum water level is far from reached from 24th of April to the 30th of April. This is most likely due to the fact that both of the water storage tanks are in use. There are several rapid changes where the water pressure falls to zero. This may indicate that the valve is closed several times during the six days of measurements. The water volume reaches 2.9 cubic metres at the highest.

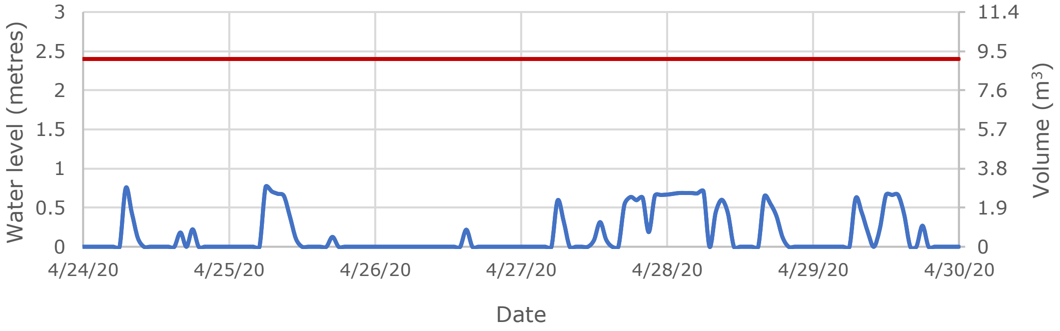


Figure 4.5: Water level and volume in the water storage tank in Basonyagwe village.

Endagaw Chini Village

In Endagaw Chini village, the water storage tanks are smaller than the water storage tanks in Basonyagwe village and Mewadani village. The maximum water level for one water storage tank in Endagaw Chini village is 1.8 metres which is equal to 5.1 cubic metres. As seen from Figure 4.6, the maximum water level is reached, and even exceeded, several times. This indicates that the water tank has been full several times from the 10th of April to the 16th of April. In addition, the water pressure rapidly falls to zero similarly as in Basonyagwe village, indicating that the valve has been closed several times.

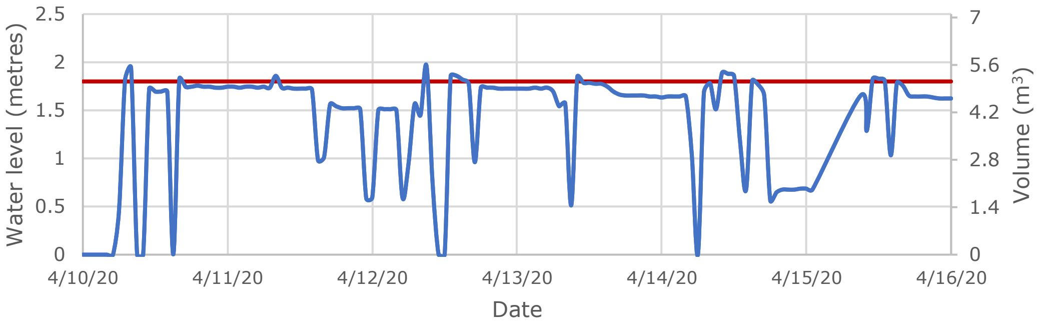


Figure 4.6: Water level and volume in the water storage tank in Endagaw Chini village.

Mewadani Village

The water storage tank in Mewadani village is of equal size as in Basonyagwe village, and has the same maximum water level of 2.4 metres which is equal to 9.4 cubic metres. As in Endagaw Chini, the maximum water level is reached, and exceeded, several times from 10th of April to 16th of April. As Figure 4.7 indicates, the valve has most likely been closed once during the six days, where the water pressure rapidly falls to zero and reaches a value of 3,1 cubic metres one hour later.

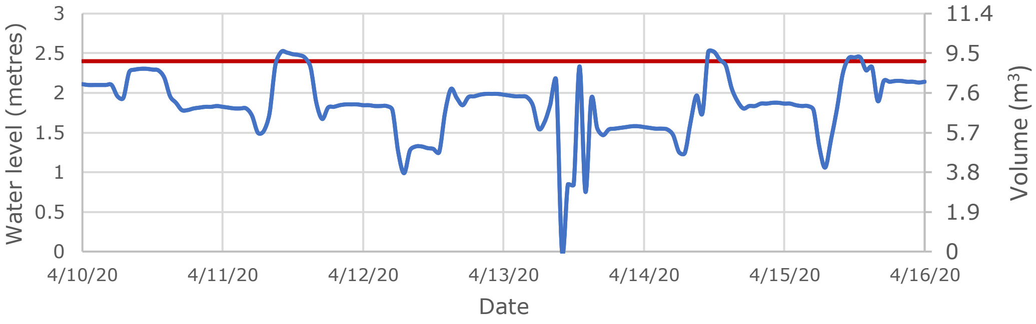
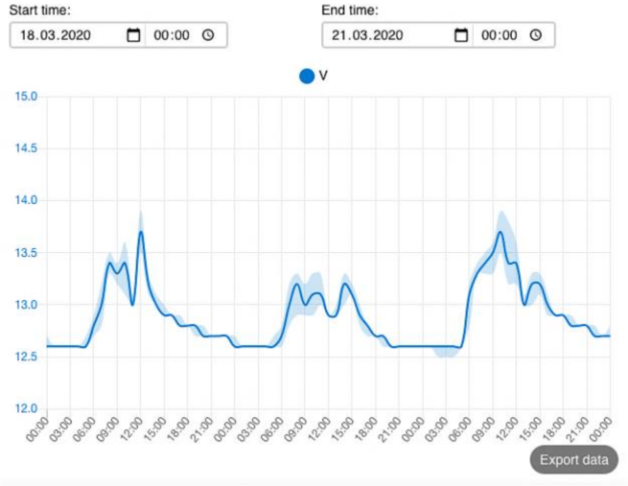


Figure 4.7: Water level and volume in the water storage tank in Mewadani village.

4.2.3 Digitizer – Voltage

As previously mentioned, the voltage digitizer is directly connected to the battery and sends the available battery voltage to the cloud. In the figures presented in this chapter, the dark blue line represents the middle values whereas the light blue coloured areas represent the minimum and maximum values. Thus, the light blue coloured areas show the uncertainties of the measured values. The figures are retrieved from the user interface: neuronsensors.app.


Start time: 18.03.2020 00:00

End time: 21.03.2020 00:00

Figure 4.8: Available battery voltage in Basonyagwe village.

Basonyagwe Village

There are variations of the avalable battery voltage in Basonyagwe village, as seen from Figure 4.8. The voltage rises from 12.6V to 13.7V around 05:00 (07:00 Tanzanian time) when the sun most likely rises and supplies power to and charges the battery. The available voltage falls to 12.6V 00:00 (02:00 Tanzanian time) and 20:00 (22:00 Tanzanian time) on the 18th and 19th of March respectively.

The available battery voltage in Basonyagwe village is never below 12.6V during 18th to 21st of March.

Endagaw Chini Village

As Figure 4.9 shows, there are relatively large variations of available battery voltage within short time intervals in Endagaw Chini village. Similarly as in Basonyagwe village, the voltage rises around 05:00 (07:00 Tanzanian time) every day from 18th to 21st of March. However, the voltage rises to a higher value than in Basonyagwe village, to a maximum value of 14.5V. The available voltage falls to 12.8V at 01:00 (03:00 Tanzanian time) every day from the 18th to the 20th of March.

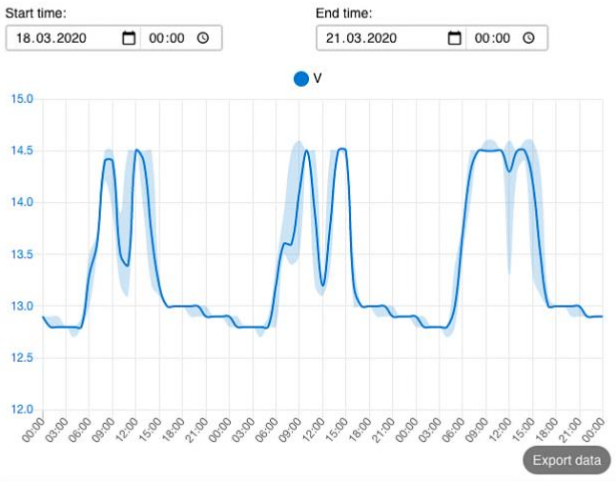


Figure 4.9: Available battery voltage in Endagaw Chini village.

The available battery voltage in Endagaw Chini village is never below 12.8V during 18th to 21st of March.

Mewadani Village

In Mewadani village the middle curve has relatively low minimum values. As seen from Figure 4.10, the minimum level measured is 10.3V the 18th of March at 06:00 (08:00 Tanzanian time). The pattern of low minimum values repeats around the same time of the day from 18th to the 20th of March. The highest value measured during the three days is 14.6V on the 20th of March at 12:00 and 14:00 (14:00 and 16:00 Tanzanian time).

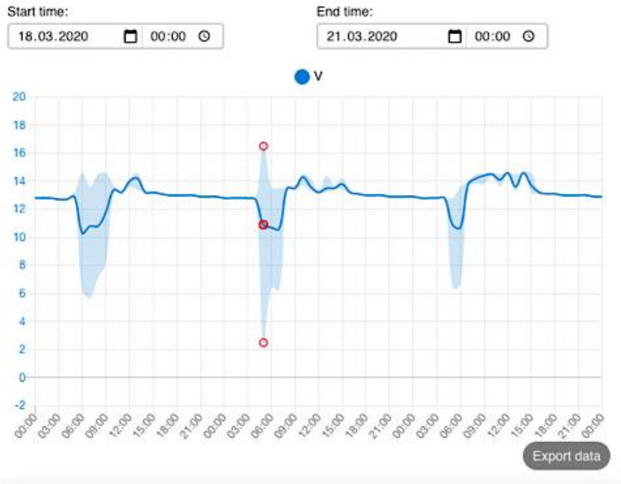


Figure 4.10: Available battery voltage in Mewadani village.

In addition, there are large uncertainties in the measured voltage compared to in the two other villages. The largest uncertainty range is found on the 19th of March at 05:00 (07:00 Tanzanian time), with a minimum value of 2.5V, a maximum value of 16.5V, and a middle value of 10.9V. The values are shown as red circles in Figure 4.10. The other time intervals of large uncertainties, shown as light blue areas in Figure 4.10, are found to be at approximately the same time of the day at the 18th and the 20th of March.

4.2.4 Vibration Sensor and Surface Temperature Sensor

As seen from Figure 4.11, there is minimal variation in the vibration values measured from 18th of February to 21st of February. In addition, there are time-intervals during the

three measurement days where no vibration data are transmitted online. The vibration measurements in Endagaw Chini and Mewadani were also nearly constant.
The temperature measured by the vibration sensor is similar to the temperatures measured by the surface temperature sensor, indicating that both of the sensors may be affected by air temperature.

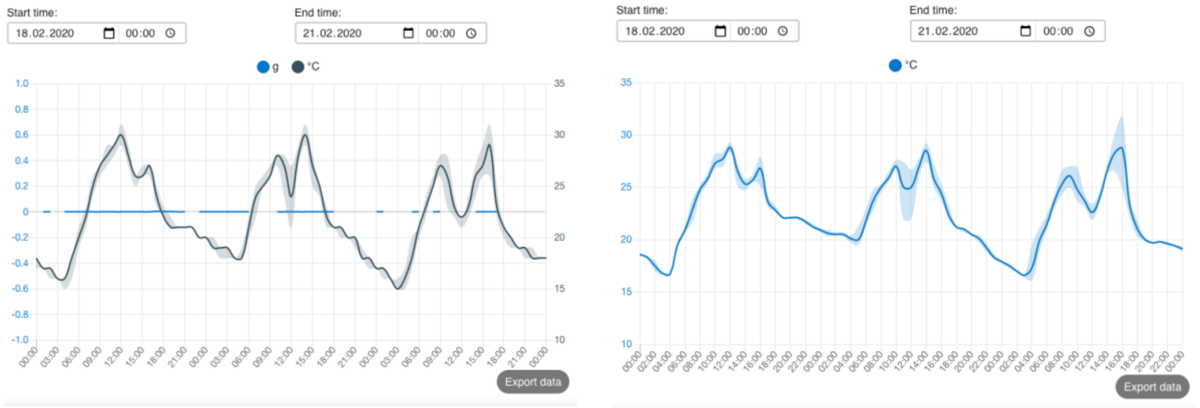


Figure 4.11: Measured data from vibration sensor (left) and surface temperature sensor (right) in Basonyagwe village.

4.3 Discussion

4.3.1 Pressure Sensor in the Well

In both Basonyagwe village and Mewadani village, the groundwater level rises significantly from the middle of February to the beginning of June. Groundwater level fluctuations due to aquifer storage changes involve either the addition or extraction of water from the aquifer, both through natural means and human involvement. Groundwater recharge occurs naturally where the earth materials are sufficiently permeable to allow water to move downward through them, and can amongst others be affected by rainfall, underlying river floodplains, and variations in atmospheric pressure.

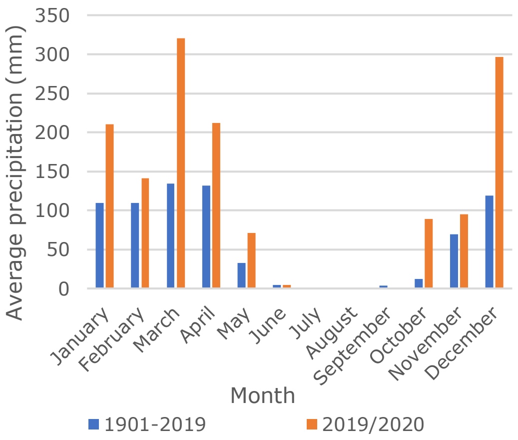


Figure 4.12: Comparison of average precipitation rates from 2019/2020 and average historical precipitation rates (GCM, 2020).

The most significant groundwater level changes due to recharge generally occur during the time of year when precipitation is generally larger and evaporation and plant usage rates are low (DNR, n.a.). Within the study area, this occurs in the rainy seasons. Thus, the average precipitation rates within the last months were compared to historical precipitation rates to investigate if there have been relatively high rates of precipitation before and during the measurements of groundwater levels. The average monthly precipitation rates from 2019/2020 and the average monthly precipitation rates from 1901-2019 are presented in Figure 4.12 (GCM, 2020). Within the 2019/2020 series, the precipitation rates from January to April are from 2020 whereas the precipitation rates from May to December are from 2019. All of the average monthly precipitation rates were equal in Basonyagwe village and Mewadani village. This may not be accurate because of the occurrence of local rainfall within the study area, also observed during the fieldwork.

Nevertheless, GCM (2020) shows significant differences between historical precipitation rates and the recent precipitation rates in Basonyagwe village and Mewadani village. The average precipitation rates are higher for every month during 2019/2020 compared to historical precipitation rates. Particularly, the high precipitation rates in January, March, and April may have led to a rise of the groundwater levels. In addition, Figure 4.12 shows a high precipitation rate in December in 2019 which may also have influenced the change. Hence, it is likely that the measurements by the pressure sensors in the well show real values. Since the groundwater levels are rising, the solar powered pumping systems in Basonyagwe village and Mewadani village are not over-abstracting the groundwater source. However, manual groundwater level measurements should be performed to validate these results.

Regarding groundwater levels within shorter time intervals (Figure 4.2 and Figure 4.4), there are relatively large uncertainties in the measurements when the groundwater level changes, and the measurements are sometimes affected by disturbances. For example the measurements sometimes indicate that there has been a lowering of the groundwater level in the middle of the night. This is unlikely as the groundwater level drops when groundwater abstraction occurs, which is not possible without sunlight in this type of water system. In addition, the lowering curve and recovery curve are sometimes equally steep which may be due to a disturbance in the signals. The disturbances can also explain the peaks after drawdown in Figure 4.4. Since the pressure sensor in the well has a relatively high measuring range, from 0-100 metres, small changes in pressure experienced by the sensor and further transmitted in mA can result in large changes in metres shown in the graphs.

The water pumps are installed at a depth of 100 metres and 105 metres below ground in Basonyagwe village and Mewadani village respectively (Appendix 2). If water is pumped from the groundwater source at too high rates relative to the inflow, the water level in the well will drop to the intake of the pump. This will either cause the pump to stop or to be damaged (Vibeke Brandvold, personal communication, 13th of May 2020). As previously mentioned, the solar powered pumping systems within the study area are installed with a well probe sensor that automatically turns the pump off when the groundwater level drops under the level of the water pump intake to prevent damages of the pump. When looking at the groundwater levels in early March for both Basonyagwe village and Mewadani village, the groundwater levels are found to be 18 metres in Basonyagwe well (Figure 4.2) and 9.6 metres in Mewadani well (Figure 4.4). Thus, there is a maximum available drawdown of 82 metres in Basonyagwe village and a maximum available drawdown of 95.4 metres in Mewadani village in early March 2020. When looking at the groundwater fluctuations from the middle of February to the beginning of June the lowest groundwater level is found to be 24.9 metres in Basonyagwe village and 10.5 metres in Mewadani village. Thus, there are maximum available drawdowns of 75.1 metres and 94.5 metres at the lowest in Basonyagwe village and Mewadani village respectively when looking at a longer time-interval. Exactly how much reduction which is considered as acceptable becomes a subjective assessment (ibid). One should take into account that the groundwater level varies with season as there is little to no precipitation and a higher amount of pumping hours in the dry season compared to the rainy season within the study area. Groundwater levels measured by the NCA are 20 metres and 38.9

metres in Basonyagwe well and Mewadani well respectively. The exact time of year when the groundwater level measurements by the NCA were made is uncertain, but the results show that the groundwater level varies. Hence, the maximum available drawdown and associating maximum allowable pump capacity should be determined after monitoring the groundwater level for at least a year. However, Figure 4.1 and Figure 4.3 indicate that the pumping capacities in the solar powered pumping systems in Basonyagwe village and Mewadani village are not negatively affecting the groundwater level and thus it may be possible to increase the pumping capacities in the solar powered pumping systems here.

Furthermore, an increase in pumping capacity needs to be considered in conjunction with the storage capacity in the water system (ibid). In Basonyagwe village, the maximum water level in the water tank is far from reached from 24th of April to the 30th of April (Figure 4.5) whereas in Mewadani village the maximum water level is reached, and exceeded, several times from 10th of April to 16th of April (Figure 4.7). According to the water committees in Basonyagwe village and Endagaw Chini village, the tanks go empty up to three times a week in the dry season. In Mewadani village, they already have a plan to fix the second water tank. Additionally, the water storage tank in Endagaw Chini village should be fixed and put into operation even without considering an increase in pump capacity, whereas an increase in pump capacity together with bigger water storage volume should be considered in Basonyagwe village.

Hence, the pressure sensor may be used to monitor trends of groundwater levels over a longer time-period. However, the measurements seem to have too large uncertainties to monitor the groundwater levels on a daily basis.

4.3.2 Pressure Sensor in the Water Tank

As previously mentioned, the pressure sensor in the water tank was installed to remotely monitor the water levels and water volumes in the water storage tanks. The aim was to use these measures to further calculate the water consumption per day. Both tapping from the water taps and filling from water pumping can occur at the same time. Thus, the measurements from the pressure sensor in the water tank must be considered in conjunction with the pressure sensor in the well to find out when water is pumped into the storage tank. Other sensors showing when water is tapped can also be used. As explained in the previous chapter, the measurements from the pressure sensor in the well are not accurate enough to be used at such short time-intervals. In addition, the pressure sensor in the water tank was installed under the valve between tapping point and water tank, due to operational considerations. This leads to an incomplete overview of water level and volume in the storage tank when the valve is closed. Both of the mentioned factors make it difficult to calculate the water consumption accurately.

However, the measurements can be used to monitor when the tanks are full and empty. If the measurements show that the tanks are empty over a long period of time, this may indicate that something is wrong with the system and thus show when one should have an inspection of the water system.

Both in Endagaw Chini village and Mewadani village, the water level exceeds the maximum water level several times. However, the excess is not significantly large and one can assume that the storage tank is full. In Basonyagwe village, the water level is far from reaching the maximum water level. This is most likely due to the fact that only one water tank works and is used in Endagaw Chini and Mewadani, whereas both of the water tanks are used in Basonyagwe.

In all three villages, the water level rapidly reaches a value of zero one to multiple times during the three days of measurement. This may indicate that the valve between the water tanks and water tap is closed. According to the water committees in the villages, the time when the water level reaches zero corresponds to the opening hours of the water systems. In Basonyagwe, the opening hours are from 6:00 to 18:00. Figure 4.5 indicates that the valve has been closed several times within this time-interval. This may be the case due to the relatively high precipitation rate in April (Figure 4.12). According to the water committee in Basonyagwe, over half of the population use rainwater harvesting as one of their main drinking water sources. Thus, it may be possible that the solar powered pumping system has been closed more than usual during April in Basonyagwe. In Endagaw Chini, the opening hours are 06:00-10:00 and 14:00-18:00. Figure 4.6 indicates that the valve was opened on the 10th of April at 06:00, closed three hours later, and opened again at 13:00. On the 12th of April, the valve closed at 12:00 and opened again at 13:00. In addition, the water level reaches a value of zero at the 14th of April at 07:00 and opens one hour later. In Mewadani village, the opening hours of the water system is 06:00-12:00 and 14:00-18:00. Figure 4.7 indicates that the valve closes on the 13th of April at 11:00. Hence, the measurements transmitted by the pressure sensor in the water storage tanks seem logical.

Regarding both the pressure sensor in the well and the pressure sensor in the water tank, the display on the user interface provided by El-Watch is not optimal. The display of the pressure sensor in the well shows the water column above the sensor, where a display of metres below top of the well would be beneficial to make the monitoring of groundwater levels more intuitive for the user. Similarly, it would be beneficial to show the water level or water volume in terms of the pressure sensor in the storage tanks. Currently, the user interface shows the pressure in Bar. El-Watch argues that this conversion in their user interface is difficult to achieve due to costs, and suggests to use an application programming interface program (Hallvard Helgetun, personal communication, 19th of March 2020). This should be executed if the systems are to be used in the future.

Currently, the pressure sensor in Endagaw Chini does not transmit data online. The sensor stopped transmitting the 22nd of April 2020. El-Watch is not currently able to identify the reason for the lost contact (Hallvard Helgetun, personal communication, 4th of June 2020). 4CCP has been asked to inspect the system, but currently there has been no response from 4CCP.

4.3.3 Digitizer – Voltage

For the equipment in the remote monitoring systems installed in the three villages, the variations in voltage are expected to be within a range of 9.5V to 14.5V. A voltage of 9.5 means that the battery is almost completely discharges, whereas a voltage of 14.5 means that the battery is fully charged. If the voltage falls below 9.5V, the transmission of data is expected to fail (Endre Våland Bø, personal communication, 4th of June 2020). In Basonyagwe village and Endagaw Chini village the available battery voltage does not fall below 12.6V and 12.8V respectively, and thus this is not a problem. In Mewadani village, the occurrence of relatively low minimal values seems to follow a repeating pattern, with the lowest values found as 10.3V in the morning around 08:00 Tanzanian time. Within the same time-period, Figure 4.10 shows large uncertainty ranges. This is most likely due to disturbances of which there can be many sources; wires or other components made out of steel, cheap regulators, solar conditions, etc. If the voltage falls below 7-8V, the data would not be transmitted. Thus, a battery voltage of 2V cannot be correct as the battery would have been fully discharged and the system would not be able to transmit data. Hence, these uncertainty ranges can be neglected. The middle value curve is more representative in this case, but should be used with reservations (ibid).

The voltage digitizer shows large fluctuations within short time-intervals, especially in Endagaw Chini village (Figure 4.9). The reason for this may be that some of the components use more power than they should or that the battery is overcharged and needs to unload energy quickly. However, this will not affect the system significantly but rather lead to some uncertainties in the transmitted measurements. The measurements can be used to study trends of available battery voltage, and thus monitor when the solar panel is activated or not. If the available battery voltage is rising, the solar panel is charging the battery. When the available battery voltage is falling, the components are using energy from the battery when there is insufficient sunlight. Hence, the voltage digitizer can give an indication on the operation of the remote monitoring system and that the components work properly (ibid).

4.3.4 Vibration Sensor and Surface Temperature Sensor

The vibration sensor and surface temperature sensor were installed to measure the uptime of the system and to monitor when there was running water through the pipes. Figure 4.11 shows that there are small variations in the measurements from the vibrations sensor and that both of the sensors may be affected by air temperature. Thus, the surface temperature sensor does not show a lower surface temperature when water is flowing through the pipe. The vibration sensor does not show variations big enough to conclude when the pump is on or off. In addition, there are some time-intervals in Basonyagwe when the data from the vibration sensor are not transmitted online. The sensor was placed inside the well under a metal lid, which may have caused the disturbance in the data transmission. The vibration sensor was also placed on the outlet pipe of the water storage tank. In this case, there were no disturbances in the transmission of data, but the data were nearly constant. The vibration sensor measures every two minutes for 100 milliseconds and thus it is unlikely that it senses a relevant movement. The sensor is built for monitoring equipment in constant motion (Tor Øistein Skjermo, personal communication, 18th of February 2020). Thus, the vibration sensors and surface temperature sensors were removed from the remote monitoring systems.

5 Water Quality Parameters

The chapter presents the water quality within the study area and discusses to what extent the solar powered pumping systems and other local water sources provide sufficient drinking water quality. Firstly, general groundwater quality in Tanzania and in the study area are presented in addition to the importance the water quality parameters measured during the fieldwork.

5.1 Background

Safe drinking water is a basic consideration for human health. The use of contaminated sources poses health risks to the population of Tanzania as evidenced by water borne diseases such as cholera and diarrhea. In Tanzania, the water sources are unevenly distributed and the quality of water varies greatly (URT, 2002). As previously mentioned, groundwater is an important water source in Tanzania and is the main source of water for most rural water systems and municipalities (Kashaigili, 2010). Groundwater has traditionally been regarded as having good natural quality where the quality is controlled largely by the geology (MacDonald and Calow, 2009). For most of the geological environments this is a fact, but this does not mean that natural groundwater quality always is sufficient for drinking.

In the Rift zone of the north in Tanzania, groundwaters are typically alkaline and soft with high pH values (BGS, 2000). In groundwaters from both the volcanic terrains and crystalline basement rocks in the central plateau, fluoride concentrations are known to be high (Kashaigili, 2010). One of the best-known high fluoride belts on land extends along the East African Rift (WHO, 2017). Misund and Møller (2019) tested the pH and fluoride concentrations in several villages within Mbulu, Mkalama and Hanang districts in Tanzania. They found that the groundwater sources represented a safe source, except for elevated fluoride levels. In 7 out of 9 water sources tested, the fluoride concentration exceeded the recommended upper limit value of 1.5 mg/L given by the WHO (WHO, 2017). Some of the results only show that the concentration exceeds 1.5 mg/L and the exact concentrations are not given due to that the test has an upper measuring limit of 1.5 mg/L and the lack of deionized water to dilute the samples with during their fieldwork. The high concentrations of fluoride are a problem in both Rift zones where concentrations as high as several tens to hundreds of milligrams per litre have been reported for some groundwaters (Kashaigili, 2010). Misund and Møller (2019) also found that there was a clearly elevated level of fluoride along the edge of the Rift Valley compared to the other measured sources.

Groundwater sources are more protected against pollution and contamination than surface sources, particularly groundwater in sediments. However, two concerns in rural areas are the rise in nitrate concentrations due to the use of fertilisers and intensive stock rearing, and pesticide contamination. The extent of pesticide contamination is unknown due to wide range of chemicals involved and the complexity of the decay processes. Natural processes reduce the concentration of many contaminants, including microorganisms, as the water moves through the ground. The type of soil and rock and the type of contaminant affect the degree to which attenuation occurs. Additionally, the travel time for water to move downward from the water table to the intake of borehole for low-yielding boreholes can be considerable even for small distances. This travel time will reduce the hazard from less persistent contaminants including multiple microorganisms arriving at the borehole intake (Morris *et al.*, 2003). A distance of 50 metres is the generally accepted minimum separation for pollution source and groundwater supply (Xu and Usher, 2006).

During the fieldwork, different water quality parameters were tested. Firstly, it was of interest to measure the fluoride concentrations within the study area. Particularly, the villages where Misund and Møller (2019) found that the fluoride concentrations exceeded 1.5 mg/L, to investigate if the water sources exceed the limit given by the Tanzanian drinking water standards. Additionally, turbidity, conductivity, pH, alkalinity, and the presence of hydrogen-sulphide producing bacteria were tested during the fieldwork. The turbidity is important to measure and monitor because of the possible screening of pathogens. High levels of turbidity levels may be acceptable to consumers, but it is recommended that drinking water should be kept below 1 NTU since pathogens can adsorb onto suspended particles (UNICEF, 2008). In addition, high turbidity levels may indicate high content of sand which will affect the sustainability of the water pumps in the wells.

The pH usually has no direct impact on consumers, but it is however one of the most important operational water quality parameters and influences different processes that occur in water (WHO, 2017). The pH in combination with the alkalinity indicates the stability of the water and control the corrosion of water mains and pipes. No health-based guideline value has been proposed for pH or hardness in drinking water. WHO recommends a pH of 6.5 or higher in drinking water to prevent corrosion. Regarding the hardness caused by calcium and magnesium, the consumers are likely to notice changes. The taste threshold for the calcium ion is in the range of 100-300 mg/L and lower for magnesium. Water with higher hardness than approximately 200 mg/L may cause scale deposition in pipeworks and tanks, depending on the interaction with factors such as pH and alkalinity. In contrast, soft water with a hardness of less than 100 mg/L may have a low buffering capacity and so be more corrosive for water pipes and other components in the water system (ibid). High salinity can also enhance some kinds of corrosion, but dissolved calcium and alkalinity can reduce corrosion by forming passive calcium carbonate coatings on the metal surfaces (UNICEF, 2008).

Lastly, the presence of hydrogen-sulphide producing bacteria was tested to investigate if the water sources are safe in terms of pathogenic microorganisms. Many serious diseases can be traced directly to pathogenic microorganisms in polluted water.

5.2 Results

The groundwater quality from the wells in every village visited was tested. In addition, the water quality parameters in a local dam in Basonyagwe, a local spring in Endagulda, and the rainwater harvesting systems at Mewadani primary school and Haydom secondary school were measured. The water quality parameters tested in every village were pH, fluoride concentration, alkalinity, conductivity, and turbidity. Additionally, the presence of hydrogen-sulfide producing bacteria was tested in four of the solar powered pumping systems, Basonyagwe local dam, the two rainwater harvesting systems (RWH), and Endagulda local spring.

5.2.1 pH and Fluoride Concentrations

Table 5.1 shows the locations measured with associated pH and fluoride concentrations. Regarding the pH value, the Tanzanian government has given an upper limit of 9.2 and a lower limit of 6.5. Regarding the fluoride concentrations, the lower limit is 1.5 mg/L and the upper limit is 4.0 mg/L (TBS, 2005). The water temperatures are also presented as high temperatures can negatively impact water quality by enhancing microorganism growth, and may increase taste, odour, colour and corrosion problems (WHO, 2017).

Table 5.1: pH and fluoride concentrations measured from water sources within the study area. The exceeded values according to Tanzanian drinking water standards are highlighted in red.

Water source	District	Temp. (°C)	pH	Fluoride (mg/L)	Remark
Basonyagwe	Mbulu	21.9	7.33	1.2	Tank full, pump not running
Diling'ang	Hanang	25.3	6.74	3.0	No pumping since November
Endagaw Chini	Mbulu	25.3	7.14	0.6	Tank full, pump not running
Endamilay	Mbulu	21.4	7.10	1.4	Tank full, pump not running
Endanachan	Mbulu	24.1	7.30	4.2	
Gidbyo	Mbulu	26.5	7-8	1.4	
Gidurudagew	Mbulu	23.6	6.45	2.0	Pump not running
Harar	Mbulu	21.1	7.47	1.4	No pumping since 27th of January
Haydom secondary (borehole)	Mbulu	-	7.00	2.4	
Hilamoto	Mkalama	-	7.80	2.8	Tank full, pump not running
Isene	Mkalama	-	7-8	2.8	
Mewadani	Mbulu	21.7	7.24	1.4	Tank full, pump not running
Munguli	Mkalama	29.5	7-8	4.8	
Murukuchida	Mbulu	22.0	7.67	1.4	Tank not full, pump not running
Basonyagwe dam	Mbulu	30.2	6.82	0.2	
Endagulda spring	Mbulu	25.5	6.96	0.0	
Haydom kiosk	Mbulu	-	7.00	2.0	
Haydom secondary school (RWH)	Mbulu	-	6.00	0.0	
Mewadani primary school (RWH)	Mbulu	26.0	6.44	0.0	

The pH values differ in accuracy due to the fact that pH-meter was broken after a few weeks in the field. pH paper was further used to measure the pH value in Gidbyo, Haydom Secondary School, Hilamoto, Isene, and Munguli (see Chapter 3.7.2).

The results show that two out of the nineteen water sources tested exceed the upper limit of fluoride concentration given by the Tanzanian drinking water standard; Endanachan and Munguli. However, when looking at the recommended upper limit of fluoride concentration in drinking water given by the WHO, being 1.5 mg/L, eight out of nineteen water sources contain too high fluoride concentrations.

5.2.2 Alkalinity, Conductivity and Turbidity

Table 5.2 shows the alkalinity, conductivity, and turbidity values measured in the water sources within the study area. According to the Tanzanian drinking water standard the lower alkalinity limit is 75 mg $CaCO_3$/L and the upper limit is 300 mg $CaCO_3$/L. Regarding the turbidity, the lower limit is 5 NTU and the upper limit is 25 NTU (TBS, 2005). FNU and NTU are the same, where FNU is most often used when referencing the ISO 7027 (European) turbidity method whereas NTU is most often used when referencing the USEPA Method 180.1 (Hach, 2020). The upper limit for electrical conductivity is 2000 µS/cm given by the Tanzania National standard (Zachayo Makobero, personal communication, 6th of April 2020).

Table 5.2: Alkalinity, conductivity, and turbidity values measured from water sources within the study area. The exceeded values according to Tanzanian drinking water standards are highlighted in red.

Water source	**District**	**Alkalinity ($mgCaCO_3$/L)**	**Conductivity (µS/cm)**	**Turbidity (FNU)**
Basonyagwe	Mbulu	225	719	1.29±0.06
Diling'ang	Hanang	300	1966	0.67±0.04
Endagaw Chini	Mbulu	-	1086	0.17±0.06
Endamilay	Mbulu	200	833	4.84±0.01
Endanachan	Mbulu	150	653	68.30±0.07
Gidbyo	Mbulu	300	1540	0.22±0.01
Gidurudagew	Mbulu	300	907	0.20±0.04
Harar	Mbulu	325	975	0.65±0.02
Haydom secondary (borehole)	Mbulu	350	1945	0.23±0.01
Hilamoto	Mkalama	400	1317	0.52±0.18
Isene	Mkalama	100	529	0.52±0.19
Mewadani	Mbulu	300	1211	0.14±0.01
Munguli	Mkalama	450	2180	0.32±0.12
Murukuchida	Mbulu	175	685	0.64±0.01
Basonyagwe dam	Mbulu	0	70	40.65±0.15
Endagulda spring	Mbulu	-	723	5.66±0.64
Haydom kiosk	Mbulu	300	1700	0.18±0.00
Haydom secondary school (RWH)	Mbulu	0	47	0.93±0.04
Mewadani primary school (RWH)	Mbulu	-	18	0.94±0.40

The turbidity value was tested two or three times in each of the water sources, and thus the column representing the turbidity values shows the average value and associating standard deviation. The rest of the water quality parameters in Table 5.1 and Table 5.2 were measured once in each of the water sources.

5.2.3 Hydrogen-Sulphide Producing Bacteria

The presence of hydrogen-sulphide producing bacteria for detection of Salmonella, Citrobacter, Proteus, Edwardsiella and some species of Klebsiella in some of the water sources within the study area was tested. The results are presented in Table 5.3.

Table 5.3 shows that the majority of the water sources tested within the study area had one (or more) positive test(s) in terms of the presence of hydrogen-sulfide producing bacteria. Only Basonyagwe well and the RWH system at Haydom Secondary School tested negative. Thus, Table 5.3 indicates that there is presence of hydrogen-sulfide producing bacteria in some of the wells, in Basonyagwe local dam, in Endagulda local spring, and in the RWH system at Mewadani Primary School.

Table 5.3: Results from hydrogen-sulfide producing bacteria test within the study area.

Water source	Test results (#positive tests/#total tests taken)
Basonyagwe	Negative (0/1)
Endagaw Chini	Positive (1/1)
Diling'ang	Positive (1/2)
Mewadani	Positive (1/1)
Basonyagwe local dam	Positive (2/2)
Endagulda local spring source	Positive (2/2)
Endagulda local spring tap	Positive (2/2)
Haydom Secondary School (RWH)	Negative (0/1)
Mewadani Primary School (RWH)	Positive (2/3)

5.3 Discussion

In Endanachan and Munguli, the fluoride concentration exceeds the upper limit of 4 mg/L given by the Tanzanian drinking water standard. However, looking at the upper limit recommended by the WHO which is 1.5 mg/L, eight out of nineteen water sources contain to high concentrations of fluoride. Fluoride is beneficial at low doses up to 2 mg/L. However, for children under 6 years the ingestion of water having a higher concentration of fluoride than 1 mg/L, it can lead to dental fluorosis characterized by staining or pitting of dental enamel. Ingestion of 6 mg/day has shown to increase the risk of skeletal fluorosis and ingestion of 14 mg/day poses a clear risk of skeletal fluorosis. Skeletal fluorosis involves stiffness and pain in joints, and in severe cases ligaments can calcify and bone structure may change (UNICEF, 2008). The staining of dental enamel was observed during the fieldwork. This indicates that people within the study area ingest higher concentrations of fluoride than recommended. Tanzania has an upper limit of 4 mg/L due to having an upper limit of 1.5 mg/L would result in abandoning about 30 percent of the water sources that currently are in use. However, a fluoride concentration of 1.5 mg/L or higher is still high enough to potentially cause fluorosis. Thus, it is of great importance to look at possible treatment methods that can reduce the fluoride concentrations in the groundwater within the study area.

A range of treatment technologies are available for reducing fluoride concentrations. In small supplies, bone charcoal, contact precipitation, activated alumina and clay are favoured methods (WHO, 2017). In 2020 a project report on fluoride treatment methods was written as a part of a module at NTNU (Eikeland *et al.*, 2020). Eikeland *et al.* (2020) investigated adsorption treatment methods using aluminium based materials, clay and soil, bone charcoal, and leaf powder. Based on their findings, the adsorption methods with bone charcoal and leaf powder appeared to be most favoured in rural Tanzania. This was due to the relatively high fluoride purification results and because they require little resources to be carried out. The removal of fluoride was 84 percent given a fluoride concentration of 10 mg/L and optimal pH 7 for bone charcoal, 80 percent removal of fluoride given a fluoride concentration of 10 mg/L and optimal pH 2 for Neem-leaves, and 98 percent removal of fluoride given a fluoride concentration of 2 mg/L and optimal pH 8 for Moringa-leaves. Although the efficiencies of the methods mentioned will decrease at a neutral pH value, the removal of fluorides will most likely be sufficient within the study area. The removal depends on the initial fluoride concentration in the water source and how much fluorides that need to be removed to achieve the desired water quality. More thorough review and practical testing of the methods are required to determine whether they can be applied in a sustainable way in rural Tanzania. The optimal amount of adsorbents should be determined, and one should investigate if the adsorbent should be used at household level or water system level (ibid).

In Endanachan well and Basonyagwe local dam, the turbidity value exceeds the upper limit given in the Tanzanian drinking water standards with a turbidity value of 68.30 FNU and 40.65 FNU, respectively (see Figure 5.1). Five out of the nineteen water sources tested have turbidity levels that exceed the recommended limit of 1 NTU given by the WHO (WHO, 2017). High levels of turbidity can amongst other stimulate the growth of bacteria (ibid). The water committees in Basonyagwe village and Endamilay village stated that the water smell and taste nice, and that there has been a reduction in water related diseases in the area. Although there are high levels of turbidity in the groundwater in Basonyagwe and Endamilay, the water is of sufficient quality for drinking in terms of bacteria and other organisms that lead to water related diseases. According to the water committee in Basonyagwe village, the local dam is mostly used for other activities than for drinking. However, it may be used as a drinking water source if the solar powered pumping system gets broken. Because of a high level of turbidity and the presence of hydrogen-sulphide producing bacteria (Table 5.3), Basonyagwe local dam is not recommended to be used as a drinking water source. Currently, there has been no downtime of the solar powered pumping system in Basonyagwe village. For the same reasons as in Basonyagwe local dam, the Endagulda local spring is neither recommended to be used as a drinking water source.

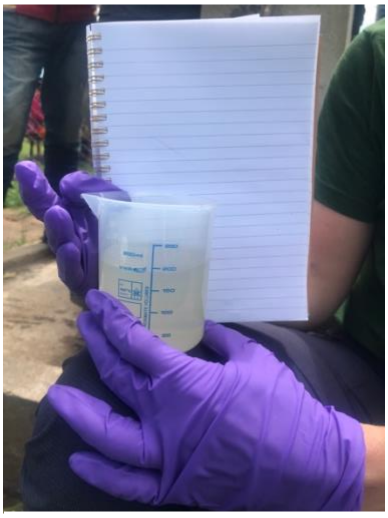


Figure 5.1: Water from the well in Endanachan village, showing a relatively high level of turbidity.

In the water sources where the conductivity values are relatively high, the alkalinity is also relatively high. In the well at Haydom Secondary school, Hilamoto village and Munguli village the alkalinity values exceed the upper limit given in the Tanzanian drinking water standard. There are no health concerns related to the alkalinity, but high levels may contribute to scaling (ibid).

Seven out of nine water sources tested positive on the presence of hydrogen-sulphide producing bacteria. A large number of bacteria can lead to hydrogen-sulphide production, most of which are faecal in origin. Both human and animal faces contain hydrogen-sulphide producing organisms (UNICEF, 2008). In Basonyagwe local dam and Endagulda local spring this may be true as the livestock also use these sources for drinking and because the water sources are not as protected to contamination as groundwater sources. Thus, the probability of contamination is considered as high in both Basonyagwe local dam and Endagulda local spring. The borehole in Endagaw Chini village and Diling’ang village also tested positive on the presence of hydrogen-sulphide producing bacteria. The groundwater levels measured in Endagaw Chini village and Diling’ang village were 30.8 metres and 85 metres respectively. Thus, the groundwater sources are likely to be protected to some extent as contamination from the surface needs to pass through thick layers of soil to reach the groundwater source. It was observed during the fieldwork, and can be seen from Figure 5.3, that livestock stayed close to the well, being less than 50 metres, and thus there is a possibility of groundwater contamination. However, in both Endagaw Chini village and Diling’ang village the water committees reported that the drinking water is safe and that there has been a strong reduction in water related diseases in the village after the installation of the solar powered pumping systems.

Figure 5.2: Rainwater harvesting system at Mewadani Primary school. Photos by: Vibeke Brandvold.

The water committee in Mewadani asked for water quality measurements from the RWH system at Mewadani Primary School as some of the children in the village refused to drink the water at the school. Two out of three samples from the RWH system at Mewadani Primary School tested positive on the presence of hydrogen-sulphide producing bacteria. According to the principal of the school, the RWH system is used from January to June, when there is presence of rainfall, whereas the borehole in Mewadani is used otherwise. The roofs and storage tanks are cleaned once a year, in December. Thus, there is a high probability of contamination during the usage period. This can be minimized by clearing trees and overhanging branches away from the rooftop, ensuring that gutters are cleaned regularly and designing a “first-flush” diversion system for rinsing the rooftop before rainwater is collected. Worth mentioning is that existing literature about the hydrogen-sulphide producing bacteria test caution that some conditions may lead to false positive results, especially the presence of sulphate-reducing bacteria (ibid). Hence, more tests should be carried out to validate the results regarding the faecal contamination of the water sources. However, the results in combination with observations and interviews during the fieldwork indicate where improving measures should be implemented within the study area. The RWH systems in schools should be prioritised as the pupils and other employees use this water source as their main drinking water source several months a year. Additionally, the results show the importance of both minimalizing the downtime of the solar powered pumping systems and of ensuring that the solar powered pumping systems continuously provide sufficient quantities of water, as using secondary sources such as local dams and local springs may negatively affect the users’ health.

According to the Tanzanian water policy "water quality monitoring and assessment will be undertaken systematically so as to identify extent and status of the quality of the water resources so that problems are detected early and remedial actions employed timely" (URT, 2002, p. 20). 4CCP wishes to have a frequent check-up to ensure the health of the communities within the study area and states that once a year is sufficient. Currently the water quality is tested every five years within the study area. The main problem is although the district water engineers know how to execute the tests, they lack the equipment to do so (Interview with 4CCP, February 2020).

Figure 5.3: Activities often found nearby the solar powered pumping systems. Cattle stayed quite close to the well, being less than 50 metres.

6 Water Situation and Quantity of Water

The chapter presents the water supply situation within the study area. First, a general background on the access of water, water demand, and water scarcity in Tanzania and districts within the study area are presented. The rest of the chapter aims to answer if the solar powered pumping systems provide enough water to meet the water demands, both for domestic uses and for productive uses, today and in the future. The water supply situation includes current drinking water sources, quantity of water provided from the systems compared to the water demand, and the distance to the water sources.

6.1 Background

6.1.1 Access to Improved Drinking Water

At the end of 2015, nearly half of the population in Tanzania did not have access to improved water sources for drinking, making them one of 17 countries that did not meet their MDG water target "to halve the proportion of people without improved drinking water and sanitation in 1990 by 2015" (World Bank, 2018, p. xv). According to 2016 estimates, the proportion of people who have access to improved drinking water has increased with 2 percentage points since 1990, standing at 59 percent coverage in total in Tanzania (World Bank, 2018). However, there are large inequities in access between urban and rural areas. According to the United Nations (2018), 66 percent of the population in Tanzania live in rural areas where only 48 percent have access to improved water sources. The people in these areas make their own, often insufficient, arrangements to meet their needs for basic survival. The Joint Monitoring Program (JMP) is the official interagency UN mechanism tasked with global monitoring of the sustainable development goals (SDG) targets related to WASH and is a collaboration between the WHO and UNICEF. Table 6.1 sets out the technologies considered "improved" and those considered "unimproved" by the JMP (World Health Organization, 2019). The breakdown of types of water sources used by rural residents shows that a large proportion are getting their water from unimproved sources, where unprotected dug wells makes up the highest category (24 percent). Within the improved sources, the two highest categories are public tap or standpipe (17 percent) and protected wells (15 percent) (World Bank, 2018).

Table 6.1: Definitions of improved and unimproved drinking water sources (World Health Organization, 2019).

Improved drinking water	Unimproved drinking water
Piped water into dwelling, yard or plot	Unprotected dug well
Public tap or standpipe	Unprotected spring
Tubewell or borehole	Cart with small tank or drum
Protected spring	Tanker truck
Protected dug well	Surface water (river, dam, lake, pond, stream, canal, irrigation channel)
Rainwater collection	Bottled water (considered to be improved only when the household uses drinking water from an improved source for cooking and personal hygiene)

In urban areas, 87 percent have access to improved water. Even though the access to improved water is higher in the urban areas of Tanzania, the access has declined from 92 percent in 1990. The decrease could be a consequence of population growth and high level of rural to urban migration straining public services.

A possible reason for the low coverage of improved drinking water percentage in the rural areas is the poor long-term sustainability of the water points. A data collection done by the Tanzania’s Ministry of Water and Irrigation show that more than 40 percent of 83.000 water points identified in Tanzania are non-functional, mostly due to a broken engine, pipe, pump, or source damage (19 percent of all non-functional points), or an out-of-use water tank, broken tap, or poorly sited tap (11 percent of all non-functional points). They further arranged the regions of Tanzania into five groups based on the proportion of functional water points. In Mkalama and Mbulu districts, 66.1 to 77.1 percent of all water points are functional, whereas in Hanang district, 77.2 to 96.1 percent of all water points are functional (ibid).

6.1.2 Water Demand and Distance to Source

The importance of adequate water quantity for human health has been recognized for many years and there has been an extensive debate about the relative importance of water quantity, water quality, sanitation and hygiene in protecting and improving health. Today, 20 litres per capita per day has been internationally recognised as a benchmark consumption figure (Watkins, 2006). This is also stated in the human right to water, saying that 20 litres per capita per day is a minimum quantity required to realize minimum essential levels of the right. However, to ensure the full realisation of the right, the quantity of water accessed should be at least 50 to 100 litres per person per day (ibid).

It has also been found that the distance to the water source has a strong impact on the quantity of water collected. The quantity collected is often reduced to less than 20 litres per capita per day (lpcd) when the time needed to collect water exceeds five minutes, which corresponds to a distance of more than 100 metres, shown in Figure 6.1. After five minutes, there is a plateau effect of per capita water usage at the household when the water collection time is between five and thirty minutes. After thirty minutes, which corresponds to a distance of 1 km home to source assuming no waiting time at the tap, a decline occurs from 15 lpcd to around 5 lpcd (Oxford University Press, 2015).

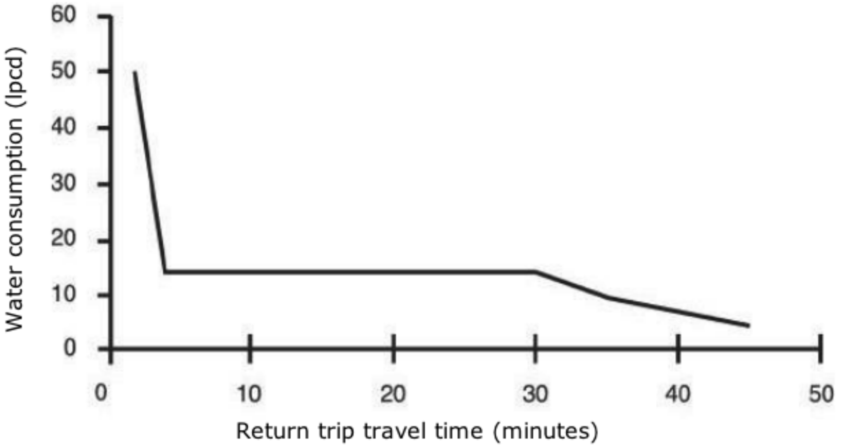


Figure 6.1: Graph of relationship between travel time (minutes) and water consumption (lpcd) (Oxford University Press, 2015; Cairncross and Feachem, 1993).

Thus, the water consumption depends on accessibility of water. The accessibility of water is primarily determined by distance and time, but also reliability and potentially costs are affecting factors. Howard and Bartram (2003) define accessibility in terms of service levels. The service levels and to what extent they meet requirements to sustain good health and interventions to ensure health gains are maximized, are shown in Table 6.2.

Table 6.2: Requirements for water service level to promote health (Howard and Bartram, 2003).

Service level	**Access measure**	**Needs met**	**Level of health concern**
No access (quantity collected often below 5 lpcd)	More than 1000 m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practiced at source)	Very high
Basic access (average quantity unlikely to exceed 20 lpcd)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 lpcd)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 lpcd and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

With only 35 percent of residents in the rural areas of Tanzania that can access improved drinking water not having to travel more than 30 minutes each roundtrip, the majority of the population here are fetching water over long and strenuous distances. In the urban areas 79 percent can access improved drinking water not having to travel more than 30 minutes each roundtrip, which is over twice as much as for the residents in the rural areas in Tanzania (World Bank, 2018). According to the district water engineer in Mbulu, 47 to 49 percent of the committees in Mbulu district council and 52 percent of the committees in Mbulu town council are getting improved drinking water within 400 metres (interview at his office, 28. January 2020). According to the district executive director in Mkalama, the proportion of residents within Mkalama district having access to improved drinking water within 400 metres has increased from 45 to 63 percent in the last three years (interview at his office, 18. February 2020). Thus, it is likely that many people in these areas are consuming less water than recommended in order to protect and improve their health.

6.1.3 Water Resources and Water Use

Today, Tanzania is facing a water security crisis in some parts of the country, as water demands exceed available resources. Over the last 25 years the population in Tanzania has doubled, but water availability has remained the same. Growing demand on a finite resource has resulted in water stress within the country. The water resources are dropping below 1700 cubic metres per capita, the threshold level below which a country is considered to be water stressed (TAWASANET, 2019). This figure will continue to decline, reaching around 1400 by 2025 (see Figure 6.2). This is still in excess of 1000 metres per capita, internationally considered to be the threshold for absolute scarcity. However, crossing the “water stress” threshold of 1700 cubic metres per capita is a warning signal for the Tanzanian people. Action on water resources is urgently needed (World Bank, 2017). The national water demand is already at 150% of accessible supply in dry seasons and the demand could rise to as much as 2016 percent of supply by 2035 (TAWASANET, 2019).

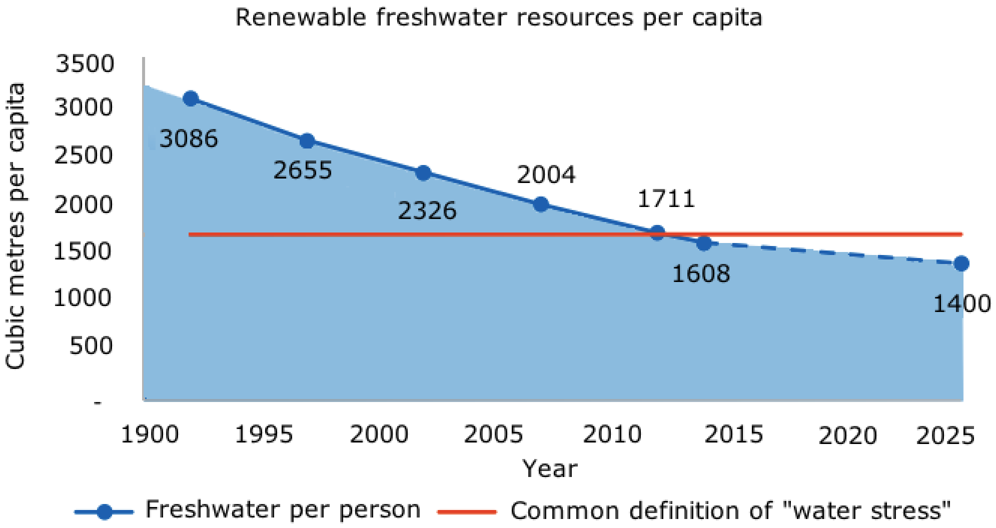


Figure 6.2: Renewable freshwater resource trend in Tanzania, showing that Tanzania has become a water stressed country (World Bank, 2017).

Tanzania has numerous and diverse water resources such as wetlands, lakes, rivers and groundwater. However, critical and widespread water shortages exist in many parts of the country because of climate variability, uneven distribution of the resource in time and space, and inadequate management of the water resources (URT, 2006). Internal renewable surface water resources are estimated at 80 000 million m3/year and renewable groundwater resources at around 30 000 million m3/year. In 2002, the total water withdrawal in mainland Tanzania was estimated to be 5 142 million cubic metres. The groundwater withdrawal is estimated to be around 463 million cubic metres (2010), mostly for domestic uses (60 percent), but also for livestock and fishing (28 percent), irrigation (10 percent) and industries (2 percent). The use of groundwater for industries mostly takes place in urban areas (FAO, 2016). The groundwater provided from the solar powered pumping systems within the study area are mostly used for domestic activities, livestock, and irrigation.

The challenge of addressing a sustainable water future for Tanzania begins with institutional reforms and better coordination within government. Four improvement measures have been addressed by the World Bank (2017). Firstly, a multi-sectoral coordination and investment prioritization including equipping the Ministry of Water and Irrigation, the National Water Board and Basin Water Boards with information, capacity, resources and authority, and to strengthen investment prioritization can lead to smarter investments. Second, enforcing water pricing reflective of scarcity challenges is identified as an improvement measure. Today, the systems for valuing, permitting, monitoring, and enforcement of water pricing are weak and need to be strengthened from the community level up to government agencies. This is one of the most urgent challenges in Tanzania today. The third factor includes an upscaling in the investment of data collection methods that remotely can transmit data. This can reduce staff-time requirements. Lastly, government reforms are needed to encourage Tanzania to see water as an asset, and simultaneously acknowledge its finite nature to make every drop count (ibid).

6.2 Results

6.2.1 Existing Drinking Water Sources

Types of Drinking Water Sources

In Hanang district, there are 14 solar powered pumping systems, 9 electricity pumping systems, 5 pumping systems using diesel, and 5 handpumps (Interview with DWE at his office, 14. February 2020). In Mkalama district, there are in total 731 boreholes where 711 are handpumps, 15 are pumping systems using diesel, 4 are solar powered pumping systems, and 1 is an electricity pumping system (Interview with DED at his office, 18. February 2020). The survey conducted with 87 respondents showed that almost everyone (92 percent) are using a solar powered pump as (one of) their main drinking water source(s). As Figure 6.3 indicates, some of the respondents are using multiple drinking water sources. Amongst those using only one drinking water source, which constitute 58 percent of the respondents, 86 percent use solar powered pump, 10 percent use river or pond, and 4 percent use handpump. Amongst those using multiple drinking water sources, everyone use solar powered pump, 78 percent use rainwater harvesting, 27 percent use a river or pond, 22 percent use handpump, and 11 percent use a local well. The main reasons for using a river or a pond were distance to the well and failure and downtime at well. Other reasons were waiting time at the well and that the source was traditionally used.

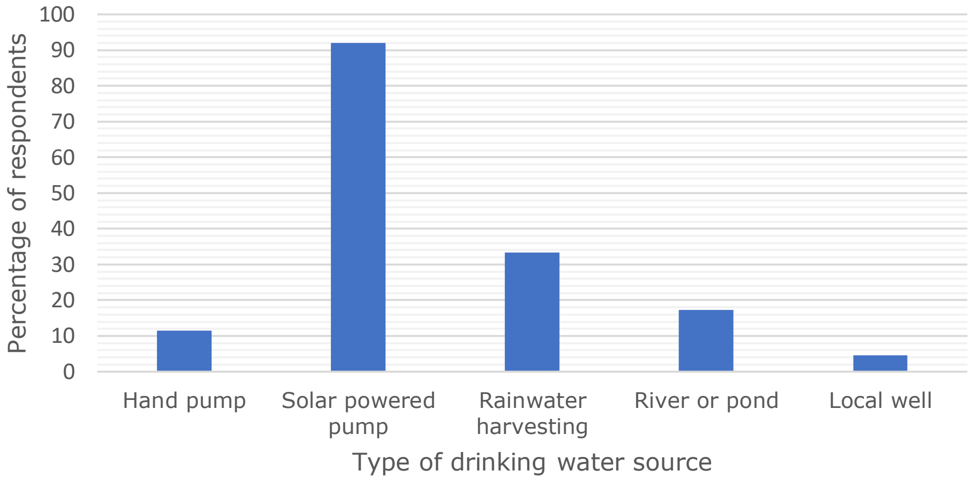


Figure 6.3: Types of drinking water sources used by villagers within the study area.

Approximately one third of the respondents are using rainwater harvesting as a drinking water source during the rainy seasons. According to the water committees within the study area, this applies to those having an iron sheet roof. The proportion having iron sheet roofs varies greatly within the villages in the study area, ranging from 10 percent to over 70 percent of people within a village. In Isene village, almost everyone have iron sheet roofs and thus use rainwater harvesting as one of their main drinking water sources during the rainy seasons. Those with mud roofs in this village are getting rainwater from those harvesting within the area.

Figure 6.4: River nearby Mewadani village.

Figure 6.5: Local dam in Basonyagwe village.

Benefits and Challenges of the Solar Powered Pumping Systems

From the survey conducted, 49 percent were very satisfied with their current water system, 41 percent were somewhat satisfied, and 7 percent were not satisfied. Fourteen percent answered that there had been interruptions where water from the drinking water source was not available. The reasons for the interruption were failure of pump (58 percent), no sun (34 percent), and too small pressure (8 percent). The interruptions lasted for two weeks, few days, and four hours, respectively. From the interviews with the water committees within the study area, different benefits and challenges regarding the solar powered pumping systems were identified and are presented in Table 6.3.

Table 6.3: Benefits and challenges regarding the solar powered pumping systems.

Benefits	Challenges
• Reduced time fetching water • Clean and safe water, leading to reduced water related diseases • Easy access to water for people, pupils, and cattle • More sustainable than handpumps • Shorter line at water taps compared to handpump • Creating income • Low operation cost • Low maintenance	• No water when there is no sun • Expensive project to implement • Long chain of people at the water taps in dry seasons • Too small tanks • Low pressure in tap • Too low water level in dry seasons • Not enough water

In ten out of thirteen solar powered pumping systems visited, there had been no downtime of the system. In Endagaw Chini, the pump had been broken once. The downtime of the system lasted for two weeks. In Hilamoto, the pump stops due to lowering of the groundwater table three times a week during dry seasons. In Munguli there was a pump failure in 2019 due to low maintenance. It took three months to change the pump.

When asked about the challenges of the solar powered pumping systems, the majority of the water committees said they wish to expand the project so that people living in sub-villages with greater distances to the water source can access clean and safe water. The distribution of extra people connected to the water projects in the villages is presented in Table 6.7, with associated increase in water demand.

6.2.2 Water Demand versus Water Supply

Water Demand

The water supply and demand were calculated for each pumping station to evaluate whether the systems are succeeding in supplying sufficient quantities of water to the beneficiaries. The water demand per person is calculated from the survey conducted, with 87 respondents. A water demand of 23 litres per capita per day for SUS was found and is used in further calculations. For MUS, a water demand of 52 lpcd was found. The number of people using the solar powered pumping systems, number of cattle using the borehole, and the size of veggie-garden are found from interviews with water committees within the study area. The water demand for productive activities (MUS) includes mostly water demand for cattle, but also water demand for veggie-gardens in Basonyagwe, Endagaw Chini, Haydom Secondary, and Murukuchida. The water demand per cow is set to 20 litres per day, based on reports from the NCA and interviews with villagers within the study area. The water demand for veggie-gardens is set to 4.5 litres per square meter based on reports from the NCA (see Appendix 15). In the villages where no number of cattle is specified, the cattle are not using the well as drinking water source. They use other drinking water sources such as rivers, dams, and local springs.

Table 6.4: Water demand for domestic activities and productive activities in the villages.

Village	**District**	**Number of people**	**Number of cattle**	**Water demand domestic (SUS) (m$_3$/day)**	**Water demand productive (MUS) (m$_3$/day)**
Basonyagwe	Mbulu	900	1900	20.7	59.6
Diling'ang	Hanang	1800	-	41.4	41.4
Endagaw Chini	Mbulu	1200	600	27.6	51.6
Endanachan	Mbulu	1300	2400	29.9	77.9
Endamilay	Mbulu	756	3650	17.4	90.4
Gidbyo	Mbulu	1800	1000	41.4	61.4
Gidurudagew	Mbulu	960	15	22.1	22.4
Harar	Mbulu	2324	3320	53.5	119.9
Haydom Secondary[a]	Mbulu	1460	2	33.6	44.6
Hilamoto	Mkalama	2300	1200	52.9	76.9
Isene	Mkalama	2498	-	57.5	57.5
Mewadani	Mbulu	805	-	18.5	18.5
Munguli	Mkalama	866	-	19.9	19.9
Murukuchida	Mbulu	2900	6600	66.7	199.6

[a] The well at Haydom Secondary school has an electricity pump, not a solar powered pump.

Water Supply Based on Theoretical Calculations

The water production from the wells was calculated based on the pump curve and system curve for each well. All of the pumps in the villages presented are provided from Dayliff, and the pump curves are sourced from their homepage (see Appendix 13). The system curves were calculated using Equation 3.1. The water production is defined from the operating point, and that the pump runs eight hours per day. The type of pump, flow rate from the operational point, and the water production minus both water demand for SUS and MUS are presented in Table 6.5.

The villages visited not presented in the table do not have sufficient data available to use the method to calculate the water production. Table 6.5 shows that only the solar powered pumping system in Basonyagwe village provides enough water to meet the water demand for SUS. None of the systems are providing enough water to meet the water demand for MUS.

Table 6.5: The water supply versus water demand for both SUS and MUS from the wells with associated flow rates and pump types.

Village	**Type of pump**	**Flow rate (m_3/h)**	**Water production (m_3/d)**	**Production minus demand for SUS (m_3/d)**	**Production minus demand for MUS (m_3/d)**
Basonyagwe	DSP 5/16	3.5	28.0	7.3	-31.6
Diling’ang	DS 2/23	1.8	14.4	-27.0	-27.0
Gidbyo	DSP 3/16	2.9	23.2	-18.2	-38.2
Gidurudagew	DSP 3/16	2.1	16.8	-5.3	-5.6
Harar	DSP 5/16	3.6	28.8	-24.7	-91.1
Hilamoto	DSD 3/18	3.3	26.4	-27.3	-51.3
Isene	DSP 5/12	4.2	33.6	-23.9	-23.9
Mewadani	DSP 3/16	2.2	17.6	-0.9	-0.9
Murukuchida	DSP 5/16	3.4	27.2	-38.7	-171.6

Water Supply Based on Measurements

There was also conducted a bucket test in some of the villages, using a bucket of 10 or 20 litres and a stopwatch. In the majority of the villages, multiple bucket tests were conducted, and the middle value from the tests are used in further calculations. The results from the bucket testing, associated groundwater levels, and time of measurements are presented in Table 6.6.

In Basonyagwe, Endagaw Chini, Harar, and Mewadani the groundwater level was measured using a pocket dipper. In the rest of the villages, an electrical measuring tape was used to measure the groundwater level (see Chapter 3.7.1). The time of measurement and groundwater levels are also presented in the table because the water productions vary with the groundwater level which in turn may vary with time. The groundwater level may vary with time depending on the number of hours the pump has been on before the measurement. The bucket tests were executed around the same time as the groundwater level measurements, except from in Basonyagwe. In Basonyagwe the groundwater level was measured ten days before the bucket test. The weather condition when the bucket test was conducted is also presented because it can affect the irradiation on the solar panels which further affects the flow rate provided by the pump. In Haydom Secondary School, the weather condition is not relevant and was not registered because the water system has an electricity pump.

Table 6.4 and Table 6.6 show that only the well at Haydom Secondary school are providing enough water to meet the demand for SUS based on the bucket tests. However, the well does not provide enough water to meet the water demand for MUS.

Table 6.6: Results from bucket testing, showing water production with associated groundwater level and time of measurement.

Village	Time of measurement	Weather condition	Groundwater level (m)	Flow rate (m^3/h)	Water production (m^3/d)
Basonyagwe	15:30	Partly cloudy	19.5	2.7	21.6
Endagaw Chini	15:30	Partly cloudy	39.5	2.2	17.8
Endanachan	11:00	Sunny	14.1	2.4	19.0
Gibyo	12:00	Sunny	33.0	3.3	26.2
Gidurudagew	10:00	Sunny	9.4	2.5	20.3
Harar	11:00	Cloudy	20.5	3.7	29.8
Haydom secondary	16:00	-	5.6	4.8	38.4
Hilamoto	10:30	Sunny	19.8	3.2	25.2
Isene	12:30	Sunny	1.6	4.8	38.0
Mewadani	10:00	Sunny	13.7	1.4	11.2
Murukuchida	14:30	Sunny	42.7	3.1	25.1

Water Demand with Expansion of the Water Systems

The water committees in the villages presented in Table 6.7, expressed that they want to expand the water project to other sub-villages unable to fetch water from the existing solar powered pumping systems due to distance to source.

Table 6.7: Water demand for SUS and MUS expanding the water project

Village	Number of extra people	Extra water demand (SUS) m^3/day	Extra water demand (MUS) m^3/day	Distance (km)	Uphill/downhill from current well
Basonyagwe	1080	24.8	24.8	4-5	Uphill
Diling'ang	900	20.7	21.6	-	-
Endanachan	1700	39.1	102.1	9-10	Uphill
Endamilay	4 sub-villages	-	0.9	2-3	-
Gidbyo[a]	1500	34.5	50.7	10	Varies
Gidurudagew	1320	30.4	47.3	3	Uphill
Harar	930	21.4	22.3	7-8	Downhill (Harar Hill) and uphill (Endabarak A)
Isene[b]	1244	28.6	30.4	1-3	-
Mewadani	1645	37.8	38.7	-	Uphill
Murukuchida[c]	Other sub-villages	-	3.5	-	Downhill

[a] In Gidbyo village, the water committee is planning to have a 60x60 m^2 veggie-garden used as a farming learning centre for the village

[b] In Isene village they are planning on having a 25x25 m^2 veggie-garden and are waiting for advises from an agriculturalist

[c] In Murukuchida village they already have a veggie-garden, but want to add a sweet potato field (35x22 m^2) to the irrigation system

The extra water demand for domestic activities (SUS) is found from the number of extra people, assuming that the water consumption is 23 lpcd. In addition, some of the villages are planning to use water for productive activities (MUS) which in this case is irrigation and livestock watering. The size of the planned veggie-garden is 20x10 m^2. As in Table 6.4, the water demand per cattle is set to 20 litres and the water demand for veggie-garden is set to 4.5 l/m^2.

The water committees want to expand the water project either using pipes from existing solar powered pumping system or drilling a new borehole. Thus, the distance and location to the sub-village(s) are presented in Table 6.7.

6.2.3 Distance to Source

Water Consumption for SUS and MUS

The relationship between distance to source and water demands for both SUS and MUS were investigated to see how longer distances to the drinking water source affect the water consumption. The survey done in the study area showed that 74 percent of the villagers use more than 30 minutes per roundtrip fetching water. The relationship between distance to source and water consumption for SUS and MUS are presented in Figure 6.6 and Figure 6.7, respectively. The median values of water consumption are also presented, as an analysis approach using average value is more affected by extreme values. The water consumption for SUS only includes water demand for domestic activities. The water consumption for MUS includes water demand both for domestic activities and for productive activities.

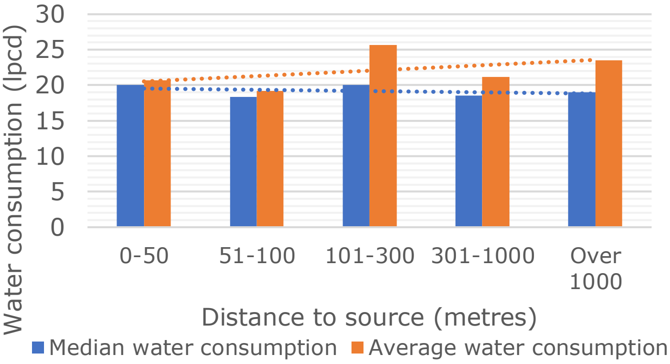


Figure 6.6: Relationship between domestic water consumption (lpcd) and distance to source (metres).

Figure 6.6 shows a weak negative linear tendency between median water consumption for SUS and distance to source. When the average water consumption per capita per day is used, there is a weak positive linear tendency between water consumption for SUS and distance to source.

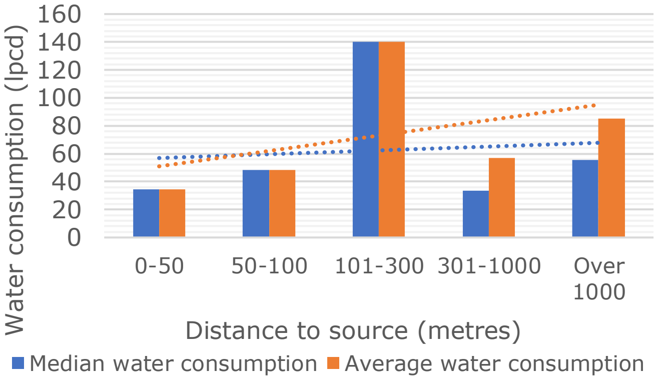


Figure 6.7: Relationship between domestic water consumption and productive water consumption (lpcd), and distance to source (metres).

Figure 6.7 shows a weak positive linear tendency between both median water consumption and average water consumption for MUS and distance to source.

Water Collection Time

The average distance to the drinking water source amongst the respondents is 672 metres, using the middle values of the distance intervals. The longest distance is 8 kilometres and the shortest distance is 50 metres. The average time on a roundtrip fetching water, including waiting time at the tap, is 53 minutes. Finding the number of trips fetching water per day based on how much water is used per household and how much water is collected each trip, give a total average time used to fetch water per person per day of 2.5 hours (see Table 6.8).

The number of trips fetching water per day depends on the amount of water collected each trip, which depends on the type of transport used. The amount of water collected each trip varies greatly from 10 litres to 480 litres. Types of transport in the study area are local transport where cattle or donkeys pull a carriage containing 120 litres drums (Figure 6.8), motorcycles, bicycles, and walking. Those using motorcycle, bicycle, or are walking, use buckets of either 10 or 20 litres, mostly the latter (Figure 6.9).

Table 6.8: Descriptive statistics of time used fetching water per day, and other affecting factors.

	Mean	Median	Std. dev	Min	Max
Distance to source (m)	672.3	650.5	1198.4	25	8000
Waiting time at tapping point (min)	27.9	23	25.0	2.5	160
Time per roundtrip (min)	52.6	37.1	59.2	3.4	205.2
Time fetching water per day (min)	150.7	60.3	212.5	3.4	915.6

If local transport is used, men and boys are often the ones responsible for fetching water. Otherwise, women and children are often the responsible ones (Interview with water committee in Endagaw Chini, 10. February 2020). From the survey conducted, 63 percent of those responsible for fetching water in the household were either mother or daughter and 23 percent were either father or son. In some households, everyone in the family or the parents were responsible for fetching water.

Figure 6.8: Local transport of water from the well, transporting two drums containing in total 480 litres of water.

Figure 6.9: Pupils fetching water on their way home from school, carrying buckets of 20 litres. Photo: Randi Sægrov.

6.3 Discussion

6.3.1 Existing Drinking Water Sources

Types of Drinking Water Sources
Almost all of the respondents (92 percent) use solar powered pumping system as their main drinking water source. Of those not using the solar powered pumping systems, constituting 8 percent of the respondents, 71 percent are using a river or a pond, and 29 percent are using handpump as their main drinking water source. Thus, the results show that witin the study area, over 94 percent are using improved drinking water sources,

being either solar powered pump or handpump. The reason for using a river or a pond was the distance to the well. The access to improved drinking water sources is almost twice as high as for the total people living in rural areas in Tanzania. The percentage also meets the goal set by the Tanzanian government that 85 percent of the rural population should have access to safe water by July 2020, excluding the distance to source (URT, 2016). However, the 87 respondents do not represent the entire population within the study area, and the real numbers may be lower. This is likely to be believed because in every village visited, the water committee wants to expand the water project to sub-villages nearby because of the distance being too long for them to fetch water at the existing waterpoint. There are in total 20 409 people using the solar powered pumping systems within the study area, and thus there are a lot of people that can access clean and safe drinking water within the study area today. The water committees want to expand the water projects to provide water to sub-villages either by using pipes from existing solar powered pumping systems, or by drilling new boreholes. The total number of people they want to expand the projects to is more than 8884, and the distribution of extra people connected to the water projects and increase in water demand are presented in Table 6.7.

According to the survey conducted within the study area approximately one third of the respondents are using rainwater harvesting as (one of) their main drinking water source(s). Rainwater harvesting may be used as a complementary backup or additional water source to the solar powered pumping systems. The weather within the study area is influenced by seasonal variations. Rainwater harvesting is easily accessed during the wet seasons when the solar powered pumping system does not work due to the cloud cover, and during the dry seasons when it is sunny and thus a lack of recharge to the rainwater harvesting source, the solar powered pumping systems can be used. However, the rainwater harvesting seems to be limited to those having iron sheet roofs within the study area. This may explain the relatively low percentage of respondents using rainwater harvesting as a drinking water source. According to the Tanzanian water policy, RWH will be promoted in rural areas and "communities will be made aware and encouraged to use rainwater harvesting" (URT, 2002, p. 35). This is also one of the priority areas for intervention within the WSDP, and thus the percentage of respondents using rainwater harvesting may increase in the future (URT, 2006). For example, a system like in Isene village could be used in the other villages where those having iron sheet roofs harvest rainwater and share with the other villagers. However, precautions must be taken if rainwater is to be used as a drinking water as there is a higher probability of contamination compared to groundwater. It is recommended that the water is treated in some way, at least boiled, when used as drinking water.

Benefits and Challenges of the Solar Powered Pumping Systems

The benefits and challenges of using the solar powered pumping system were identified based on interviews with 4CCP and water committees (Table 6.3). Benefits such as reduced time fetching water, clean and safe water, and creating income are discussed in other chapters of this thesis. Another benefit mentioned was that the systems were more sustainable and reliable than handpumps. Downtime due to destructions on the water system was minimal according to the water committees within the study area. In ten out of thirteen solar powered pumping systems visited, there had been no downtime of the system where the oldest system was constructed in 2018. In Endagaw Chini, where the solar powered pumping system was constructed in October 2018, the pump had been broken once. It took two weeks to get it fixed. In Munguli, which is the oldest amongst the solar powered pumping systems, constructed in 2015, there was a pump failure in 2019 due to low maintenance. The downtime of the system lasted for three months. Villages within the study area previously using a handpump reported that the handpump was broken up to once a week during the dry seasons. According to the DWE in Mbulu, the district where Endagaw Chini is situated, they do not have regular maintenance on the solar powered pumping systems. In Mkalama district, where Munguli is situated, the pumps are cleaned once or twice per year to avoid the pump getting rusted. He further stated that the frequency of the pump-collapses are related to the frequency of maintenance, particularly in regions such as Singida where the water is quite saline. Both in Endagaw Chini and Munguli, people got sick from fetching water from other water sources, such as rivers, during the downtimes of the pumps. Hence, a disadvantage of such systems is that maintenance of the pumps requires a certain degree of technical knowledge and skill, and thus the downtime may be long leading to an increase of water related diseases because people need to use other drinking water sources.

The water committees within the study area do minor maintenance such as cleaning the solar panels, fixing the tap with local technicians, and collect money used for maintenance. The panels should be cleaned regularly since dust accumulation decreases the system efficiency. According to the water committees, the panels are cleaned once per month to two times a week during the dry seasons, and they seemingly understood the importance of regularly cleaning. In the rainy seasons they do not clean the solar panels. However, the water committees need to be more capacitated and learn how to execute other minor maintenance correctly in order to ensure the sustainability of the solar powered pumping systems (Interview with 4CCP, February 2020). 4CCP further suggested that more training both of the water committees and PETS committees will increase the capacity. According to 4CCP, they only had one training meeting with the committees.

Easy access and shorter line at water taps compared to handpump were also mentioned as benefits using the solar powered pumping system. The easy access is an affecting factor in using water for productive activities, further discussed in the next section. According to the survey conducted by Misund and Møller (2019), 29.9 percent of the respondents used handpump and 24.3 percent used solar powered pump as one of the drinking water sources. Today 11.5 percent are using handpump and 92 percent are using solar powered pumping systems within the study area. Further, Misund and Møller (2019) found that the waiting time at the water point was greatly affected by season with the waiting time in the dry seasons more than five times longer than in the wet seasons. The comparison between waiting time at water point found by Misund and Møller (2019) and the waiting time found from the survey conducted during the fieldwork for this thesis is shown in Table 6.9. The numbers presenting the solar powered pumping systems include those using only solar powered pumping systems as their drinking water source.

Table 6.9: Waiting time for dry and wet season found by Misund and Møller (2019), and for solar powered pumping systems

Waiting time	**Dry (minutes)**	**Wet (minutes)**	**Average (minutes)**	**Solar powered pumping systems (minutes)**
Minimum	0.0	0.0	0.0	2.5
Maximum	480.0	90.0	285.0	160.0
Mean	105.2	19.9	62.5	29.8
Median	60.0	10.0	35.0	23.0

Since the values for solar powered pumping systems are not divided into dry season and wet season, the exact change in waiting time at water point is difficult to identify. In addition, the numbers from the survey conducted by Misund and Møller (2019) do not represent those using solely handpump as their drinking water source. All of the average values of the waiting time during dry and wet seasons are higher than for solar powered pumping systems. This may indicate that a higher percentage of handpumps used within an area increase the average waiting time at water point compared to when solely solar powered pumping systems are used. More research on waiting time at water point using solar powered pumping systems compared to handpump is needed to find the exact change within the different seasons. However, the waiting time at water point is still concerningly long at the maximum, particularly during the dry seasons where the waiting time is longest and the air temperature is high. In Basonyagwe, Endagaw Chini, Gidbyo, Harar, Isene people are waiting in line to fetch water from two hours to a whole day in the dry season because the water point is overcrowded. In Diling'ang, Endagaw Chini, Endanachan, Endamilay, Mewadani, and Murukushida the waiting time is prolonged during the dry season due to too small water tanks and that they need to wait for the water tanks to be filled. The villages with associated challenges identified from interviews with water committees and suggestions to reduce the waiting time at water point are presented in Table 6.10.

Multiple water taps may be an appropriate solution for villages having sufficient storage capacity compared to water consumption. In Gidbyo and Isene, the water committee did not report that the water tanks go empty, and thus multiple water taps may be possible to install. In Basonyagwe and Endagaw Chini the water committees also mentioned long lines due to no water in water tanks as a challenge. Thus, the storage capacity available dictates the type of design to be adopted and different improvement measures may need to be combined, for example increasing the storage capacity and installing multiple water taps. At Endagaw Secondary school, domestic points with multiple taps are served at peak times. This type of system could be used in other villages (Zachayo Makobero, personal communication 14th of April 2020).

In some of the villages, the water committee reported that the pump capacity is lower than the consumption and villagers need to wait even when it is sunny and the pump is on. Bigger storage tanks in combination with longer pumping time or higher flow rate provided by the pump may reduce this problem. Adding a component to the system, such as a battery or a generator, can increase the pumping time because the pump can work during the night and when it is cloudy. However, adding a battery is expensive and maintenance requires a certain degree of technical knowledge and skill. In terms of running a battery system, the induction motors attached to the pumps tend to draw high currents which damage the batteries. The inverter used in the systems can accept either AC or DC power, but cannot charge batteries. If the system is using AC power, it is possible to run the system at night or even when it is cloudy if a manual change over switch is installed which can help to select power required depending on the current condition (Zachayo Makobero, personal communication, 14th of April 2020). A feature with the inverter used within the study area is hybrid capability that enables for the connection of direct AC power from mains or generator supply. It is adaptable to any AC motor types and can be retro fitted to the solarization of existing AC supply installations (Davis and Shirtliff, 2018). The NCA has discouraged fetching water at night due to issues with supervision of the system and gender-based violence (Zachayo Makobero, personal communication, 14th of April 2020). However, if a hybrid system can make the pump work when it is cloudy, and fill up the water tanks at night without people fetching water at night, it may decrease the waiting time at the water tap during the day for a lot of people within the study area.

Table 6.10: Villages with associated challenges and possible improvement measure(s) to reduce the waiting time at water point

Challenge	Village(s)	Improvement measure(s)
Long line due to many people at the water point	Basonyagwe, Endagaw Chini, Gidbyo, Harar, Isene	• Multiple water taps
Long line due to no water in water tanks	Basonyagwe, Diling’ang, Endagaw Chini, Endanachan, Endamilay, Mewadani, Murukushida	• Bigger water tanks • Adding a component to the system that can make the pump work when there is no sun (battery or generator) • Bigger pump • Multiple solar panels • Optimise the angle and orientation of the solar panels
Hole in water tank	Mewadani Endagaw Chini	• Fix hole in water tank or install new water tank
No water when there is no sun	Endagaw Chini, Harar, Isene, Murukushida, Endamilay, Diling’ang	• Bigger water tanks • Adding a component to the system that can make the pump work when there is no sun (battery or generator)

Improvement measures to increase the flow rate provided by the water system is to install a bigger pump, install multiple solar panels and to optimize the angle of the solar panels. A bigger pump is suggested because none of the associated villages in Table 6.10 reported that the pump had stopped due to lowering of the groundwater table. Thus, the villages may be upgraded with a pump with higher pumping capacity. A cost-benefit analysis of pumps and an analysis of the effect on the groundwater table with different pumping capacities would be of interest for further research. All of the measures aiming to increase the daily water quantity provided by the water system, should be evaluated in conjunction with the groundwater level.

Regarding the solar panels, the actual usable radiation varies, depending on the geographical location, the cloud cover, smog and the hours of sunlight per day. Near the equator the annual solar power is up to 2500 kW/m$_2$. The power output is roughly linearly proportional to the intensity of the radiation. If the level of radiation is reduced, the current declines correspondingly. However, the voltage characteristic stays more or less the same, making the solar powered pumping systems function in low levels of sunlight, depending on the threshold power for starting the pump (UNICEF, 2010). However, during the fieldwork it was observed that the solar panels were sensitive to the weather condition. In some of the villages visited, a thin cloud cover led to insufficient power being supplied to the pump. Increasing the number of solar panels may lead to a less weather-sensitive system which can produce water even when there is a thin cloud cover. Another improvement measure in making the systems less weather-sensitive may be to optimize the tilt angle and the orientation in accordance to the sun. For maximum output is normally the angle of latitude of the location. However, near the equator a minimum angle of 15 should be kept for rainwater runoff to keep the panels clean. In the southern hemisphere, the general rule for solar panel placement is that the solar panels should face true north. Singh (2019) argues that the total amount of water pumped with a manually adjustable array is found to be greater by 3-5 percent compared to a fixed array throughout a year. Hence, a monthly manual tracking system could be applied within the study area. Evaluating such tracking system or adding more solar panels to the system and the associated effects on the power provided from the solar panels would be a useful topic for further research. Furthermore, it is of interest to compare cost implications of having a bigger water project, installing one or more of the improvement measures suggested in Table 6.10, vis-à-vis budget and potential impacted population (Zachayo Makobero, personal communication, 14th of April 2020).

Another major limitation of the solar powered pumping systems is the high initial capital cost. The implementation of solar powered pumping systems within the study area is largely dependent on a strong donor. According to the water committees within the study area, the villages contribute 25 to 30 percent to the project, each household contributing 10 000 TSh (4.32 USD in 2020). The rest of the project was funded by the NCA. The amount contributed varies within the study area and is dependent on the tribe within the village. The Hadzabe tribe is depending on nature and cannot contribute to the water system. The people within the Nilotic Datoga tribe are pastoralists, and sometimes it is difficult for them to contribute because they are not permanently settled. The people within the Iraqw tribe are settled, and they often have livestock and veggie-gardens and thus easier to raise funds from (Interview with 4CCP, February 2020).

6.3.2 Water Demand versus Water Supply

Single-Use Water Services

A water consumption of 23 lpcd for SUS was found from the survey conducted. This is an significant increase from the survey conducted in the same areas last year by Misund and Møller (2019), where a water consumption of 12.5 lpcd was found. The increase in water consumption may indicate that water is more available today, with at least nine new solar powered pumping systems constructed in the area during 2019 and early 2020. However, a water consumption of 23 lpcd is still worryingly low being just over the threshold defined by Howard and Bartram (2003) as "basic access" where the health concern is high (Table 6.2). The water consumption found is not sufficient in terms of the Tanzanian water policy to have a year-round supply of 25 litres of potable water per capita per day through water points located within 400 metres from the furthest homestead (URT, 2002). The distances and time involved in water collection result in use of volumes inadequate to support basic personal hygiene and may be marginally adequate for human consumption. To ensure health gains within the population served by basic access of water, providing protected water sources, promoting good water handling hygiene practices, and other hygiene behaviours such as hand washing, are critical (Howard and Bartram, 2003). This has been promoted through the NCA's WASH-program, where the last water projects within the study area were completed early in 2020. The WASH-program has amongst others provided safe drinking water sources, reduced the distance to the drinking water source for many people, and has helped people in the rural areas to understand the importance of good hygiene. Every village visited mentioned either safe and clean water or reduction of water related diseases within the village as one of the benefits using the solar powered pumping systems. Hence, the current water situation in the study area has had an overall positive effect on human health, particularly regarding water related diseases, despite the low water consumption for domestic activities.

Multiple-Use Water Services

According to Howard and Bartram (2003), the water quantities of 20, 50, and up to 100 lpcd are only used for domestic activities. However, van Koppen (2009) argues that even far below the "basic access" of 20 lpcd, water is also used and re-used for productive activities. Water for livestock is more important than personal hygiene, for example. At every higher level, even more water is used for productive activities. The empirical relationship between access to water and MUS is shown in Table 6.11.

Table 6.11: The multiple-use water ladder of service levels and water demand (van Koppen, 2009).

Service level	Volume (lpcd)	Water needs met	Distance or time of roundtrip
High level MUS	100-200	All domestic needs; combination of livestock, garden, trees and small enterprise	At homestead
Intermediate MUS	50-100	All domestic needs; livestock, garden, trees or small enterprise	< 150 or < 5 min
Basic MUS	20-50	Most domestic needs; some livestock, small garden or tree	< 500 m or < 15 min
Basic domestic	5-20	Very few domestic needs, basic livestock	> 500 m or > 15 min

The overall service level in the study area can be categorized in between "basic domestic" and "basic MUS", with a water consumption of 52 lpcd (MUS) which is a water volume within the definition of "intermediate MUS" service level. However, the average distance to source is 672 metres and the average time of roundtrip is 53 minutes. These values strongly exceed the corresponding thresholds within the "basic MUS" service level. Fundamentally, boreholes have limited potential for productive use of water at homesteads when the distance between the source and the homesteads is large and users need to carry water over long distances (ibid). This corresponds to the survey conducted during the fieldwork, with the main reason for not using water for productive uses as "distance to source" (61 percent). Other affecting factors were lack of water (29 percent), price of water (9 percent), and because they did not have livestock (1 percent).

In order to climb the MUS-ladder within the study area, a motorised pump is a prerequisite. This is because it takes a lot of effort to get a sufficient water quantity from a handpump, and thus may limit water both for domestic use and productive use. Other affecting factors are the reliability and sustainability of the water system. For the solar powered pumping systems, implementing add-ons such as a cattle through, or developing a garden next to the water point are other measures to climb the MUS-ladder (ibid). This has also already been implemented in some of the villages within the study area. With both the motorised pump and add-ons measures achieved, the next measures are to reduce the distance to the waterpoint and to increase and ensure the reliability and sustainability of the water system according to van Koppen (2009). However, Figure 6.7 indicates that an increase in distance to source does not negatively affect the water quantities used for productive activities. Thus, the reliability and sustainability of the existing water systems should be prioritised. Different improvement measures to increase both the reliability and sustainability of the water systems are to a large extent the same as the improvement measures to solve the challenges of the solar powered pumping systems presented in Table 6.10. In addition, other improvement measures are listed in chapter 8.

Water supply

From the water supply based on calculations, only the well in Basonyagwe provides sufficient quantity of water to meet the water demand for domestic activities (SUS). None of the wells within the study area are providing sufficient water quantity to meet the water demands for domestic activities and productive activities (MUS). Comparing these theoretical results with the measurements show a lower water production from every well. This may indicate bigger head losses within the system than found theoretically.

There are several sources of error that may have affected the results from the bucket testing. The time of measurement and weather condition may have affected the results where the irradiations may have been below the maximum threshold of the pump which further depict lower revolutions per minute (RPM) at time of measurement. In addition, the efficiency of the pump may have been reduced due to accumulation of dust on the solar panels. However, the results from the bucket testing indicate that the water systems are sensitive to irradiation obstructions. Another source of error is the accuracy of the measurements. Some of the water was lost during the bucket testing, particularly in high pressure wells, and thus the water production may be higher than what the results from the bucket testing show (see Figure 3.3). However, head losses in pipes and bends from the top of the well to the water tanks are not taken into account in the bucket testing which would result in even lower values.

In the calculation of flow rates, it is assumed a constant motor speed of 2850 rpm for DSD pumps and 2900 rpm for DS and DSP pumps (Davis and Shirtliff, 2014; 2017). The pump curves provided from Dayliff show when the pumps are running on 50 Hz. However, the behavior of the pump may be quite different for changed conditions, for example with different motor speeds (see Figure 6.10). During the fieldwork, it was observed several times that the pumps were running at 30 Hz and 40 Hz, also during the bucket testing. Christopher Bölter, a research assistant at TU Berlin Department of Fluid System Dynamics, argues that this may be due to that the water table in the well is located at SWL. Thus, the static head is lower and the pump can operate with a lower frequency (Christopher Bölter, personal communication, 9th of April 2020). Consequently, the values from the bucket testing may be affected by a higher water level than DWL which lead to some uncertainties. The water productions may be lower compared to if the pump was running at 50 Hz.

Based on documents provided by the NCA, it seems like the pumps installed in the wells are sometimes different to the pumps used in the pump testing. When using different pumps, there will be a difference in DWL (ibid). Thus, the DWL values used in the calculation of the system curves may not be accurate.

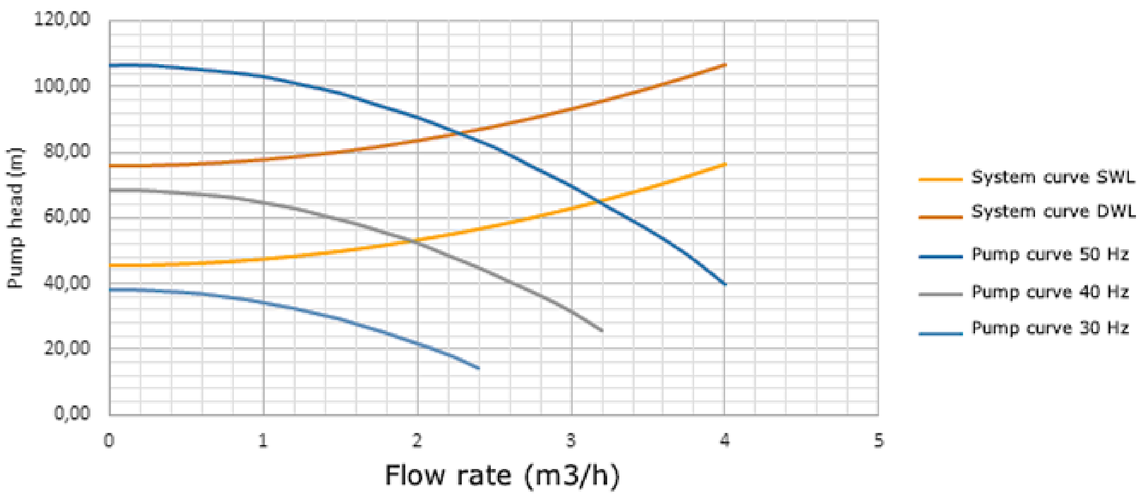


Figure 6.10: Pump curves and system curves in Mewadani village. Made by Christopher Bölter from TU Berlin (Christopher Bölter, personal communication, 9th of April 2020).

Table 6.5 shows the theoretical water production from the wells assuming optimal conditions 8 hours per day. As a general rule, tropical locations receive between 3 and 8 peak sun hours or mean daily insolation in kW/m$_2$ per day. The exact amount of insolation depends on the location and time of year, and it is possible to predict insolation fairly accurately on a monthly basis (Hankins, 2010). Figure 6.11 shows the mean daily insolation in Arusha located approximately 300 km from the study area. On a sunny day in October, Arusha receives more than 6 peak sun hours of insolation whereas on a cloudy day in July the same site receives 4.3 peak sun hours. However, local weather conditions and site altitudes cause large variations in solar radiation in sites even a few hundred kilometres apart (ibid). Thus, Figure 6.11 may not represent the mean daily insolation within the study area, but indicates that the mean daily insolation varies. Based on this, the assumption of 8 hours with sufficient sunlight can be considered as an optimal condition of the water systems.

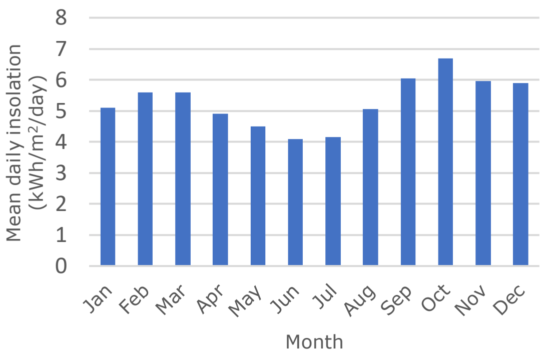


Figure 6.11: Mean daily insolation in Arusha, Tanzania (Hankins, 2010).

Hence, none of the solar powered pumping systems within the study area are producing sufficient quantities to cover both domestic and productive uses under what are considered as optimal conditions. The bucket tests conducted at the water systems show the water productions under conditions considered as not optimal leading to significant lower water productions within the study area. Thus, there is reason to believe that the actual water production from the solar powered pumping systems will be found between the theoretically water productions and the measured water productions. Based on this, it would be difficult to expand the water systems with pipes from the current solar powered pumping system since the water systems do not provide enough water to meet the current needs, even under optimal conditions. Different improvement measures presented in Table 6.10 are needed, or new wells must be drilled.

6.3.3 Distance to source

The curve of travel time and water consumption (Figure 6.1) suggests that water consumption drops substantively when water sources are located at distances greater than 30 minutes (1 km) away. The results based on the survey conducted in the study area did not show a clear decreasing water consumption with increasing distance to source, neither for SUS or MUS. The median water consumption for SUS is approximately equal for all distances and thus independent of distance to drinking water source. The median water consumption for MUS is higher for those having over one kilometre to the drinking water source than for those having up to 100 metres to the drinking water source. Hence, the water consumption for MUS does not decrease with increasing distance to source. According to 4CCP, one major task in the implementation of the solar powered pumping systems is to mobilise the communities to contribute to the solar powered pumping systems so that they can feel some kind of ownership (Interview with 4CCP, February 2020). This is primarily to increase the sustainability of the water systems as a result of the users caring enough to maintain and operate the water system adequately. Additionally, the feeling of ownership to the water system may also lead to people located at greater distances from the water source are coming to fetch water from the well. This in combination with type of water transport may explain the tendency of increasing water consumption with increasing distance in Figure 6.7. The villagers using water for both domestic and productive are likely to have cattle as 93.1 percent of them use water for livestock (see chapter 8.2.1). With greater distances, the extra effort and time used for arranging a transport with cows and cart (Figure 6.8) becomes more advantageous and may lead to a higher water consumption as more water can be collected each trip.

The survey conducted in the study area showed that on average, each household spends 2.5 hours per day fetching water. The median number was found to one hour per day. This is a remarkable decrease from the survey conducted by Misund and Møller (2019), where a median number of 2.8 hours and average number of 4.3 hours were used per day per household to fetch water. The average income per household is 1.250.345 TSh. If one assumes that they work 10 hours for 365 days per year, their payment per hour is approximately 343 TSh or 0.15 USD (2020). This is an annual increase in income of 187.793 TSh or 81 USD (2020) per household reducing the time fetching water from 4.3 hours to 2.8 hours. The increase relates with a difference of 30.000 TSh with the average income per household found by Misund and Møller (2019) found to 1.032.155 TSh. Thus, the increase in average annual income per household may be affected by the reduced time fetching water per day within the study area.

The survey further indicated that 94 percent of the respondents have access to an improved drinking water source, being either a handpump or solar powered pump. However, only 26 percent of these households use less than 30 minutes on a roundtrip fetching water. Hence, very few of the respondents fulfil the 30 minute basic service requirement (Table 6.2), and the coverage is very low compared to the national goal that 85 percent of the rural population should have access to an improved drinking water source within 400 metres by 2020/2021 (URT, 2016).

7 Willingness to Pay

The willingness to pay affects both the sustainability and replicability of a water supply system. Enough funding from the community to operate and maintain the system is a prerequisite to ensure a sustainable water supply system. From a MUS-approach point of view, one of the key assumptions in the implementation is that communities and households are willing and able to pay for "additional water" used for productive purposes.

During the fieldwork in Tanzania, a survey with 87 respondents were conducted to address the willingness-to-pay for MUS compared to SUS. In addition, the willingness-to-pay for current water source situation compared to the water source situation in 2019 based on the analyses done by Misund and Møller (2019) is also investigated. Microsoft Excel was used to analyse the data collected from the survey. The results are presented and discussed after a short presentation of the existing research on willingness-to-pay for water within rural areas.

7.1 Background

An important issue for water project designers and planners is how to ensure the financial sustainability of a water project. This may involve predicting what users will be able and willing to pay for water in the future. This indicator is commonly termed "willingness to pay" (WTP). WTP in economic terms is the maximum value that consumers attach to a commodity within the prevailing conditions (Webster, 2000). Within the study area, the WTP is a critical factor to address in terms of ensuring and increasing the sustainability of the solar powered pumping systems. In other studies it has been suggested that WTP relates to sustainability of the service in a chicken-egg-relationship. People are going to pay if the service is reliable and sustainable. However, if the performance goes down and service becomes irregular, people are less inclined to pay which may lead to diminishing of income for the water service provider, which in turn reduces the capacity to maintain and operate the service (van Koppen, 2009).

According to the water committees and PETS committees within the study area, the money collected from selling water are used to pay the caretaker and security guard, and to buy books and pens in order to register the amount of water used and sold. The remaining money is deposited into a bank account and used for maintenance or repairs of the water system if needed. Some of the water committees are also saving the money collected to expand the water project.

The water tariff within a village should be high enough to meet the financial objectives of the solar powered pumping system, and to prevent users being wasteful. Simultaneously, the tariff should be low enough to protect vulnerable user groups and thus to prevent people using other sources such as surface water. Hence, the fine line needs to be determined, and the water tariffs may vary between villages because of the variation in social and economic standing of the users. In addition, the tariff setting should be simple to administer and easy for consumers to understand. The payment method used within the study area are mainly cash per bucket at waterpoint. Other possible payment methods are mobile payments or bank transfer, and the payments could also be collected seasonal or annual. A relatively new technology within mobile payment of water is so-called "smartcards" that combines pre-paid water metering with remote monitoring. One provider of this technology is Grundfos LIFEINK A/S. The system includes a smartcard where water credits are stored, a AQ tap water ATM unit where the water is tapped and credits managed, and a water management system where data from transactions and operations are processed and published (Grundfos, N.A.). Using this system can amongst other minimize the risk of mistakes both in the reading of the water meter and in the logging of the revenue collected (see Chapter 8.2.5) as both the water consumption and revenue collected are directly transferred online. Thus, the water consumption and collected revenue can also be monitored remotely using this type of system.

Consumers' WTP for improved water services can be influenced by several factors. Recent surveys have added data from which several general conclusions can be drawn. Adepoju *et al.* (2011) have studied WTP for improved water supply in Nigeria using a binary logit model and found that income determines WTP for improved water supply. Kaliba, Norman and Chang (2003) estimated WTP to improve community-based rural water utilities in the Dodoma and Singida regions of Central Tanzania using multinomial logit functions. The study found that in the Dodoma region family size and satisfaction with the current system was a highly positive and statistically significant variable. A large family implies the need for more time and frequent trips collecting water. Thus, a service improvement reducing the time and effort expended in the water collection, such as increased pump capacity or number of watering points, are likely to be favorable for large families. Respondents that were satisfied with the current system with reference to project performance implied both an increased demand and WTP for improvement services. In the Singida region, they found a higher WTP amongst women than men. This was not found as a significant factor within the Dodoma region (ibid). Misund and Møller (2019) conducted a WTP survey within the districts of Hanang, Mbulu, and Mkalama and found that men generally have a higher WTP than women, except from spending less than 30 minutes each roundtrip. People had a varying WTP when looking at percentage of household income spent on water, where the poorest were willing to pay 30 percent of their income on water whereas the richest were willing to pay only 2 percent of their income on water.

There exists a sufficient amount of literature showing that a marginal increase in the volume of water supplied from a single use system could result in significant gains in the economic benefits realized from its users, and that these can exceed the cost involved (Kumar, 2013). Renwick *et al.* (2007) argue that once the basic domestic needs are met, which is approximately 20 lpcd, each additional lpcd generates an estimated $.5-$1 per year of income with the water being used for productive activities such as livestock rearing and kitchen garden. They further state that people are willing to pay and re-invest in systems that better meet their range of needs, but that the WTP also is related to other system performance indicators. Today, there exists a knowledge gap on the demand for MUS and willingness of the poor to pay for such services. Thus, further research is needed on WTP for multiple use services so that possible mitigation measures can be identified (ibid).

7.2 Results

7.2.1 Socioeconomic Characteristics of the Respondents

Most of the respondents (92 percent) are using a solar powered pumping system as (one of) their main drinking water source(s), as indicated in Figure 6.3. The figure also indicates that some of the respondents are using multiple water sources. The main reason for those using a river or pond was the distance to well.

Table 7.1 provides a summary of certain socioeconomic characteristics of the respondents. The sampled population is aged between 18 and 66, with and average age of 41 years. Over fifty percent of the respondents are within the ages of 30 and 50. Forty percent of the respondents were female, even though the members of the water committees within the study area most often consist of equal amount of men and women. The average annual household income is approximately 1.250.344 TSh (540 USD in 2020).

Table 7.1: Descriptive statistics of total respondents' socioeconomic characteristics

Characteristic	Definition	Mean	Std. dev	Min	Max
Gender	Binary value, 1 if respondent is female; 0 otherwise	0.40	0.49	0.00	1.00
Age	Age of respondent	41	12	18	66
Number of people in household	Numbers of household members living together	7	3	1	20
Income	Household income in Tanzanian shilling per year (USD in 2020)	1250344.8 (540.3)	1367056.3 (590.7)	10000 (4.3)	7000000 (3024.8)

The analyses of WTP is divided into those using water solely for domestic activities (SUS), constituing 64 percent of the respondents, and those using water both for domestic and productive activities (MUS) constituing 33 percent of the respondents. The descriptive statistics divided into SUS and MUS are presented in Table 7.2.

Table 7.2: Descriptive statistics of respondents' socioeconomic characteristics divided into those using water for domestic activities (SUS) and those using water both for domestic and productive activities (MUS)

Characteristic	Definition	Water use	Mean	Std. dev	Min	Max
Gender	Binary value, 1 if respondent is female; 0 otherwise	SUS	0.30	0.45	0.00	1.00
		MUS	0.10	0.33	0.00	1.00
Age	Age of respondent	SUS	38	21	18	63
		MUS	47	23	27	66
Number of people in household	Numbers of household members living together	SUS	7	4	1	20
		MUS	8	4	3	13
Income	Household income in Tanzanian shilling per year (USD in 2020)	SUS	1309464.3 (565.7)	1365648.3 (589.9)	20000 (8.6)	7000000 (3024.8)
		MUS	1143548.4 (494.0)	835899.8 (361.1)	10000 (4.3)	4000000 (1727.9)

7.2.2 WTP Scenarios

Four scenarios are further investigated in terms of WTP and are based on the socioeconomic information collected from the survey. Some of the scenarios are also defined based on the scenarios made by Misund and Møller (2019) to simplify the comparison between current WTP and the WTP in 2019. Additionally, a new scenario from those defined by Misund and Møller (2019) is investigated in the WTP analysis to evaluate the potential of implementing, or improve, water projects providing water for multiple uses. Each scenario is divided into those using water only for domestic activities (SUS) and those using water for both domestic activities and productive activities (MUS).

- Using less than 30 minutes when fetching water. This is a roundtrip that includes walking both ways to the water point and waiting time at the well
- Tap shared with five neighboring households to improve service in terms of distance to source
- Tap in house, which is the closest alternative in terms of distance to source
- The source providing enough water to create an income using water for productive uses

Table 7.3: Summary of total WTP for different improved services and differences in the mean values between the survey conducted by Misund and Møller (2019) and 2020. The values are given in TSh/bucket where a bucket is 20 litres.

WTP Scenario	Max	Min	Median	Mean	Difference from mean 2019
<30 minutes	200.0	10.0	50.0	44.7	-33.3
Five neighbors	150.0	10.0	50.0	67.5	-51.5
Tap in house	200.0	10.0	100.0	95.3	-26.6
Create an income	200.0	10.0	75.0	79.0	-

As found from the analysis done by Misund and Møller (2019), the average of total WTP increases with decreasing distance to source. However, all mean values found from the survey conducted in 2020 are lower than those found in 2019. Furthermore, the survey showed a relatively high WTP for having a water source that can provide enough water to be used to productive activities and thus create an income (Table 7.3).

Table 7.4: The average WTP values divided into respondents using water for domestic activities (SUS) and those using water for productive activities (MUS).

WTP Scenario	Mean total	Mean SUS	Mean MUS	Mean total 2019
<30 minutes	44.7	48.3	38.6	78.0
Five neighbors	67.5	80.4	45.2	119.0
Tap in house	95.3	103.7	82.1	122.0
Create an income	79.0	79.0	78.8	-

The respondents using water only for domestic activities (SUS) have a higher WTP for all scenarios compared to the respondents using water both for domestic activities and productive activities (MUS).

7.2.3 Gender and WTP

The effects of gender on the WTP for water service improvements were investigated with both median WTP and mean WTP for all scenarios and are presented in Figure 7.1 and Figure 7.2. There are differences in WTP for women and men using both average and median values. Generally, men are willing to pay more for water than women, with an average WTP of 74 TSh per bucket compared to 67 TSh bucket for women for all scenarios. The only scenario where women are willing to pay more than both men groups is for a tap shared between five neighbors, using the median values.

Men using water solely for domestic uses (SUS) have the highest average WTP for all scenarios. Women using water solely for domestic activities have a higher average WTP than men using water for multiple activities for all scenarios except from when they can create an income. Within this scenario, the women using water for multiple activities are willing to pay more than both men using water for multiple activities and women using water for domestic activities.

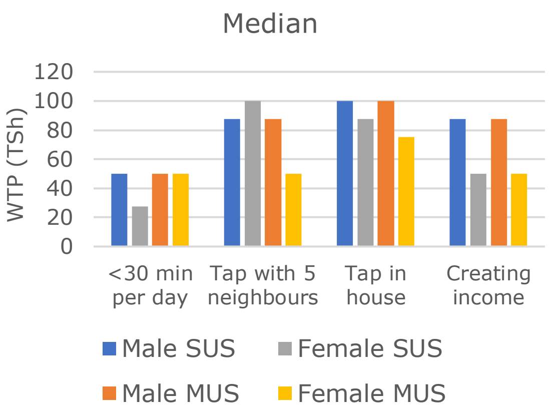


Figure 7.1: WTP using median values for women and men, given in TSh/20 L bucket.

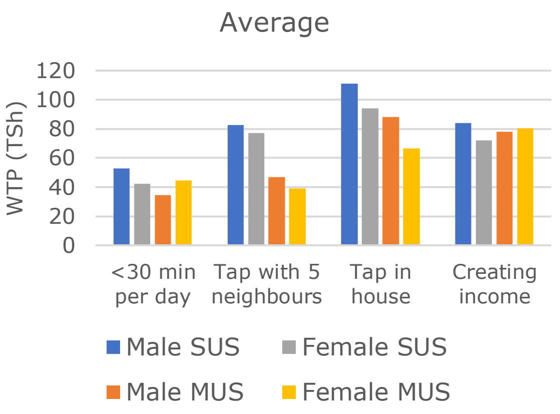


Figure 7.2: WTP using average values for women and men, given in TSh/20 L bucket.

As shown in Table 7.4, respondents using water solely for domestic activities are willing to pay more than the respondents using water for both domestic and productive activities. The average WTP for all scenarios is 82.7 TSh for men (SUS), 71.4 TSh for women (SUS). 61.9 TSh for men (MUS), and 57.6 TSh for women (MUS).

7.2.4 Income and WTP

The respondents were divided into 10 income groups because of large income disparities. Out of the 87 respondents, 65 gave information about distance to source. It is of interest to see if the income data are anchored to a particular location to the water source. The total household income by distance to source is shown in Table 7.5.

Table 7.5: Distribution of annual income per household (TSh) with distance to water source

Annual income per household (TSh)	**# of respondents**	**0-50m**	**51-100m**	**101-300m**	**301m-1000m**	**>1000m**
1.000-90.000	7	28.6%		6.3%	10.7%	16.7%
100.000-200.000	7	14.3%		18.8%	7.1%	16.7%
300.000-400.000	10	28.6%	25%	12.5%	10.7%	16.7%
500.000	7		50%		10.7%	
600.000-800.000	3			6.3%	3.6%	16.7%
900.000-1.000.000	11			18.8%	21.4%	33.3%
1.200.000-1.500.000	3				10.7%	
2.000.000	6		12.5%	12.5%	10.7%	
2.500.000-3.000.000	4	14.3%		12.5%	3.6%	
4.000.000-10.000.000	7	14.3%	12.5%	12.5%	10.7%	
Average annual income per household (TSh)		1.230.000	1.212.500	1.571.875	1.251.786	521.667

Table 7.5 shows that none of the households with a distance to water source over 1000 metres have an income within the highest income groups. The highest percentage within the highest income group are those located closest to the water source. However, the households located closest to the source are also those with highest percentage within the lowest income group. The household located within a distance of 101-300 metres to the source have the highest average annual income. Out of the 87 respondents, 85 gave information about how much time they use per roundtrip fetching water. Households using less than 30 minutes per roundtrip have an average annual income of 1.360.476 TSh and households using more than 30 minutes per roundtrip have an average annual income of 1.225.156 TSh, which equals a difference of 58.5 USD (2020).

Furthermore, the mean values of the four different improved services for each of the income interval groups were calculated, plotted and divided into respondents using water solely for domestic activities and respondents using water for domestic (Figure 7.3) and productive activities (Figure 7.4).

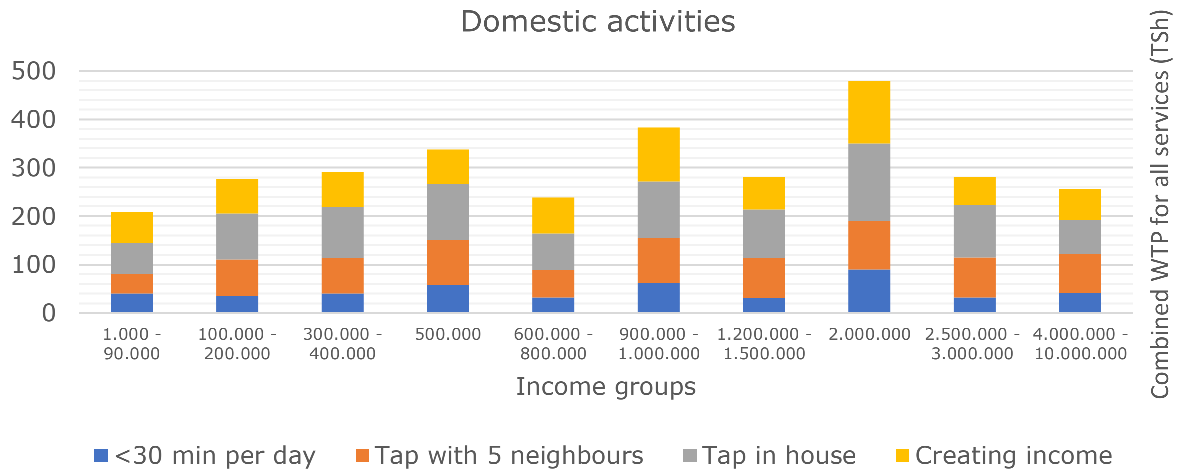


Figure 7.3: WTP for SUS where the respondents are divided into income scales

As seen from Figure 7.3, the lowest income group has the lowest WTP. The income group where households have an annual income of 2 million TSh has the highest WTP. The highest income group are among the income groups with lowest WTP. The two income groups with highest WTP have a relatively high WTP for creating an income compared to the other income groups.

Amongst the respondents using water for domestic and productive activities, the highest WTP is found within the second highest income group. As in Figure 7.3, the WTP for creating income is relatively high within the two income groups with the highest combined WTP compared to the other income groups in Figure 7.4.

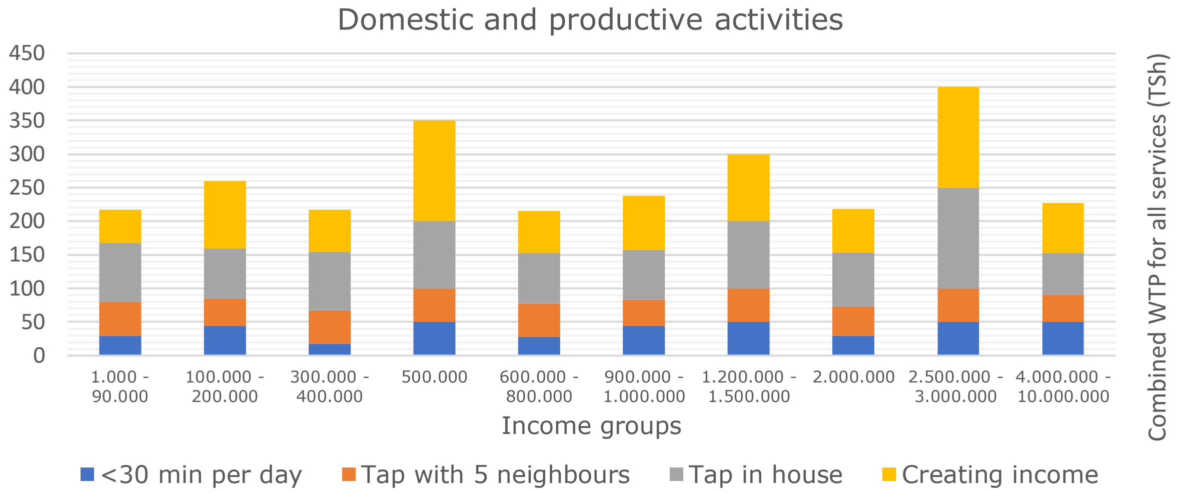


Figure 7.4: WTP for MUS where the respondents are divided into income scales

Figure 7.5 and Figure 7.6 illustrate the median WTP over all the five factors for a years' average use of water, plotted as a percentage of income that they are willing to pay for water. The average use of water is found individually for each household.

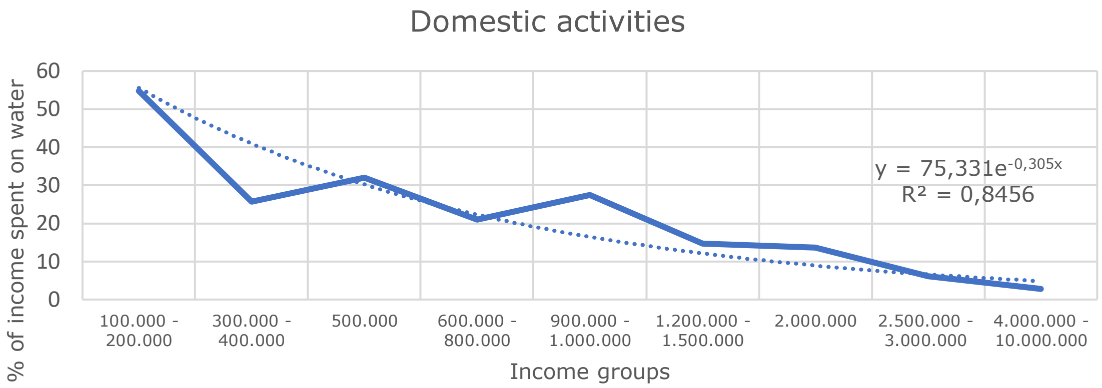


Figure 7.5: WTP as a percentage of income versus income for respondents using water solely for domestic activities

As Figure 7.5 indicates, the trend line has a negative exponential decay, with a R-squared value of 0.85. Thus, the people within the lowest income group have a higher WTP in percentage of their income compared to the people within the highest income group.

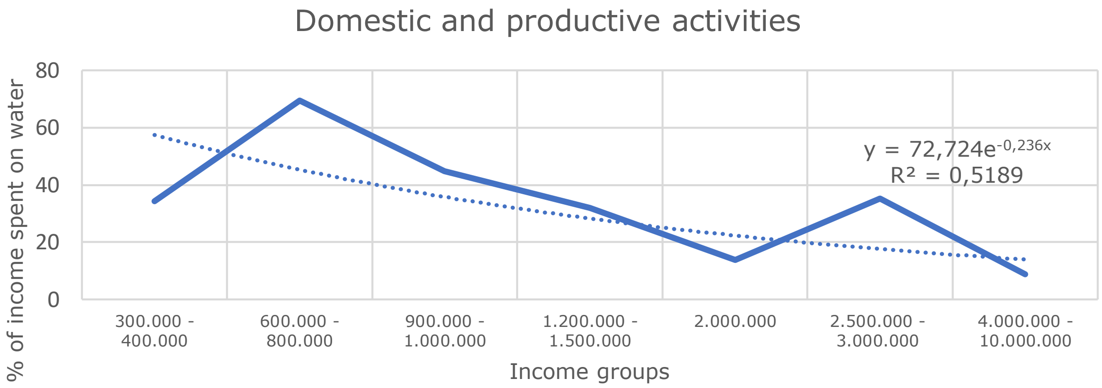


Figure 7.6: WTP as a percentage of income versus income for respondents using water for domestic and productive activities

As in Figure 7.5, the trend line in Figure 7.6 has a negative exponential decay. The R-squared value of 0.52 is lower than for people using water solely for domestic uses. Hence, there is not a clear relationship between the percentage of income spent on water and income for people using water for domestic and productive activities.

During the calculation of the percentage of income used on water, it was found that some of the households are willing to pay more than 100 percent of the income. If a respondent agrees to pay over 50 percent of their income on new water supply offered this would call into question the accuracy of the data. Although in some extreme cases people have been known to spend over 50 percent of their income on water during droughts and very dry seasons (Wedgwood and Sansom, 2003). Hence, the households willing to spend more than 100 percent of their income on water are removed from the analysis both in Figure 7.5 and Figure 7.6. Thus, the lowest income group in Figure 7.5, and the two lowest income groups and the 500.000 income group in Figure 7.6 are removed. All of the respondents within these groups were willing to spend more than 100 percent of the income on water.

7.2.5 Time and WTP

According to the survey conducted, 64 of the 87 respondents gave information regarding distance to source, waiting time at water tap, average water consumption per household per day, and how much water was collected each trip. When asked about the time used per roundtrip, 64 out of 86 answered that they use more than 30 minutes per roundtrip and 21 out of 86 answered that they used less than 30 minutes per roundtrip. Respondents using more than 30 min on a roundtrip are willing to pay 71.4 TSh per bucket whereas the respondents using less than 30 minutes per roundtrip are willing to pay 73.5 TSh per bucket, using the average WTP for all scenarios. Furthermore, dividing the respondents into nine groups based on their mean roundtrip time, plotted against mean WTP for all scenarios, gave a R-squared value of 0.05 and 0.01 for respondents using water for domestic activities and respondents using water both for domestic and productive activities, respectively. Dividing the respondents into the same groups based on their mean time fetching water per day, plotted against mean WTP for all scenarios, gave a R-squared value of 0.21 and 0.08 for respondents using water for domestic activities and respondents using water for both domestic and productive activities, respectively. All of the plots showed a weak negative linear tendency of people using more time to fetch water, per roundtrip and per day, are less willing to pay for water. However, the R-squared values for all of the plots are too low to conclude that there is a relationship between time used fetching water and WTP.

As can be seen from Figure 7.7, there are negative tendencies for having water source within 30 minutes, tap in house, and creating an income. The only positive tendency is associated with sharing tap with five neighbors, but this tendency has the lowest R-squared value among the scenarios. All of the R-squared values for people using water solely for domestic activities are too low to conclude that there is a relationship between WTP and mean time spent on fetching water per day.

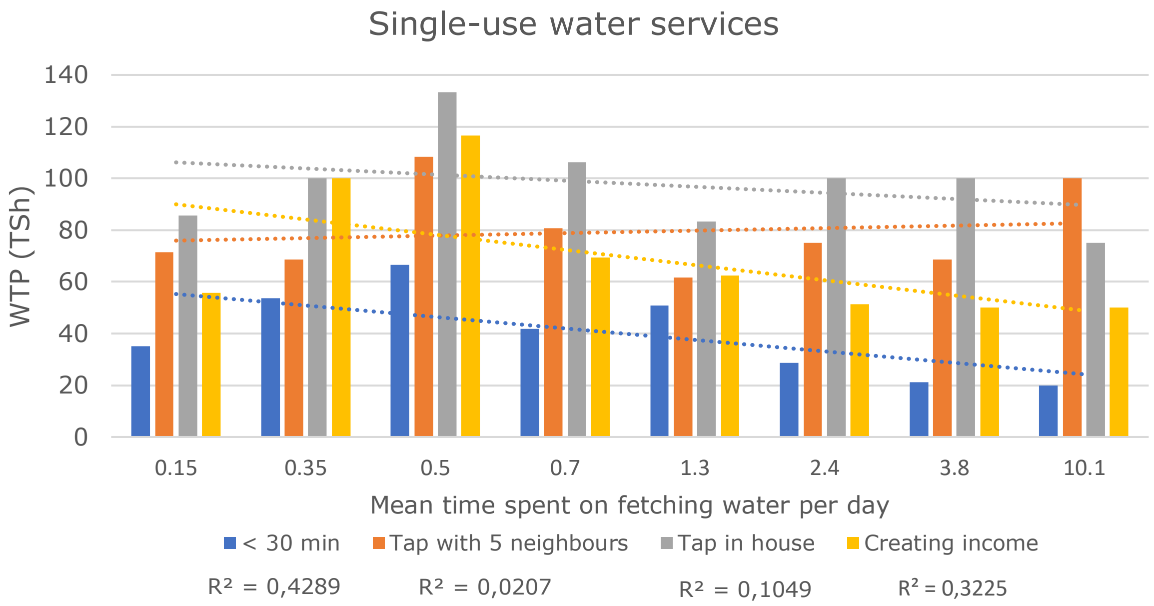


Figure 7.7: WTP versus mean time spent on fetching water per day for those using water solely for domestic activities

The only positive tendency of the scenarios for those using water for domestic and productive activities is to have a water tap in house (Figure 7.8). However, the R-squared values for all scenarios are too low to conclude that there is a relationship between WTP and time spent fetching water per day.

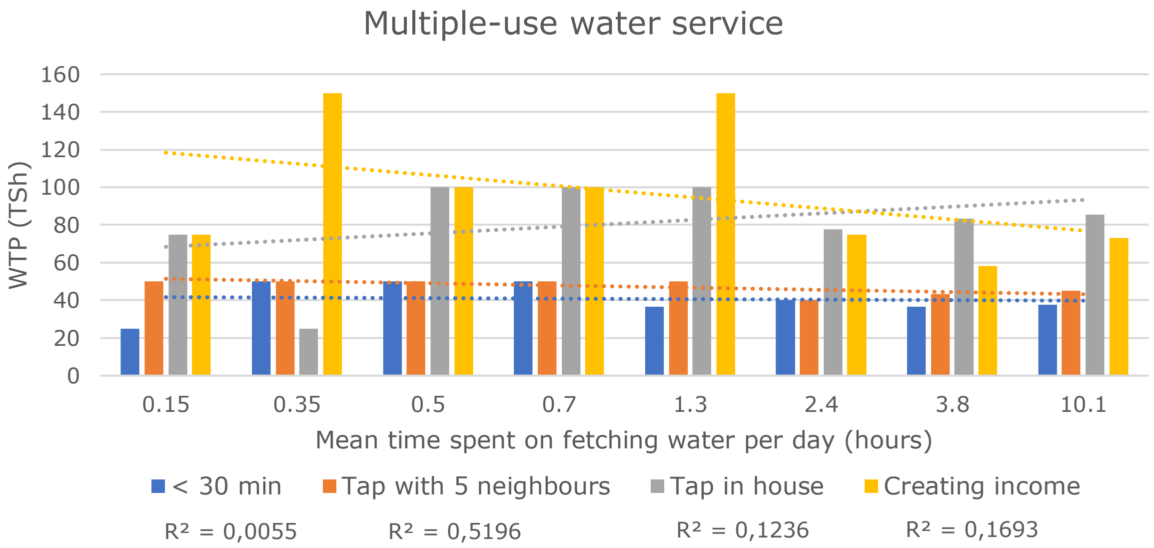


Figure 7.8: WTP versus mean time spent on fetching water per day for those using water solely for domestic and productive activities

7.2.6 WTP for Current versus Improved Service

Figure 6.3 shows that 92 percent of the respondents use solar powered pumping system as (one of) their main drinking water source(s). Of those using water solely for domestic activities, 86 percent use solar powered pumping systems as their main drinking water source. Of those using water for domestic and productive activities, everyone are using solar powered pumping systems as one of their main drinking water sources. Five respondents use a river or a pond as their main drinking water source, and two respondents use handpump as their main drinking water source. Due to the small proportion of respondents using handpump, river or pond, the further analyses only include respondents using solar powered pumping systems as drinking water source. The average price per bucket within the study area is 28.8 TSh where 51.7 percent of the respondents pay 20 TSh, 6.9 percent pay 25 TSh, 19.5 percent pay 30 TSh, and 21.8 percent pay 50 TSh per bucket. Only respondents who pays 50 TSh per bucket are willing to pay more for water from the current water source. 12 out of the 19 respondents paying 50 TSh are willing to pay more per bucket with an average increase per bucket of 92.7 percent, which equals a total price of 96.4 per bucket.

Furthermore, the WTP per bucket for improved services compared to current price per bucket was investigated. Figure 7.9 illustrates the percentage increase of the WTP per bucket for improved services compared to the current prices per bucket. Some of the price-per-bucket groups and improved sources are not presented in Figure 7.9 because the respondents within these groups were not willing to pay more for improved services than they currently are paying per bucket of water.

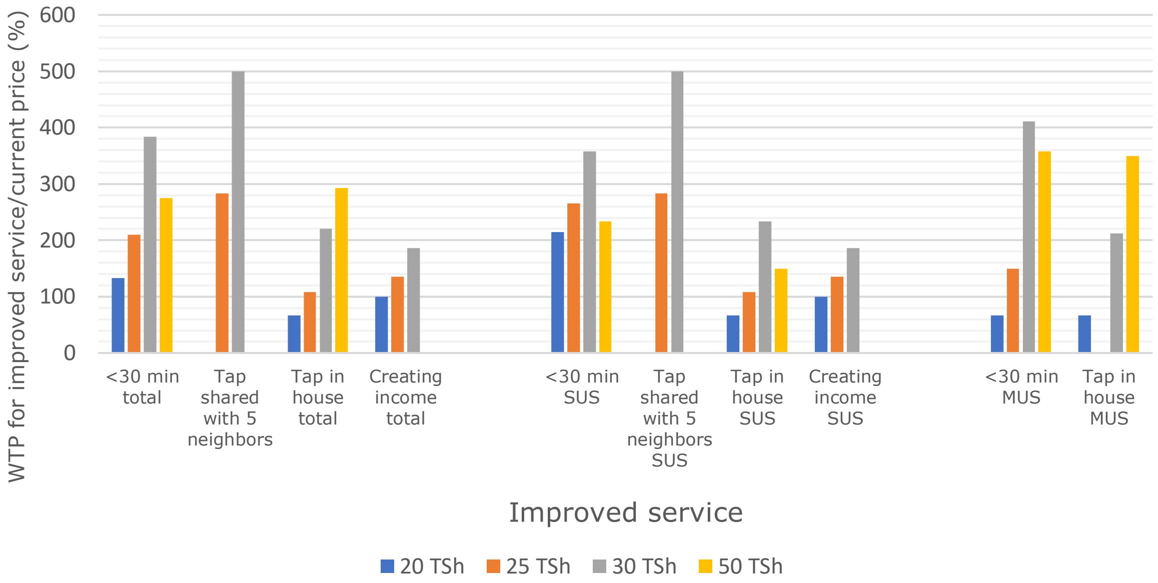


Figure 7.9: Percentage increase of the WTP per bucket for improved services compared to the current prices per bucket of water

The average percentage increases in WTP for an improved service compared to current price of water are 99.7, 184.2, 322.5, and 284 for the respondents paying 20 TSh, 25 TSh, 30 TSh, and 50 TSh per bucket respectively. This equal total prices per bucket of 39.9 TSh for respondents paying 20 TSh, 71 TSh for respondents paying 25 TSh, 126.8 TSh for respondents paying 30 TSh, and 192 TSh for respondents 50 TSh.

When the respondents were asked how high the annual income had to be in order for them to be willing to pay more per bucket of water, 33 percent answered under 2000 TSh, 39 percent answered 2000-6000 TSh, 17 percent answered 6000-10.000 TSh, and 11 percent answered over 10.000 TSh.

In addition, the relationship between WTP and reliability of the current system was investigated. When asked how satisfied they were with the current system, 49 percent were very satisfied, 41 percent were somewhat satisfied, and 7 percent were not satisfied. A regression analysis of the average total WTP for all improved services amongst users and the reliability of the system, in terms of satisfaction degree of the current system, gave a R-squared value of 0.98. The R-squared values for each improved service are shown in Figure 7.10.

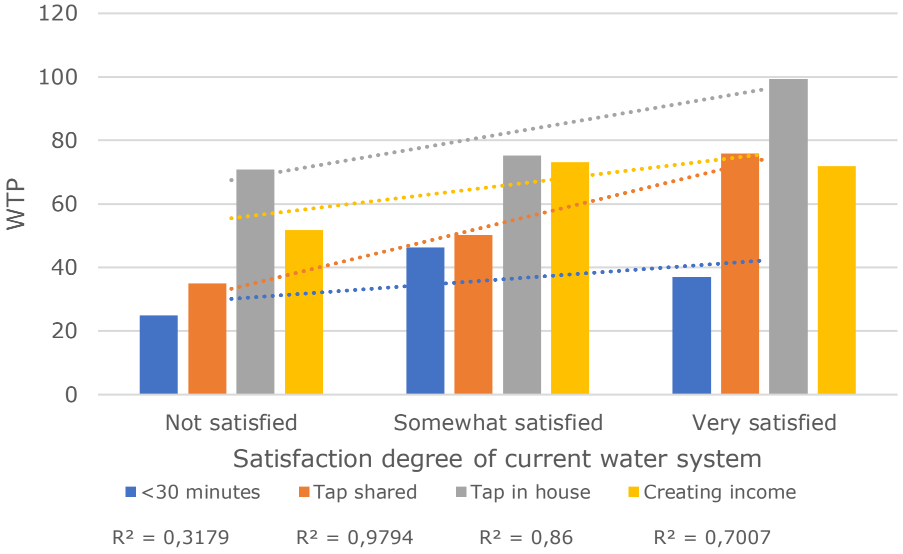


Figure 7.10: Relationship between WTP and reliability of current water system

Figure 7.10 shows an increasing trend in WTP with increasing reliability of the current system for a tap shared with five neighbors, tap in house, and creating an income. The R-squared value for having a drinking water source within 30 minutes is too low to conclude that there is a relationship between WTP and reliability of the system. This is due to a higher WTP amongst the respondents that are somewhat satisfied than the WTP amongst the respondents that are very satisfied of current water system.

7.3 Discussion

The effects of gender on the WTP for water service improvements were investigated. The analyses showed that men generally had a higher WTP than women for all scenarios. A minimal difference in WTP between gender was found for using less than 30 minutes each roundtrip fetching water with an average WTP of 43.7 TSh for men and 43.3 TSh for women. The biggest difference in average WTP between men and women was found within the scenario of having a tap in the house where men were willing to pay 24 percent more per bucket than women. Kaliba, Norman and Chang (2003) found that in the Singida region, females were more willing to pay for improvement services than male respondents. They further argue that this was not a surprising result since the females are primarily responsible for water fetching activities. This difference was not found in the Dodoma region which they saw as an unexpected result. However, there were generally few complaints regarding the utility project within the Dodoma region due to high reliability of the system which could have affected the results (ibid). The results from the survey conducted by Misund and Møller (2019) also showed a generally higher WTP amongst men, except from the aspect where reduction to 30 minutes per roundtrip fetching water was addressed. This corresponds to the findings in this thesis and may indicate that even though the women mostly have the responsibility of fetching water, men care. Misund and Møller (2019) argue that the higher WTP amongst men may be due to the social aspect of collecting water, meaning that women often meet friends on the way fetching water. This was not mentioned as a motive amongst women during the fieldwork and is not supported by the data from the survey, as the average WTP is highest for a tap in house amongst women.

One interpretation for the higher average WTP amongst men could be due to the women's lack of access to finances, and that they therefore are hesitant to make higher bids. A WTP analysis based on choice modelling by Kanyoka, Farolfi and Morardet (2008) showed that a lower income had a negative impact on the WTP for all improvement services. Within the study area, men state that the household have an annual average income of 1.534.039 TSh compared to 828.857 TSh amongst women, which corresponds to a 85 percent higher annual household income for men. Thus, this may be a reason why there is a difference in the WTP between men and women.

An unexpected finding from the survey conducted was that respondents using water for both domestic and productive activities have a lower WTP than the respondents using water solely for domestic activities, as can be seen from Table 7.2. The same table shows that MUS-respondents have a lower average annual income than the SUS-respondents which may affect the WTP. This contradicts other literature stating that there is a significant increase in income when the water consumption exceeds the quantity of water that covers the basic domestic needs of 20 lpcd (Renwick *et al.*, 2007). According to 4CCP, it is easier to raise funds from the communities that use water for productive activities compared to communities dependent on the nature and pastoralist communities, which is also contradictory to the findings from the survey (Interview with 4CCP, February 2020). The results may be affected by the relatively small sample size of respondents using water for productive activities. Thus, more research is needed to validate the results from the survey conducted.

Furthermore, the results show that people within the lowest income scales have a higher WTP in percentage of their income compared to the people within the highest income scales. This tendency was also found by Misund and Møller (2019). They argue that this result shows the importance of the access of water. Water is highly prioritised amongst people living in a rural low-income setting. According to the results, the SUS-respondents with the lowest income are willing to use over half of their annual income on improvement measures to increase the access of clean and safe drinking water. MUS-respondents within the lowest income group are willing to pay 34 percent of their annual income. According to the Tanzanian water policy, one of the rural water supply objectives is to "provide adequate, affordable and sustainable water supply services to the rural population" (URT, 2002, p. 30). However, the Tanzanian water policy does not define an affordability threshold. According to The National Growth and Poverty Eradication Strategy, the consumers should pay tariffs that recover costs within an affordability range of 3-5 percent of income (The World Bank, 2018). The villagers within the study area pays more than ten times as much. Hence, the results from the survey show that the water tariffs within the study area may be affordable for some, but might not provide an universal access of water.

The WTP is relatively high both amongst SUS-respondents and MUS-respondents for the scenario of the source providing enough water to create an income using water for productive uses. The smallest difference in WTP between SUS-respondents and MUS-respondents is found within this scenario. The survey showed that 89 percent of the total respondents are willing to pay 80 TSh per bucket of water if they can create a daily income of less than 10000 TSh which equals 4.3 USD (2020). This result can be taken into account in the designing and implementation of new solar powered pumping systems or if improvement measures are to be introduced to existing water systems. It may be possible to increase the existing price of water. However, this must be seen in conjunction with the previous section. The tariff cannot be too high in order to ensure that all villagers connected to the well can afford sufficient quantities of clean and safe water.

Within the study area, 49 percent of the respondents were very satisfied, 41 percent were somewhat satisfied, and 7 percent were not satisfied with the current water system. It is not clearly shown that provision of water for multiple use leads to an increased willingness to pay for operation and maintenance costs. However, WTP often depends on the reliability of systems and reliable systems often facilitate multiple use (van Koppen, 2009). Figure 7.10 shows an increase in WTP with an increase of satisfaction degree of the current water system, particularly for having a tap in house and sharing a tap with 5 neighbours. Thus, the results indicate that poor conditions in terms of satisfaction degree of current water system affect the ambitions and willingness of rural households to improve their status. Increasing the reliability of the current water system will increase both the WTP for improving measures amongst the respondents and may lead to more people using water for productive activities. Furthermore, the highest WTP was for a tap in house, both amongst SUS-respondents and MUS-respondents. Both increasing the reliability of the system and having a private tap will facilitate multiple use of water due to an increase of the water availability which further will lead to a higher total water demand amongst users. Currently, the water supply systems within the study area do not provide sufficient quantities of water today (see Chapter 6.2.2). Thus, a hybrid-system where a solar powered pump is connected to a grid, battery, or a diesel generator is most likely required.

8 Multiple-Use Water Services

This chapter deals with the productive uses of water both at a household level and at a water system level within the study area. The chapter aims to identify benefits and challenges of using water for productive activities. In addition, influencing factors on the willingness of villagers to use water for productive activities are investigated and further discussed.

8.1 Background

In rural areas of Tanzania, water is needed for a variety of essential uses ranging from drinking, hygiene and sanitation to food production and income generation. Multiple-use water services (MUS) take this range of needs as the starting point when planning, financing, and managing water services (MUS group, 2013). There are three main ways in which MUS can be implemented: 1) upgrading by installing an "add-on" to an existing system, 2) single-"plus", in which a single-use system is designed to allow for subsequent phased expansion, and 3) MUS by design where services are designed for multiple use from the start (ibid). In the implementation phase, an over-estimate of the total water demand gives the communities the possibility to climb the ladder shown in Table 6.11, in terms of increased water quantity.

Past studies have shown benefits of MUS in terms of water-based income generation and women's empowerment. Marks SJ (2016) also reports great benefits using MUS compared to SUS in terms of indirect impacts such as livelihood, income, food security and reliability of the water system. The results were based on a survey conducted in the Morogoro region of Tanzania with a total household sample size of 1377. Farmers using MUS were more likely to be undertaking and earning more income from activities with water. Total income earned amongst MUS users were typically $125 during the rainy seasons and $350 during dry seasons compared to $75 during wet season and $200 during dry seasons amongst SUS users. Furthermore, the report shows that the food security was significantly better among household belonging to MUS, as compared to households belonging to SUS. 84 and 65 percent of farmers reported their food security as "very secure" within MUS and SUS respectively. In addition, households belonging to MUS consumed 6.4 food types, as compared to 5.7 by SUS householdings showing that MUS have higher potential of varied diet compared to SUS householdings. When asked about the satisfaction of the current water supply system, 57 percent amongst villagers using water for productive activities said "very satisfied" compared to 44 percent amongst villagers using water solely for domestic activities (ibid).

Within the study area, the NCA has installed add-ons in 6 of the 29 completed solar powered pumping systems; an irrigation system for veggie-garden, a cattle trough, or both. The add-ons were implemented from November 2018 to February 2019 (4CCP, personal communication, February 2020). Amongst the villages visited during the fieldwork, Basonyagwe, Endagaw Chini, and Murukuchida have irrigation systems for veggie-gardens directly connected to the water storage tanks. According to the water committees within the study area, the majority of the rest of the villages visited wish to have veggie-gardens in the future. In Endanachan village, Gidbyo village, and Gidurudagew village the water committee is planning on adding a cattle trough to the solar powered pumping system.

According to the survey conducted, 64 percent of the respondents are using water from the solar powered pumping systems solely for domestic activities (SUS), whereas 33 percent of the respondents are using water both for domestic and productive activities (MUS).

8.2 Results

The results presented are based on the survey conducted within the study area, with 87 respondents. In addition, water consumption for cattle and veggie-garden directly connected to the solar powered pumping systems is investigated based on readings by the water system caretaker in Basonyagwe village.

8.2.1 Productive Activities

Amongst the 33 percent of the villagers within the study area using water for productive activities, 93.1 percent use water for livestock watering, 41.1 percent use water for construction, 24.1 use water for irrigation, and 6.9 percent use water for beer brewing. The results indicate that some of the respondents (48.3 percent) use water for multiple productive activities.

The reasons for not using water for productive activities were distance to source (61 percent), lack of water (29 percent), price of water (9 percent), and that they did not have a livestock (1 percent).

8.2.2 Satisfaction of Current Water System

When asked how satisfied the respondents were with the current water supply system 49.4 percent were very satisfied, 41.4 percent were somewhat satisfied, and 6.9 percent were not satisfied. Amongst the respondents using water solely for domestic activities, 10 percent were not satisfied, 10 percent were somewhat satisfied, and 80 percent were very satisfied with the current water supply system. Amongst the respondents using water for both domestic and productive activities 13.3 percent were not satisfied, 66.7 were somewhat satisfied, and 20 percent were very satisfied with the current water supply system.

8.2.3 Food Security and Nutrition

Amongst respondents using water solely for domestic activities 67.9 percent categorized their food situation as insecure, 30.4 percent as somewhat insecure, and 1.8 percent as very secure. Amongst respondents using water for productive activities 16.1 percent and 83.9 percent categorized their food situation as insecure and somewhat insecure respectively. None of the respondents using water for productive activities categorized their food situation as very secure.

Respondents using water solely for domestic activities consume a wider variety of food types (5.3 food types) as compared to the respondents using water for both domestic and productive activities (4.8 food types). Since the main productive activity within the study area is livestock watering, the consumption of meat, dairy, and eggs was also investigated. SUS-respondents were much more likely to have eaten one or more animal products in the past week (98.2 percent) compared to respondents using water for domestic and productive activities (80.6 percent). However, MUS-respondents were more likely to have consumed dairy products (51.6 percent) compared to SUS-respondents (26.8 percent).

8.2.4 Income versus Water Consumption

The average daily water consumption per household amongst respondents using water for both domestic and productive activities was plotted against income groups to investigate if there is a correlation between income and water consumption. Figure 8.1 shows an increasing trend in water consumption with increasing income. However, the R-squared value are too low to conclude that there is a relationship between average daily water consumption per household and income.

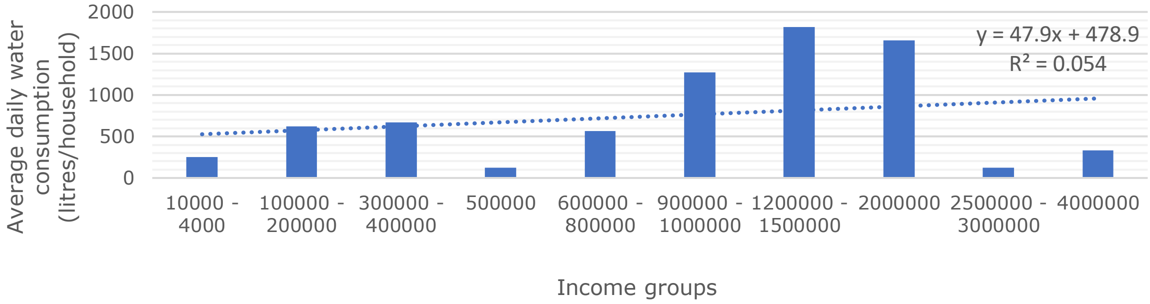
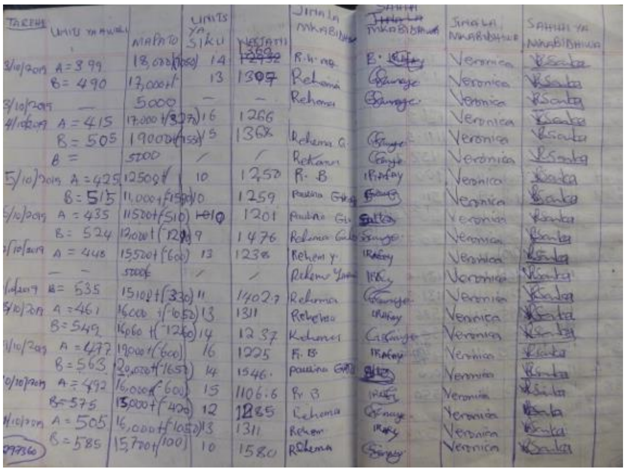


Figure 8.1: Household income groups and associated average water consumption for domestic and productive activities.

8.2.5 Veggie-garden and Cattle Trough

In the solar powered pumping system in Basonyagwe village there are two water meters, one of which measures the water consumption for both the veggie-garden and the water taps, whereas the other water meter measures water consumption from the cattle trough. Based on the readings registered in the water book during September 2019 (Figure 8.2), the water consumption for both cattle and veggie-gardens was calculated.

In Figure 8.2 water meter A shows water consumption for the veggie-garden and water taps, whereas water meter B shows the water consumption from the cattle trough.



TAREHE	UNITI YA AWALI	MAPATO	UNITS YA SIKU	WASTANI	JINA LA MKABIDHI	SAHIHI YA MKABIDHI	JINA LA MKABIDHIWA	SAHIHI YA MKABIDHIWA
3/10/2019	A = 399	18,000/(1050)	14	~~12432~~ 1369	R.h.ng		Veronica	
	B = 490	13,000+/	13	1307	Rehema		Veronica	
3/10/2019	—	5000	—	—	Rehema		Veronica	
4/10/2019	A = 415	17,000+/(327)	16	1266			Veronica	
	B = 505	19000+/(155)	15	1368	Rehema G.		Veronica	
	B =	5000	/	/	Rehema		Veronica	
5/10/2019	A = 425	12500+/	10	1250	R. B		Veronica	
	B = 515	11,000+/(1590)	10	1259	Paulina G.		Veronica	
5/10/2019	A = 435	11500+/(510)	~~10~~ 10	1201	Paulina G.		Veronica	
	B = 524	13,000+/(120)	9	1476	Rehema G.		Veronica	
/10/2019	A = 448	15500+/(600)	13	1238	Rehem y.		Veronica	
—	—	5000	/	/	Rehema Y.		Veronica	
/10/2019	B = 535	15100+/(330)	11	1402.7	Rehema		Veronica	
/10/2019	A = 461	16000+/(1052)	13	1311	Rehema		Veronica	
	B = 549	16060+/(1260)	14	1237	Rehema		Veronica	
/10/2019	A = 477	19000+/(600)	16	1225	R. B		Veronica	
	B = 563	20,000+/(1652)	14	1546	Paulina G.		Veronica	
0/10/2019	A = 492	16,000+/(600)	15	1106.6	R. B		Veronica	
	B = 575	15,000+/(420)	12	1285	Rehema		Veronica	
/10/2019	A = 505	16,000+/(1052)	13	1311	Rehema		Veronica	
99736	B = 585	15,700+/(100)	10	1580	Rehema		Veronica	

Figure 8.2: Registered water consumption and collected revenue in Basonyagwe village.

It is assumed that the caretaker has registered the number from the water meters in the evening, and thus the collected revenue represents the difference in the number from the water meter in cubic metres from the day before. The price of water in Basonyagwe village is 30 TSh per bucket of 20 litres. The size of the veggie-garden in Basonyagwe village is 200 m_2 and the number of cattle using the solar powered pumping system is 1900. Based on this, an average daily water consumption for the veggie-garden was found to be 14.9 litres/m_2. The average daily water consumption per cattle was found to be 6.4 litres. The numbers used in the calculation with associated standard deviations are shown in Appendix 14.

Regarding the revenue collected from the veggie-garden, the villages stated that they are still at the beginning stage, so they are not yet producing to the market. Thus, they do not have a number on revenue collected from the veggie-garden.

8.3 Discussion

When asked about the satisfaction of the current water supply system, 20 percent amongst villagers using water for productive activities said "very satisfied" compared to 80 percent amongst villagers using water solely for domestic activities. The results indicate that villagers use water for productive activities regardless of the satisfaction degree of the current water system. One could think that a higher satisfaction degree of the current water system may lead to people using water for productive activities. However, the use of water for productive activities may rather affect the degree of satisfaction negatively, as the users expect more from the water system than solely to provide enough quantities of water to cover domestic activities. Hence, the results based on the survey conducted within the study area indicate that the water systems to a large extent provide sufficient water quantities to cover domestic activities, but not productive activities.

Regarding the food security, the results show that MUS-respondents have a higher food security than SUS-respondents where 16.1 percent and 67.9 categorized their food security as insecure respectively. However, the SUS-respondents have a higher variety of food types consumed than the MUS-respondents. One would think that MUS-respondents are more likely to consume animal products compared to SUS-respondents as 93 percent of the MUS-respondents use water for their livestock. The results from the survey conducted are contradictory to the hypothesis with a 98.2 percent probability amongst SUS-respondents to consume animal products compared to a probability of 80.6 amongst MUS-respondents. However, the probability of consuming dairy products was almost twice as high for MUS-respondents compared to SUS-respondents. The results may be seasonal as the livestock have access to water and food during the rainy season, and it would be beneficial for livestock keepers to feed the livestock during the rainy season to produce an optimal amount of meat. The survey within the study area were conducted when there still was presence of heavy rain and thus access to food and water for the livestock. However, more research on the differences in nutrition amongst SUS- and MUS-respondents within different seasons is needed to draw a conclusion.

Comprehensive estimations of water demands and supply in different cropping systems in Tanzania are lacking (Kimaro, 2019). A water consumption for the veggie-garden in Basonyagwe was found to be 14.9 litres/m^2 based on readings from the water meter. This is a significantly higher number than used by the NCA in their calculation of the expected water demand for the installed veggie-gardens, which is 3-6 litres/m^2. The number used by the NCA are based on the experience from their agronomist and existing Climate Smart Economic Empowerment projects (Zachayo Makobero, personal communication, 7th of May 2020). However, there are large uncertainties in the calculations based on the water meter readings. As seen from Figure 8.2 the caretaker registers the number from the water meter in cubic metres. One cubic meter equals 50 buckets of 20 litres. Thus, the number registered does not represent the exact water consumption from the water tap and veggie-garden. In addition, there is a high probability of human error in the readings and registrations of both the water metres and the collected revenue. For example, on the 23rd of September 2019, the money collected in Basonyagwe village exceeds the amount of water read from the water meter leading to a negative water consumption for the veggie-garden using this method (see Appendix 14). Martinsen (2018) also faced challenges in the calculation of water consumption based on water meter readings due to human errors, and argues that more intensive training and follow-up of the reader are needed to get reliable results. Another possible solution to this problem is the use of smartcards, which is previously mentioned in chapter 7.1.

The NCA defines a MUS system as a water system providing water for both domestic and productive activities (Manfred Arlt, personal communication, 8th of April 2020). However, they distinguish between a water system *used* for multiple activities and a water system *designed* for multiple activities. In documents from the NCA with an overview of solar powered pumping systems within the study area and associated water demand and water supply, a system is categorized as a MUS system when a cattle trough or an irrigation system for veggie-garden is directly connected to the water system (see Appendix 15). Thus, Gidbyo, Endamilay, Murukuchida, and Basonyagwe village are designed as MUS-systems. However, according to the survey and interviews conducted within the study area, people are using water for productive activities even though the water system is not designed for it. A general problem is that there are relatively few wells within the study area, which lead to a higher demand than designed for because villagers are bringing their livestock to the well and people from greater distances are coming to fetch water (ibid). The increased demand for water is expected due to the increased availability of water (Zachayo Makobero, personal communication, 14th of April 2020).

The solar powered pumping systems within the study area are designed from WASH TCP guidelines for domestic use and national guidelines. The guidelines recommend to provide 25 lpcd through water points, and ensures that the water points are used by a maximum of 250 persons within 400 metres from the source (Zachayo Makobero, personal communication, 7th of May 2020). Thus, there are significant differences in the water demands calculated by the NCA and the water demands based on interviews and survey conducted within the study area. For example, in Murukuchida village the calculated daily water demand by the NCA is 35 m^3 whereas the daily water demand calculated based on interview with the water committee in Murukuchida village and survey conducted is 200 m^3 (see Table 6.4 and Appendix 15). Hence, it is currently difficult for some of the villages within the study area to climb the MUS ladder (Table 6.11) because of the insufficient quantity of water to cover domestic activities. This is also a concern from 4CCP. They state that there are multiple benefits regarding MUS such as increase in income, family health, and living standard. However, sufficient quantity to cover domestic activities must be provided from the solar powered pumping systems before one can start to think of using water for productive activities within the study area, particularly in terms of veggie-gardens (4CCP, personal communication, February 2020).

Furthermore, 4CCP has identified two other problems related to the veggie-gardens. During the dry seasons, the veggie-garden is green compared to the surrounding areas. This currently leads to that the crops are often damaged by insects and other animals. Additionally, the presence of heavy rainfall has shown to damage crops due to erosion (Interview with 4CCP, February 2020). According to Zachayo Makobero, a solution to protect crops from insects and animals is to change the types of crops to fruits that are more resilient such as mango, orange, banana, and pawpaw (Zachayo Makobero, personal communication, 7th of May 2020). Further work is needed to identify improvement measures which can solve issues related to erosion of the veggie-gardens within the study area.

9 General Discussion and Conclusions

This Master's thesis focused on the solar powered pumping systems installed from WASH TCP 2015-2019. The research has been done through case study, aiming to answer five research questions. The research questions have been investigated in cooperation with the EWB Norway, the NCA, and 4CCP through a fieldwork over five weeks in Hanang, Mbulu, and Mkalama districts in northern Tanzania. The results from the fieldwork have subsequently been compared to literature, particularly the research by Martinsen (2018) and Misund and Møller (2019). Furthermore, this thesis is to a large extent divided into two groups related to if water is solely used for domestic activities (SUS) or if water is used for both domestic and productive activities (MUS).

- *How can a remote monitoring system affect the sustainability of a solar powered pumping system?*

During the fieldwork, three remote monitoring systems were installed within the study area. Multiple sensors provided by the Norwegian companies NGI and El-Watch were installed with the overall goal to increase the sustainability of the solar powered pumping systems. The remote monitoring systems include a pressure sensor in the well, a pressure sensor in the storage water tank, and digitizers transmitting data regarding the groundwater levels and the available battery voltage within the remote monitoring system. According to the data transmitted from the pressure sensor in the well in Basonyagwe village and Mewadani village, the groundwater levels have increased since the installation of the sensor and seem to be highly affected by precipitation. Based on the results, the pressure sensor in the well can be used to monitor trends of groundwater levels over a longer time-period. However, the measurements seem to have too large uncertainties to monitor the groundwater levels on a daily basis because of some measurements that are considered as unlikely and sometimes even impossible. The measurements are affected by disturbances which are most likely due to the sensors having a relatively large measuring range. This further leads to small changes in pressure experienced by the sensor and further transmitted in mA can result in large changes after the conversion to groundwater level in metres.

Furthermore, the results from the pressure sensor in the water tanks indicate that it is possible to remotely monitor the water level in the tank when the valve between the tanks and tap is open, and thus to know when the water storage tanks are full or empty. If the sensor shows that the water tanks have been empty or the valve has been closed for a longer period of time, it may indicate that there is something wrong with the system and calls for a check-up of the water system. The available battery voltage can indicates on when the solar panel is activated or not and on the operation of the remote monitoring system to monitor that the components work properly.

Hence, the installed remote monitoring systems may positively affect the sustainability of the solar powered pumping systems as one can monitor that the water systems are not over-abstracting the aquifer over longer time-periods. Additionally, the pressure sensor in the water tank can be used to monitor the downtime of the system as one can check if the water storage tanks are empty or if the valve from the water tanks to the tap is closed. However, the challenge regarding the remote monitoring systems is related to management, in deciding who is responsible for maintaining and operating the systems, and how to potentially upscale the systems to be used in other rural areas. Further research is needed to address these challenges.

- *To what extent do the solar powered pumping systems provide sufficient drinking water quality?*

The water quality parameters tested at the solar powered pumping systems during the fieldwork were pH, alkalinity, fluoride concentration, conductivity, and turbidity. The same water quality parameters were also tested in a local dam in Basonyagwe village, a local spring in Endagulda, and the RWH systems at Haydom secondary school and Mewadani primary school. In addition, the presence of hydrogen-sulphide producing bacteria was tested in four of the solar powered pumping systems, Basonyagwe local dam, the two RWH systems, and Endagulda spring.

According to the Tanzanian drinking water standard, the water provided from the solar powered pumping systems is generally of sufficient quality to drink, except from high levels of fluoride concentration in Endanachan village and Munguli village and a high turbidity value in Endanachan village. However, when comparing the water samples with the upper limit of turbidity given by WHO, Basonyagwe village and Endamilay village also provide water with exceeding turbidity values. Although the turbidity values were high, which may stimulate the growth of bacteria, the groundwater is considered to have a sufficient quality for drinking. The water committees in the villages stated that there has been a strong reduction in water related diseases in the area. The water provided from six of the solar powered pumping systems exceed the upper limit of fluoride content given by the WHO. Therefore, treatment methods to reduce the fluoride concentration in the groundwater should be tested and implemented within the study area to reduce the health risks related this may cause.

In addition, the water quality testing showed presence of hydrogen-sulphide producing bacteria in the groundwater in Endagaw Chini village and Diling’ang village. However, the results in combination with observations and interviews during the fieldwork indicate that the water provided from the solar powered pumping systems in Endagaw Chini village and Diling’ang village currently are clean and safe for drinking. Multiple tests are needed in the wells in Diling’ang village and Endagaw Chini village to eliminate the risk of the presence of hydrogen-sulphide producing bacteria. According to the water committees and the district water engineers within the study area, the solar powered pumping systems installed by the NCA have led to a significant reduction of waterborne diseases within the study area.

- *To what extent do the solar powered pumping systems meet the water demands, both for domestic uses and for productive uses, today and in the future?*

The water demand for the villagers within the study area was found to be 23 lpcd for villagers using water solely for domestic activities, and 52 lpcd for villagers using water for both domestic and productive activities. This is a significant increase from the water consumption of 12.5 lpcd found by Misund and Møller (2019). The results indicate that there has been an increase of the availability of water due to the new solar powered pumping systems installed within the study area during 2019 and early 2020.

Furthermore, the time used to fetch water has decreased after the installation of the solar powered pumping systems. The results show that on average, each household spends 2.5 hours per day fetching water. The median number was found to be one hour per day. This is a remarkable decrease from the results found by Misund and Møller (2019), where an average number of 4.3 hours and median number of 2.8 hours were used per household per day. According to 4CCP, the decrease in time used fetching water has led to a number of benefits within the study area such as more time used to productive activities, improved performances amongst pupils at schools, improved living standard amongst villagers, and improved children's health since women do not need to leave their children at home for many hours to fetch water (Interview with 4CCP, February 2020). However, the water consumption is still worryingly low, particularly amongst those using water solely for domestic activities. The national goal that 85 percent of the rural population should have access to an improved drinking water source within 400 metres by 2020/2021, is unlikely to be met. Currently only 26 percent of the households within the study area use less than 30 minutes on a roundtrip fetching water. Hence, although there has been an increase of water availability within the study area, more work is needed to make the water availability universal and to meet the Tanzanian water policy goals.

Based on the identified water consumptions, the water quantities provided by the solar powered pumping systems within the study area were compared to the water demands. The results from the study show that only the well in Basonyagwe village provide enough water to cover the water demands under what is considered as optimal conditions when assuming that water is only used for domestic activities. None of the wells provide enough water to cover the water demands for both domestic and productive activities assuming optimal conditions. Thus, improvement measures are needed to meet the water demand both for domestic activities and productive activities presently and in the future. The major problem with the solar powered pumping systems identified based on observations and interviews during the fieldwork is that they do not produce water when there is not sufficient sunlight. Suggested improvement measures to increase the water production from the wells are to build a hybrid-system with either a battery or diesel generator in combination with bigger water storage tanks, add multiple solar panels, optimise the angle and orientation of the solar panels, and installing a stronger pump.

- *What is the willingness to pay for the multiple-use water services compared to single-use water services, and what are the affecting factors?*

The WTP was investigated for four different scenarios including different improvement measures related to water accessibility. The highest WTP, being 95.3 TSh per bucket, was not surprisingly found for having a tap inside the house. The scenario with the second highest WTP, being 79 TSh per bucket, was for having a water source that provides enough water to create an income using water for productive activities (MUS). Thus, the results show that the respondents are willing to pay more for a MUS-system than for sharing a tap between 5 neighbours and for using less than 30 minutes on a roundtrip. Out of the total number of respondents, 89 percent are willing to pay 79 TSh per bucket of water if they can create a daily income of less than 10000 TSh which equals 4.3 USD (2020). This can be taken into account in the implementation of MUS-systems or if improvement measures are to be introduced to existing SUS-systems. However, the water tariff cannot be too high in order to ensure that all villagers connected to the water system can afford sufficient quantities of clean and safe water.

The WTP analyses show that this is already a problem within the study area, with households in the lowest income group spending over 30 percent of their income on water. This is more than 10 times more than the World Bank defines as affordable for a household.

Furthermore, the results show that a higher satisfaction of current water system increases the WTP for having a tap in house, for creating income, and for sharing a tap with 5 neighbours. Thus, increasing the reliability of the current water system will according to the results increase the WTP for multiple improvement measures amongst the respondents. This may further lead to more people using water for productive activities as reliable water systems often facilitate multiple use. In addition, the results showed a higher WTP amongst men compared to women. This difference may be due to that men stated that their household income is 85 percent higher than household income stated by women, and that women therefore are hesitant to make higher bids.

> *What are the benefits and challenges of multiple-use water services compared to single-use water services?*

The results from this study have identified multiple benefits using water for productive activities. The villagers can create an income, women can start with productive activities, the family health increases, and the living standard amongst villagers increase. Additionally, the results showed that respondents using water for both domestic and productive activities have a higher food security than respondents solely using water for domestic activities with 16.1 percent and 67.9 percent categorized their food security as insecure, respectively. However, the major challenge regarding the MUS concept within the study area is related to the insufficient water production from the solar powered pumping systems. The water provided from the wells need to meet the domestic water demands before using water for productive activities can be considered within the study area. As mentioned above, the results have shown that the solar powered pumping systems to a large extent do not provide enough water to meet the demands for domestic activities. This is most likely due to that the water projects are undersized in terms of predicted water demand.

The NCA distinguishes between a water system *used* for productive activities and a water system *designed* for productive activities. Within the study area, the solar powered pumping system is designed as a MUS-system if a cattle trough or irrigation system to a veggie-garden is directly connected to the water storage tanks. The water demands for both cattle and veggie-gardens are defined by the NCA, but they are not taken into account in the calculation and presentation of the total water demand for the solar powered pumping systems. Furthermore, the solar powered pumping systems are designed from WASH TCP and national guidelines. Thus, the NCA has designed the solar powered pumping systems to provide water to villagers living within 400 metres from the source, which in this case is defined as half of the population in the village. This leads to a significantly higher total water demand found in this thesis. The total water demand in this thesis includes the people using the solar powered pumping system as their primary drinking source regardless of distance to source, for cattle using the solar powered system as their drinking source, and from the veggie-gardens. Hence, the Tanzanian water policy should be updated to better meet the total water demand. Based on the results found from this study, the current water policy and associating design basis leads to the total water demand in the design of the solar powered pumping systems being underestimated and brings risks to the sustainability of the water systems.

To conclude the research questions in this thesis:

- The remote monitoring systems installed have successfully transmitted data online. The measurements seem logical, but should be compared to observations or manually testing to be validated. Furthermore, the results from this study have shown that the remote monitoring systems may positively affect the sustainability of the solar powered pumping systems. However, the remote monitoring systems should be continued to monitor and analyse the data transmitted over a longer time-period and include data from different seasons. In addition, a challenge needed to be addressed regarding the remote monitoring systems is to determine who will be responsible for the maintenance and operation of the systems. This applies to both the existing remote monitoring systems and potential future expansions of the systems to other villages within the study area.

- The solar powered pumping systems only meet the water demand in Basonyagwe village when water is solely used for domestic activities. None of the solar powered pumping systems meet the water demand when water is used for both domestic and productive activities. Improvement measures are required to increase the water production to further meet the water demand today and in the future.

- The installation of the solar powered pumping systems has led to a significant reduction in water related diseases within the study area. The water provided from the solar powered pumping systems is generally of sufficient quality to drink, except from some high levels of fluoride concentration. Treatment methods to reduce the high values of fluoride concentration should be tested and be further implemented within the study area to reduce the health risks related to the ingestion of high fluoride concentrations.

- Respondents are willing to pay more for multiple-use water services than sharing a tap with two neighbours and to use less than 30 minutes per roundtrip fetching water. The major affecting factor was the reliability of the water system, with a higher WTP for higher satisfaction degree of current water system.

- Multiple benefits regarding the use of multiple-use water services were identified. However, the major challenge is that none of the solar powered pumping systems within the study area provide enough water to be used to productive activities as the water systems are undersized in terms of predicted total water demand. The extra water demand from livestock, veggie-garden, and people located over 400 metres from the water source, have to be taken into account in the future if new solar powered pumping systems are to be built and designed as MUS-systems. The current design basis is not sufficient and may bring risks to the sustainability of the water systems.

10 Future Work

The research conducted in this thesis has left some questions unanswered and identified areas of interest considered as highly relevant for further research. Since the time-frame of this thesis has led to limitations of collected data from the installed remote monitoring systems, a continuation in analysing the measurements is needed to investigate the trends during the dry seasons. Combining the measurements transmitted from the sensors with manual measurements and observations is recommended to validate that the online data is up to date. Furthermore, one should determine the distribution of responsibilities in terms of maintenance and operation of the remote monitoring systems. It would also be interesting to look into if other sensors can be added to the system, such as water quality sensors, sensors measuring the electricity delivered by the solar panels, and other sensors measuring the functionality of different parts of the solar powered pumping system.

More thorough reviews and practical testing of the methods on reducing fluoride concentrations in the groundwater are required to determine whether they can be applied in a sustainable way in rural Tanzania. Particularly the use of the adsorption methods with bone charcoal and leaf powder should be tested, as it has shown to be highly beneficial in rural Tanzania. The optimal amount of adsorbents should be determined, and one should investigate if the adsorbent could be used at household level or water system level.

The NCA and 4CCP plan to install six new solar powered pumping systems within the study area. These systems could be used as pilots with the introduction of one or more of the suggested improvement measures. A comparison between these systems and existing systems, particularly in terms of water production versus water demand, are of great interest for further research. Furthermore, associated cost-benefit analyses of these systems should be executed to compare cost implications of having a bigger water project vis-à-vis budget and the potentially impacted population.

More research on the WTP to use water for productive activities is needed. Furthermore, the study has shown that villagers using water solely for domestic activities have a higher annual income than villagers using water for both domestic and productive activities. Thus, investigating these findings and identifying affecting factors on the income generated by using water for productive activities is of interest.

Finally, veggie-gardens directly connected to the solar powered pumping systems are still in a pilot phase. 4CCP and the water committees within the study area are still uncertain about both the water demand and how much revenue can be collected from the projects. Methods to measure the exact water demands for different types of crops and within different seasons should be investigated, to further be used in the designing of the MUS-systems to ensure that the water production can meet the water demand. Additionally, erosion is also a challenge regarding the veggie-gardens. Improvement measures to address this issue should be identified, as it would increase the resilience of the veggie-gardens.

References

4CCP (2020) *Our story*. Available at: 4ccp.org (Accessed: 04. April 2020).

Adepoju, A. *et al.* (2011) Social capital and rural farming households' welfare in Southwest Nigeria, *World Rural Observations*, 3(3), pp. 150-161.

Ahmed, S. and Asraf, R. M. (2018) The workshop as a qualitative research approach: lessons learnt from a "critical thinking through writing" workshop, *Turk Online J Des Art Commun*, (Special edition), pp. 1504-1510.

Baumann, E., Ball, P. and Beyene, A. (2005) Rationalization of Drilling Operations in Tanzania, *Review of the Borehole Drilling Sector in Tanzania*.

Baumann, E. *et al.* (2010) *WASH Technolgy Information Packages* (UNICEF Report): United Nations. Available at: https://sswm.info/sites/default/files/reference_attachments/MONTANEGRO%20et%20al%202010%20WASH%20Technology%20Information%20Packages.pdf (Accessed: 27 May 2020).

BGS (2000) *Groundwater Quality: Tanzania*. (British Geological Survey Report): British Geological Survey. Available at: http://nora.nerc.ac.uk/id/eprint/516324/1/Tanzania.pdf (Accessed: 5 June 2020).

Brannen, J. (1992) Combining qualitative and quantitative approaches: an overview *Mixing methods: Qualitative and quantitative research.* Routledge, pp. 3-37.

Brundtland, G. H. (1987) *Report of the World Commission on environment and development:" our common future."*. Oslo: United Nations. Available at: file:///Users/trineroer/Downloads/our_common_futurebrundtlandreport1987.pdf (Accessed: 14 March 2020).

Cairncross, S. and Feachem, R. G. (1993) *Environmental health engineering in the tropics: An introductory text*. 2nd edn. Chichester: John Wiley and Sons Ltd.

Chilton, J. (1996) Chapter 9 - Groundwater, in Chapman, D. (ed.) *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring* Second edn. UNESCO/WHO/UNEP.

Dalland, O. (2012) *Metode og oppgaveskriving for studenter.* Gyldendal Akademisk. .

Davis and Shirtliff (2014) *DS/DSP Submersible Borehole Pumps - Installation & Operating Manual*. Available at: https://www.dayliff.com/media/com_hikashop/upload/safe/ds-dsp_instruction_manual_62715300.pdf (Accessed: 6 May 2020).

Davis and Shirtliff (2017) *DSD 3/18*. Available at: https://davisandshirtliff.com/water-pumps/product/1352-dsd-3-18 (Accessed: 16 May 2020).

Davis and Shirtliff (2018) *SV2/1.5M - Product overview*. Available at: https://www.davisandshirtliff.com/solar/product/1403-sv2-1-5m (Accessed: 14 May 2020).

DNR (n.a.) *Why water level rises*. (Missouri Geological Survey Report): Missouri Department of Natural Resources. Available at: https://dnr.mo.gov/geology/wrc/docs/WhyWaterLevelsChange.pdf (Accessed: 4 June 2020).

Eikeland, J. N. *et al.* (2020) Florid i Tanzania. Trondheim: NTNU. (Accessed: 11 June 2020).

El-Watch (2020) *Et komplett trådløst sensorsystem*. Available at: https://www.el-watch.com/neuronsensors/ (Accessed: 30 May 2020).

El-Watch (n.a.) *Neuron sensors: utvalg*. Available at: https://www.el-watch.com/neuronsensors-utvalg/ (Accessed: 31 May 2020).

Engineering Toolbox (2004) *Minor or Dynamic Loss Coefficients for Pipe or Tube System Components*. Available at: https://www.engineeringtoolbox.com/minor-loss-coefficients-pipes-d_626.html (Accessed: 10 June 2020).

Fagerland, J. (2020) Veggie-garden, i Report, N. (ed.). E-mail exchange with Manfred Arlt. (Accessed: 4 April 2020).

FAO (2016) *Country profile - United Republic of Tanzania*. Rome, Italy: AQUASTAT and Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/3/i9836en/I9836EN.pdf (Accessed: 1 April 2020).

Fierro, A. *et al.* (2019) Rural Water Supply Management in Tanzania: An Empirical Study on COWSO Strategy Implementation and Private Sector Participation *JUNCO| Journal of UNiversities and international development COoperation*, (2). (Accessed: 28 May 2020).

GCM (2020). Available at: https://www.globalclimatemonitor.org/ (Accessed: 4 June 2020).

Ghoneim, A. (2006) Design optimization of photovoltaic powered water pumping systems, *Energy conversion and management*, 47(11-12), pp. 1449-1463.

Groundwater Relief (2020) *The Pocket Dipper*. Available at: https://groundwater-relief.org/tools/the-pocket-dipper (Accessed: 15 June 2020).

Grundfos (N.A.) *AQtap water dispenser* Available at: https://www.grundfos.com/products/find-product/aqtap.html#overview (Accessed: 25 May 2020).

GWIC (2020) *Typical well construction and terms*. Available at: https://mbmggwic.mtech.edu/sqlserver/v11/help/welldesign.asp (Accessed: 11 June 2020).

Hach (2020) *What is the difference between the turbidity units NTU, FNU, FTU, and FAU?* Available at: https://support.hach.com/app/answers/answer_view/a_id/1000336/~/what-is-the-difference-between-the-turbidity-units-ntu%2C-fnu%2C-ftu%2C-and-fau%3F-what (Accessed: 12 June 2020).

Hankins, M. (2010) *Stand-alone solar electric systems: the earthscan expert handbook for planning, design and installation*. Earthscan.

Harvey, P. (2011) *Sustainable supply chains for rural water services - linking local procedure of handpumps and spare parts supply*. Rural Water Supply Network. Available at: http://www.rural-water-supply.net/_ressources/documents/default/214.pdf (Accessed: 12 June 2020).

Howard, G. and Bartram, J. (2003) *Domestic Water Quantity, Service, Level and Health*. WHO. Available at: https://apps.who.int/iris/bitstream/handle/10665/67884/WHO_SDE_WSH_03.02.pdf?sequence=1&isAllowed=y (Accessed: 10 April 2020).

International Association of Hydrogeologists (2019) *What is Hydrogeology and what do Hydrogeologists do?* Available at: https://iah.org/education/general-public/what-is-hydrogeology (Accessed: December 10th 2019).

Kaliba, A. R. M., Norman, D. W. and Chang, Y.-M. (2003) Willingness to pay to improve domestic water supply in rural areas of Central Tanzania: Implications for policy, *International Journal of Sustainable Development & World Ecology*, 10(2), pp. 119-132. doi: 10.1080/13504500309469791.

Kanyoka, P., Farolfi, S. and Morardet, S. (2008) Households' preferences and willingness to pay for multiple use water services in rural areas of South Africa: An analysis based on choice modelling, *Water Sa*, 34(6), pp. 715-723.

Kashaigili, J. J. (2010) *Assessment of groundwater availability and its current and potential use and impacts in Tanzania*. IWMI. Available at: http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/1484 (Accessed: 1 April 2020).

Khare, A. and Economu, N. (2019) *Solar water pump - technology roadmap*. International Climate Finance (ICF). Available at: https://assets.publishing.service.gov.uk/media/5d31c9e4ed915d2fefd0bdea/Solar-Water-Pump-Technology-Roadmap.pdf (Accessed: 28 May 2020).

Kimaro, J. (2019) A Review on Managing Agroecosystems for Improved Water Use Efficiency in the Face of Changing Climate in Tanzania, *Advances in Meteorology*, 2019. doi: 10.1155/2019/9178136.

Kruseman, G. P., De Ridder, N. A. and Verweij, J. M. (2000) *Analysis and evaluation of pumping test data*. Second edn. International institute for land reclamation and improvement, The Netherlands.

Kumar, M. D. (2013) Water management, food security and sustainable agriculture in developing economies, in Kumar, M. D., Sivamohan, M. and Bassi, N. (ed.) *Water Management, Food Security and Sustainable Agriculture in Developing Economies.* Routledge, pp. 208-229.

Lema, M. and Majule, A. E. (2009) Impacts of climate change, variability and adaptation strategies on agriculture in semi arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania, *African Journal of Environmental Science and Technology*, 3(8), pp. 206-218.

Lufingo, M. (2019) Public Water Supply and Sanitation Authorities for Strategic Sustainable Domestic Water Management. A Case of Iringa Region In Tanzania, *J—Multidisciplinary Scientific Journal*, 2(4), pp. 449-466.

MacDonald, A. and Calow, R. (2009) Developing groundwater for secure rural water supplies in Africa, *Desalination*, 248(1-3), pp. 546-556.

Marks SJ, S. A., Kavura V, Vogt K, Ndyamukama M, Renwick, M., (2016) *An Impact Evaluation of Multiple-Use Water Services in the Morogoro Region of Tanzania.* The Sandex Department at Eawag and the Global Water for Sustainability Program (GLOWS). Available at: https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/schwerpunkte/WST/impact_evaluation_water_services_morogoro.pdf (Accessed: 20 April 2020).

Martinsen, R. (2018) *Sustainable water supply in the rural districts of Mbulu, Hanang and Mkalama, Tanzania*, NTNU.

Matata, P., Bushesha, M. and Msindai, J. (2019) Assessing Rainfall and Temperature Changes in Semi-Arid Areas of Tanzania, *American Journal of Climate Change*, 8(2), pp. 173-189.

McSweeney, C., New, M. and Lizcano, G. (2010) *UNDP Climate Change Country Profiles: Tanzania*. Available at: https://www.geog.ox.ac.uk/research/climate/projects/undp-cp/UNDP_reports/Tanzania/Tanzania.hires.report.pdf (Accessed: 1 April 2020).

Misund, I. and Møller, S. E. (2019) *Resilience of water supply systems in Sub-Saharan Africa*. Team Report.

Morris, B. L. *et al.* (2003) *Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management*. United Nations Environment Programme.

Mudzingwa, A. R., Nyakutsikwa, B. F. and Ngogodo, K. C. (2016) Replacing Type «B» Bush Pumps With Solar Powered Pumps For Rural Water Supply. 7th RWSN Forum «Water for Everyone». Available at: https://rwsnforum7.files.wordpress.com/2016/11/full_paper_0172_submitter_0258_mudzingwa_annie.pdf (Accessed: 14 May 2020).

MUS group (2013) *Matching water services with water needs*. MUS group. Available at: https://www.musgroup.net/sites/default/files/MUS_Group_Briefing_Note_2013_0.pdf (Accessed: 6 June 2020).

Nagel, C. *et al.* (2015) Evaluating Cellular Instrumentation on Rural Handpumps to Improve Service Delivery: A Longitudinal Study in Rural Rwanda, *Environmental science & technology*, 49(24), pp. 14292-14300.

National Bureau of Statistics (2019) *Tanzania in Figures 2018*. Dodoma. Available at: https://www.nbs.go.tz/nbs/takwimu/references/Tanzania_in_Figures_2018.pdf (Accessed: 5 May 2020).

Noel, S. (2012) The economics of climate change Tanzania, *Water Resources. Stockholm Environment Institute SEI-Africa Centre. Institute of Resource Assessment, University of Dar es Salaam, Tanzania*, 32.

Norwegian Church Aid (2015) *Norwegian Church Aid Tanzania Strategy 2016-2020*. Available at: https://www.kirkensnodhjelp.no/contentassets/a11f250a5fc145dbb7bf932c8363c998/tanzania--nca-country-strategy-2016-2020.pdf (Accessed: 17 March 2020).

O'Dea, S. (2020) *Penetration rate of voice telecom and internet services in Tanzania from 2013 to 2019*. Available at: https://www.statista.com/statistics/1082352/tanzania-voice-telecom-and-internet-penetration/ (Accessed: 28 May 2020).

Olsson, N. (2011) *Praktisk rapportskriving*. Tapir akademisk.

Oxford University Press (2015) *Oxford textbook of global public health*. 6 edn. United Kingdom: Oxford University Press.

Purvis, B., Mao, Y. and Robinson, D. (2019) Three pillars of sustainability: in search of conceptual origins, *Sustainability Science*, 14(3), pp. 681-695.

Qu, S. Q. and Dumay, J. (2011) The qualitative research interview, *Qualitative research in accounting & management*.

Renwick, M. *et al.* (2007) Multiple use water services for the poor: assessing the state of knowledge, *Winrock International, IRC Water and Sanitation Centre, International Water Management Institute www. winrockwater. org*.

Rienecker, L. and Jørgensen, P. S. (2006) *Den gode oppgaven: håndbok i oppgaveskriving på universitet og høyskole*. Fagbokforlaget.

Schlumberger (2007) *Diver Office - User's Manual*. Available at: https://www.sdec-france.com/ouverturepdf.php?file=1207901885_8.pdf (Accessed: 31 May 2020).

Sémhur (2009) *Locator map of the Pwani Region of Tanzania* [FreeArt]. Available at: File:Tanzania location map.svg.

Singh, V. (2019) Influence of Manually Adjustable Photovoltaic Array on the Performance of Water Pumping Systems, *Global Challenges*, 3(11), pp. 1900009.

Sontake, V. C. and Kalamkar, V. R. (2016) Solar photovoltaic water pumping system-A comprehensive review, *Renewable and Sustainable Energy Reviews*, 59, pp. 1038-1067.

TAWASANET (2019) *Water Sector Equity Report 2019*. Tanzania Water and Sanitation Network. Available at: https://static1.squarespace.com/static/571f35432b8dde095f4a77e1/t/5c91fd0d9140b7d5faf749d1/1553071379665/WWI_Tanzania_Equity_report_WEB.pdf (Accessed: 20 April 2020).

TBS (2005) *National environmental standards compendium*. Tanzania Bureau of Standards. Available at: http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cross_cutting_groups/environment_and_natural_resources/Resources/Sector_Documents_-_Government_of_Tanzania/National_Environmental_Standards_Compendium.pdf?fbclid=IwAR1zdDSuVau0-Y58Y840vBwyUDJB-3BSv1EpgMKo5rI2bdzhzxXWokW5YG8 (Accessed: 10 June 2020).

The Geological Society of London (2012) East African Rift Valley, East Africa. Available at: https://www.geolsoc.org.uk/Policy-and-Media/Outreach/Plate-Tectonic-Stories/Vale-of-Eden/East-African-Rift-Valley.

The Geological Survey of Tanzania (2020) *Geological and Mineral Information System*. Available at: https://www.gmis-tanzania.com/ (Accessed: 24 April 2020).

The World Bank (2018) *Project Information Document/Integrated Safeguards Data Sheet (PID/ISDS)*. (PIDISDSC23080): The World Bank. Available at: http://documents.worldbank.org/curated/en/888911525731838915/pdf/Concept-Project-Information-Document-Integrated-Safeguards-Data-Sheet-Water-Supply-and-Sanitation-Project-P164901.pdf (Accessed: 12 June 2020).

The World Bank (2019) *The World Bank In Tanzania*. Available at: https://www.worldbank.org/en/country/tanzania (Accessed: 24 April 2020).

The World Bank (2020a) *Employment in agriculture (% of total employment) (modeled ILO estimate) - Tanzania*. Available at:

https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=TZ (Accessed: 24 April 2020).

The World Bank (2020b) *Poverty headcount ratio at national poverty lines (% of population) - Tanzania*. Available at: https://data.worldbank.org/indicator/SI.POV.NAHC?locations=TZ (Accessed: 24 April 2020).

The World Bank (2020c) *Population, total - Tanzania*. Available at: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=TZ (Accessed: 24 April 2020).

Thomson, P. (2018) *Literature review: Remote monitoring of rural water supplies*. (UNC Water Institute Report): School of Geography and the Environment, University of Oxford. Available at: https://www.pseau.org/outils/ouvrages/unc_wash_policy_digest_8_remote_monitoring_handpump_functionality_2018.pdf (Accessed: 28 May 2020).

Tormatic AS (2020) *PTX5032 - Nedsenkbar trykksensor*. Available at: https://www.tormatic.no/prosess/niva/unik-5000-ptx5032---nedsenkbar-trykksensor (Accessed: 31 May 2020).

Trust Engineering and IDBWO (2015) *Report on hydrogeological/geophysical survey for Munguli, Getanyamba and Endagaw villages, Mkalama district*.

UN General Assembly (2010) Resolution 64/292: The human right to water and sanitation: resolution / adopted by the General Assembly, *64th Session,*, A/RES/64/292.

UNICEF (2008) UNICEF handbook on water quality, *United Nations Childrens Fund, New York/USA*.

UNICEF (2010) WASH Technology Information Packages for UNICEF WASH Programme and Supply Personnel, *UNICEF and Skat-Swiss Resource Centre and Consultancies for Development, Copenhagen*.

United Nations (2018) *Population*. Available at: https://www.un.org/en/sections/issues-depth/population/index.html (Accessed: November 21st 2019).

URT (2002) *National Water Policy*. Dar Es Salaam, Tanzania: Ministry of Water. Available at: http://www.tawasanet.or.tz/files/Tanzania%20water%20policy%20-%202002.pdf (Accessed: 10 April 2020).

URT (2006) *Water Sector Development Programme 2006-2025*. Dar es Salaam, Tanzania: The United Republic of Tanzania - Ministry of Water. Available at: http://www.tzdpg.or.tz/fileadmin/documents/dpg_internal/dpg_working_groups_clusters/cluster_2/water/WSDP/Background_information/WSDP_Main_Document__2006_-_2025__Nov_2006.pdf (Accessed: 27 May 2020).

URT (2016) *National five year development plan 2016/17-2020/21*. (URT Report): Ministry of finance and planning. Available at: https://mof.go.tz/mofdocs/msemaji/Five%202016_17_2020_21.pdf (Accessed: 28 May 2020).

USAID (2018) Climate Risk Profile: Tanzania. Available at: https://www.climatelinks.org/resources/climate-risk-profile-tanzania (Accessed: November 26th 2019).

van Koppen, B. (2009) *Climbing the water ladder: multiple-use water services for poverty reduction*. IWMI.

Watkins, K. (2006) Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis, *UNDP Human Development Reports (2006)*.

Webster, M. (2000) *Effective Demand for Rural Water Supply in South Africa: Technical and financial implications of designing to meet demand*. WEDC, Loughborough University.

Wedgwood, A. and Sansom, K. (2003) *Willingness-to-pay surveys: a streamlined approach: guidance notes for small town water services*. WEDC, Loughborough University.

WHO (2017) *Guidelines for drinking-water quality: first addendum to the fourth edition*. Geneva.

WI (2012) *Multiple-Use Water Services*. Winrock International Available at: https://www.winrock.org/wp-content/uploads/2016/03/MUS-and-Winrock-Briefing-v3-may-2013.pdf (Accessed: 12 June 2020).

Wilson, J. (2014) *Essentials of business research: A guide to doing your research project*. Sage.

World Bank (2017) *Tanzania Economic Update - Managing Water Wisely*. Washington DC: The World Bank Group Macroeconomics and Fiscal Management Global Practice, Africa Region.

World Bank (2018) *Reaching for the SDGs : the untapped potential of Tanzania's water supply, sanitation, and hygiene sector*. WASH Poverty Diagnostic. Available at: http://documents.worldbank.org/curated/en/167791521012037920/pdf/124255-PUBLIC-P159820-the-untapped-potential-of-Tanzania-s-water-supply-sanitation-and-hygiene-sector.pdf (Accessed: 20 April 2020).

World Health Organization (2019) *Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities*. World Health Organization.

Xu, Y. and Usher, B. (2006) *Groundwater pollution in Africa*. UNEP/Earthprint.

Yin, R. K. (2011) *Applications of case study research*. sage.

Yin, R. K. (2017) *Case study research and applications: Design and methods*. Sage publications.

Zainal, Z. (2007) Case study as a research method, *Jurnal Kemanusiaan*, 5(1).

Appendices

Appendix 1: Schedule for fieldwork

Appendix 2: Technical details of Boreholes installed with Solar and Electrical Grid for WASH TCP 2015-2019

Appendix 3: Technical specifications for equipment installed in the solar powered pumping systems

Appendix 4: Interview questions for the water committees

Appendix 5: Interview questions for the PETS committees

Appendix 6: Interview questions for the DWE

Appendix 7: Interview questions for the DED

Appendix 8: Interview questions for 4CCP

Appendix 9: Remote monitoring system in Basonyagwe village

Appendix 10: Remote monitoring system in Endagaw Chini village

Appendix 11: Remote monitoring system in Mewadani village

Appendix 12: Survey questions

Appendix 13: Pump curves and system curves

Appendix 14: Readings from water metres in Basonyagwe village

Appendix 15: Water supply demand for TCP

Appendix 1: Schedule for fieldwork

DATE	PROGRAM	PLACE
Tuesday 28/01/2020	• Meeting with the district executive director (DED) of Mbulu (in Dongobesh) • Meeting with the district commissioner of Mbulu (in Mbulu town) • Meeting with the district water engineer (in Mbulu town)	Dongobesh and Mbulu town
Wednesday 29/01/2020	• Installation of a remote monitoring system • Water quality measurements • Measurements of the groundwater level in the well (pocket dipper and diver measurements)	Endagaw chini
Thursday 30/01/2020	• Water quality measurements • Measurements of the groundwater level in the well (pocket dipper) (in Mewadani)	Mewadani Basonyagwe
Friday 31/01/2020	• Installation of remote monitoring systems, including pressure sensors in the wells • Measurements of the groundwater level in the wells (pocket dipper)	Mewadani Basonyagwe
Monday 03/02/2020	• Meeting with water committees and PETS committees • Water quality measurements (in Endamilay only) • Installation of Diver (in Murukushida only)	Endamilay Murukushida
Tuesday 04/02/2020	• Meeting with water committee and PETS committee (in Endanachan) • Water quality measurements	Endanachan Murukushida Spring
Wednesday 05/02/2020	• Meeting with water committee and PETS committee • Water quality measurements	Harar
Thursday 06/02/2020	• Meeting with water committee and PETS committee • Water quality measurements (Mewadani primary school)	Mewadani
Monday 10/02/2020	• Meeting with water committee and PETS committee • Visiting Basonyagwe local dam	Endagaw chini Basonyagwe
Tuesday 11/02/2020	• Meeting with water committee and PETS committee in Gidurudagew • Installation of pressure sensor in Mewadani	Gidurudagew Mewadani
Wednesday 12/02/2020	• Meeting with HANG'WA water committee • Visit to water source and water tanks of Haydom • Installation of pressure sensor in Endagaw chini	Haydom Endagaw Chini
Thursday 13/02/2020	• Inspection of remote monitoring systems in Basonyagwe, Endagaw chini, and Mewadani with the water district engineer of Mbulu • Installation of pressure sensor in Basonyagwe	Basonyagwe Endagaw chini Mewadani
Friday 14/02/2020	• Meeting with the district executive director (DED) of Hanang (in Katesh) • Meeting with the district water engineer (DWE) of Hanang (in Katesh) • Meeting with water committee and PETS committee (in Diling'ang) • Water quality measurements (in Diling'ang)	Katesh Diling'ang
Saturday 15/02/2020	• Diver measurements	Endanachan
Tuesday 18/02/2020	• Meeting with district executive director (DED) and district water engineer (DWE) of Mkalama	Mkalama
Wednesday 19/02/2020	• Meeting with water committee and PETS committee in Hilamoto • Visit Munguli primary solarized system • Water quality measurements	Hilamoto Munguli
Thursday 20/02/2020	• Meeting with water committee • Water quality measurements	Gidbyo
Friday 21/02/2020	• Meeting with water committee (in Isene) • Water quality measurements	Isene Haydom secondary school
Monday 24/02/2020	• Training in remote monitoring systems with 4CCP • Interview of 4CCP • Meeting with Dang'ayda village	4CCP office Dang'ayda

Appendix 2: Technical details of Boreholes installed with Solar and Electrical Grid for WASH TCP 2015-2019

S/N	Name of the Village	District	Total Depth (M)	Water Level (M)	Pump Intake (M)	Draw Down (M)	Recovery (M)	Dynamic (M)	Yield (L/H)	Total # of Beneficieries	Remarks
1	Endagaw – Haydom Secondary School	Mbulu	100	48	90	22	17	70	4500	1460	Connected with Electrical Grid
2	Masqaroda – Bishop Hhando Secondary School	Mbulu	14	2.5	13.5	6.8	5.2	9.03	2400	1824	Connected with Electrical Grid
3	Guye / Gidhim	Mbulu	75	24	70	36	28	60	7750	3904	Installed with Solar Power
4	Dirim – Dambia Sub Village	Mbulu	150	42	140	59	37	121	8700	1500	Installed with Solar Power
5	Bisigeta – Harong’aida Sub Village	Mbulu	100	27	90	42	33	69	6000	1920	Installed with Solar Power
6	Getanyamba – Geterer Sub Village	Mbulu	57	19	50	24	22	43	6800	1236	Installed with Solar Power
7	Mewadani	Mbulu	105	38.9	90	29.3	24.9	68.02	39000	1830	Installed with Solar Power
8	Getagujo – Dinamu Ward	Mbulu	70	34	60	27	23	61	3600	1620	Installed with Solar Power
9	Gidorsengw – Sub village – Dinamu Ward	Mbulu	70	34.5	60	27.8	23.6	62,03	6000	1824	Installed with Solar Power
10	Girdurdagew – Qaloder Sub Village – Haydom - Ward	Mbulu	95	44	85	33	21	77	2500	2752	Installed with Solar Power
11	Hilamoto – Hilamoto Sub village - Mwangeza	Mkalama	70	18	65	22	17	30	3000	3065	Installed with Solar Power
12	Murkuchida	Mbulu	90	42.64	80	18,85	16.82	61.49	6600	3215	Installed with Solar Power
13	Endagulda	Mbulu	66.6	9.11	60	25.93	12.37	33.04	5800	4226	Installed with Solar Power
14	Gibyo	Mbulu	120	30.74	100	16.38	33.91	47.12	3200	1987	Installed with Solar Power
15	Mamagi	Mbulu	133	14.80	120	46.52	42.02	61.32	4500	2985	Installed with Solar Power
16	Harar	Mbulu	103	20	90	39.5	30.71	53.93	5657	3784	Installed with Solar Power
17	Basonyagwe	Mbulu	112	20.01	100	36.09	33.75	56.09	5000	3472	Installed with Solar Power
18	Guye	Mbulu	114	11.03	100	52.54	51.16	63.57	7200	3908	Installed with Solar Power
19	Gidhim 2	Mbulu	52	30.67	50	13.67	12.13	44.31	6018	3057	Installed with Solar Power
20	Isale	Mbulu	156.40	43.98	140	49.92	24.80	91.92	2300	2095	Installed with Solar Power
21	Isene	Mkalama	78	3.85	70	13.17	12.85	17.02	5400	3132	Installed with Solar Power
22	Matere	Mkalama	66.6	24.11	60	13.87	13.11	38.00	3500	2981	Installed with Solar Power
23	Diling’ang’	Hanang’	123	80.80	110	5.18	4.77	86.29	2000	2936	Installed with Solar Power
24	Hidet	Hanang’	66	10.68	60	9.69	9.67	20.37	7800	4012	Installed with Solar Power
25	Munguli	Mkalama	78	12	64	27	22	39	4800	3798	Installed with Solar Power

Appendix 3: Technical specifications for equipment installed in the solar powered pumping systems

The technical specifications for equipment installed in the solar powered pumping systems are provided by NCA. For some of the villages visited, these data are not available.

MEWADANI			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	105	GIVEN
Borehole yield	(m_3/h)	39	GIVEN
Pump set	Distance (m)	90	GIVEN
Assumed DWL	Distance (m)	70	GIVEN
Pump Yield	(m_3/h)	6	GIVEN
Fence	Area (m_2)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 3/16 C/W 1.1kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	10	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

GIDURUDAGEW			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	95	GIVEN
Borehole yield	(m_3/h)	2.5	GIVEN
Pump set	Distance (m)	85	ON SITE
Assumed DWL	Distance (m)	75	GIVEN
Pump Yield	(m_3/h)	2	GIVEN
Fence	Area (m_2)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 3/16 C/W 1.1kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	10	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

MURUKUCHIDA			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	90	GIVEN
Borehole yield	(m_3/h)	6.6	GIVEN
Pump set	Distance (m)	80	ON SITE
Assumed DWL	Distance (m)	60	GIVEN
Pump Yield	(m_3/h)	3	GIVEN
Fence	Area (m_2)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 5/16 C/W 1.5kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	10	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

GIDBIYO			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	120	GIVEN
Borehole yield	(m_3/h)	3.2	GIVEN
Pump set	Distance (m)	100	ON SITE
Assumed DWL	Distance (m)	47	GIVEN
Pump Yield	(m_3/h)	2.5	GIVEN
Fence	Area (m_2)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Peces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 3/16 C/W 1.1kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 1.5 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	8	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

HARAR			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	103	GIVEN
Borehole yield	(m_3/h)	4.5	GIVEN
Pump set	Distance (m)	90	ON SITE
Assumed DWL	Distance (m)	54	GIVEN
Pump Yield	(m_3/h)	4	GIVEN
Fence	Area (m_2)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 5/16 C/W 1.5kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	10	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

BASONYAGWE			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	112	GIVEN
Borehole yield	(m_3/h)	5	GIVEN
Pump set	Distance (m)	100	GIVEN
Assumed DWL	Distance (m)	56	GIVEN
Pump Yield	(m_3/h)	4	GIVEN
Fence	Area (m_2)	12*13.5	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Peces	2	Supplied
Full set* Domestic Point (DP)	Pieces	4	Constructed
Submersible pump, DSP 5/16 C/W 1.5kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	10	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

DILING’ANG			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	123	GIVEN
Borehole yield	(m$_3$/h)	2	GIVEN
Pump set	Distance (m)	110	ON SITE
Assumed DWL	Distance (m)	86	GIVEN
Pump Yield	(m$_3$/h)	1	GIVEN
Fence	Area (m$_2$)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 2/23 C/W 1.1kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 1.5 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	8	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

ISENE			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	78	GIVEN
Borehole yield	(m$_3$/h)	5.4	GIVEN
Pump set	Distance (m)	70	ON SITE
Assumed DWL	Distance (m)	17	GIVEN
Pump Yield	(m$_3$/h)	4	GIVEN
Fence	Area (m$_2$)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 5/12 C/W 1.1kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 2.2 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	8	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

HILAMOTO			
Description	**Unit**	**Quantity**	**Status**
Borehole depth	Distance (m)	70	GIVEN
Borehole yield	(m$_3$/h)	3	GIVEN
Pump set	Distance (m)	65	ON SITE
Assumed DWL	Distance (m)	55	GIVEN
Pump Yield	(m$_3$/h)	2.5	GIVEN
Fence	Area (m$_2$)	15*15	Constructed
Tank tower	Distance (m)	3	Constructed
Tank	Pieces	2	Supplied
Full set* Domestic Point (DP)	Pieces	1	Constructed
Submersible pump, DSP 3/18 C/W 1.5kWMotor	Pieces	1	Supplied
DC Disconnect switch	Pieces	1	Supplied
Sunverter 1.5 kW 1PH	Pieces	1	Supplied
Solar panel 195W, 24V	Pieces	8	Supplied
Well probe sensor	Pieces	1	Supplied

*DP contains two gate valves (corks), water meter and an operational water system

Appendix 4: Interview questions for the water committees

Water committees

- What are the main tasks of the water committee?
- How often does the water committee meet?
- Which type of support do you receive from 4CCP?
- Which type of support do you receive from the district engineers?
- How are people chosen for the water committee?
- Which personal characteristics should a member of the water committee have?

Water supply in the village

- How many people are connected to this borehole?
- How many cattle use this borehole?
- What is the average water consumption per household?
- When was the system constructed?
- Which sources did you use before?
- Did they consider other sites of drilling?
- What are the benefits of the solar-powered water pumping systems?
- What are the challenges of the solar-powered water pumping systems?
- How has the implementation of a solar powered water pumping system affected the village?
- Have you participated in the planning of the systems?
- Have you participated in the construction of the systems?
- How satisfied are you with your involvement in the planning and construction of the system? Are there any improvements that can be done?
- What is the water used for? (Drinking, cleaning, cooking, irrigation, livestock)
- Do you use different kind of water sources?
  If yes: Which?
- How many have iron sheet roofs in the village?
- Does the water smell and taste nice?
- Do you have any thoughts about the safety of the water?
- Is there enough water for everyone? E.g. are the water tanks sometimes empty?
- Which improvements would you like to see regarding the water supply in the village?
- How often do most families collect water?
- Who in the household is responsible for collecting water?

Willingness to pay:

- How is the price for water determined?
- How is the money collected?
- How often do people pay for water? (annually, monthly, per bucket)
- How would you prefer to pay for water?
- Who is in charge of the funds?
- Are the funds stored in a bank account?
- What are the funds used for?

O&M

- Are the solar panels cleaned regularly? If yes, how often are they cleaned?
- What else do you do to take care of the solar water yard?
- Has there been any downtime of the solar powered water pump?
- What do you do if the pump stops working?
- How long does it take to get help?
- When is the solar water yard open? Is it closed during the night?
- Has there been any problems with vandalism?

- Do you have any questions to us?

Expansion

- How many households do you want to expand the project to?
- Is the sub-villages located downhill or uphill from here?
- What is the distance to the other sub-villages?

Appendix 5: Interview questions for the PETS committees

- What are the main tasks of the PETS committee?
- How often does the PETS committee meet?
- Who does the PETS committee collaborate with?
- What are public funds used for in your village?
- Which improvements would you like to see in your village?
- How would you describe the water supply situation in your village?
- Which improvements would you like to see regarding the water supply in the village?

Appendix 6: Interview questions for the DWE

Water supply in the district

- How would you describe the water supply situation in the district?
- How many have water in their houses?
- How could the water supply situation be improved, in your opinion?
- What kind of sources do you have within the district? Do you have any number of each kind?

Solar water pumping systems:

- Many solar powered water pumping systems have been built in this area in the last few years. What are the benefits of this water supply option?
- What are the challenges?
- How is the responsibility for the solar water pumping systems divided between the different stakeholders?
    - Which responsibilities does the district engineer have?
    - Which responsibilities does the local community have?
    - Which responsibilities does 4CCP have?
- Do you think this is a suitable division of responsibilities?
- Is it enough water for everyone?
- Are there any villages in the district without access to boreholes? What are the plans here?

O&M and repairs

- What type of maintenance procedures are followed?
- What can be done to ensure satisfactory operation and maintenance?
- What are the main challenges related to operation and maintenance?
- Have you experienced any failures with the solar-powered water pumping system?
- If so, what were the causes?
- Who is responsible for repairs when failures happen?
- What is the procedure for telling about the failure?
- Are failures and repairs registered in a database?

In Mbulu district:

Data handling / Remote monitoring

- What kind of data concerning the water pumping systems is acquired?

E.g. water consumption, pumping rate

- How is the data acquired?
- What is the data used for?
- How is the data stored and systemized?
- What do you think are the potential uses of remote monitoring?
    - Benefits
    - Challenges
- Which parameters could be of interest for remote monitoring?
    - Water consumption, water level in storage tanks, information about whether the pump is operating or not
- In what ways do you think installing a remote monitoring system would affect your job?
- What would be an affordable price level for a remote monitoring system?
- Are there other data acquisition methods that you think would be more suitable than remote monitoring?

Appendix 7: Interview questions for the DED

Water supply

- How would you describe the water supply situation in the district?
- How has the recent improvements in water supply affected the villages?
- To what extent does the water supply situation affect the economic development in the district?
- What are the main challenges regarding water supply in the district?
- What are the goals regarding water supply in the district, both in a short and long-term perspective?

Appendix 8: Interview questions for 4CCP

4CCP

- What are the main tasks of 4CCP?
- What does 4CCP stand for?
- When was 4CCP funded?
- How does 4CCP receive its funds?

Water supply

- How would you describe the water supply situation in rural Tanzania today?
- What are the main challenges regarding water supply in rural Tanzania?
- Explain 4CCP's work regarding water supply

Solar-powered water pumping systems

- What has been 4CCP's role regarding the implementation of solar-powered water pumping systems?
- What are the benefits of the solar-powered water pumping systems?
- What are the challenges of the solar-powered water pumping systems?
- How has the improvements in water supply affected the villages?
- What does a system typically cost?
- How much do the local communities typically contribute?
- Why are people settling where there is a long distance to the water source?
- Is the income of the pumping system enough to cover the future costs such as repairs?
- What is the income of the security guard and the caretaker?
- Do the solar-powered water pumping systems provide enough water for the local community?
- Are there any concerns regarding the quality of the water?

Management

- How is the responsibility for the solar water yards divided between the different stakeholders? (NCA, 4CCP, district engineer, water committee)
- Will the division of responsibilities change? E.g. will NCA pull out of the project?
- To what extent was the local community involved in the planning and construction of the pumping systems?
- What is the function of a water committee?
- When you establish water committees, is always the treasurers women?
- Has there been any challenges related to the implementation of water committees?
- What type of support does the water committees receive from 4CCP?
- Why are water committees not called COWSOs anymore?
- What are the most important factors for making sure that the water supply schemes are sustainable?

O&M and repairs

- What type of maintenance are the local communities in charge of?
- Are maintenance procedures followed?
- What can be done to ensure satisfactory operation and maintenance?
- Who is responsible for repairs?

Data handling / Remote monitoring

- What do you think are the potential uses of remote monitoring?
- What could be the benefits of remote monitoring?
- What could be the challenges of remote monitoring?
- Which parameters would be of interest for remote monitoring?
- Do you think it is realistic to implement a remote monitoring system in this context?
- What would be an affordable price level for a remote monitoring system?

MUS

- What benefits and challenges do you see by using water for multiple-use water services?
- You have also implemented some veggie-gardens in some of the villages. How do you choose which village should have a veggie-garden?
- How did you check the amount of water there?
- When did you implement the veggie-garden?

Appendix 9: Remote monitoring system in Basonyagwe village

The system includes:

- Pressure sensor in the well (installed 70 metres under top of the well)
- Pressure sensor in outlet pipe of tanks (installed 1.4 metres under the water tank)
- In the wooden box: digitizer sensor x2 (voltage and current), gateway, regulator, battery, and cable with resistance
- Solar panel

Appendix 10: Remote monitoring system in Endagaw Chini village

The system includes:

- Pressure sensor in outlet pipe of tanks (installed 1.2 metres under the water tank)
- In the wooden box: digitizer sensor (voltage), gateway, regulator, and battery
- Solar panel

Appendix 11: Remote monitoring system in Mewadani village

The system includes:

- Pressure sensor in the well (installed 69 metres under top of the well)
- Pressure sensor in outlet pipe of tanks (installed 1.5 metres under the water tank)
- In the wooden box: digitizer sensor x2 (voltage and current), gateway, regulator, battery, and cable with resistance
- Solar panel

Appendix 12: Survey questions

General information

- District: ___________________________

- Age: ________

- Gender:
  ☐ Male
  ☐ Female

- Status:
  ☐ Mother
  ☐ Father
  ☐ Son
  ☐ Daughter
  ☐ In-law
  ☐ Grandmother
  ☐ Grandfather
  ☐ Other (please specify): _____________________

- Number of people in household: ________

- Who in the household is usually in charge of collecting water: ________________

- Average yearly income (for household): ______________

Current water system

- What is your daily source of water for drinking and cooking?
  ☐ Hand pump
  ☐ Solar powered pump
  ☐ Rainwater harvesting
  ☐ River or pond (if yes, please answer next question)
  ☐ Other (please specify): _______________________

- If you use a river or pond, what is the main reason for this?
  ☐ Price of water
  ☐ Distance to well
  ☐ Failure and downtime at well
  ☐ Waiting time at well
  ☐ Taste, odour
  ☐ Habit, tradition
  ☐ Other (please specify): _____________________________

- What is the distance to your water source?
  ☐ 0-50 m
  ☐ 51 – 100 m
  ☐ 101 – 300 m
  ☐ 301 – 1000 m
  ☐ More than 1000 m (please specify): __________________

- How long do you normally wait in line at your water point?
  ☐ 0-5 min
  ☐ 6-10 min
  ☐ 11-15 min
  ☐ 16-30 min
  ☐ 31-60 min
  ☐ More than 60 min (please specify): ___________________

- How much time is usually spent collecting water in total (travel + waiting time)?
  ☐ Less than 30 min
  ☐ More than 30 min

- How much water does your household use on an average daily basis? ____________

- How much water is normally collected each trip? ________________

- What do you use the water for?
  ☐ Domestic uses (cooking, cleaning, drinking etc.).
  ☐ Productive uses (irrigation, beer making, livestock watering etc.) If yes, please answer the two next questions

- What kind of productive uses do you use the water for?
  ☐ Irrigation
  ☐ Livestock watering
  ☐ Beer making
  ☐ Other (please specify): __________________________

- How much water do you use for productive uses? __________________

- If the water is only used for domestic uses: What do you think are the reasons why you do not use water for productive uses?
  ☐ Distance to source
  ☐ Price on water
  ☐ Lack of water
  ☐ Other (please specify): ____

- How satisfied are you with your current water system?
  ☐ Very satisfied
  ☐ Somewhat satisfied
  ☐ Not satisfied
  ☐ Do not know

- Have there been any interruptions where water from your drinking water source not has been available? If yes, please answer the two next questions
  ☐ Yes
  ☐ No
  ☐ Do not know

- For how long did the last interruption in service last? ___________________

- What was the reason for the interruption? ____________________

- How would you describe your household’s situation with food security in the past year?
  ☐ Very secure
  ☐ Somewhat secure
  ☐ Insecure
  ☐ Do not know

- In the past week, did your family consume any of the following types of food?
  ☐ Starchy foods
  ☐ Beans
  ☐ Nuts
  ☐ Dairy
  ☐ Meat
  ☐ Eggs
  ☐ Leafy greens
  ☐ Vegetables
  ☐ Fruits

- (Among families with at least one child under the age of 10): Has your child(ren) been sick with diarrheal illness within the past month?
  ☐ Yes – How many?: ____
  ☐ No
  ☐ Do not know

- In the past year, has anyone of any age in your home been hurt while collecting water, either along the path or at the water point?
  ☐ Yes
  ☐ No
  ☐ Do not know

- How are you charged for water?
  ☐ Annual
  ☐ Seasonal
  ☐ Per bucket
  ☐ Other (please specify): __________________________

- How do you pay for water?
  ☐ Cash at waterpoint
  ☐ Cash beforehand
  ☐ Mobile payment water point
  ☐ Mobile payment beforehand
  ☐ Other (please specify): __________________________

- How much do you currently pay for water? __________________

- How much would you like to pay for your current water service? _________________

- How much can you accept to pay for your current water service? _________________

- What time of year (month) is preferred for paying a yearly fee for water? _________

Willingness to pay (1 jerry can)

- How much are you willing to pay for using less than 30 minutes for a round trip of collecting water?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ___________
  ☐ Stated limit: _____________

- How much are you willing to pay if the water comes from solar powered pumps, rather than hand pumps?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ____________
  ☐ Stated limit: _____________

- How much are you willing to pay if the water point was only shared between your 5 neighbouring households?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ___________
  ☐ Stated limit: ____________

- How much are you willing to pay if there was a water tap in your house?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ___________
  ☐ Stated limit: ____________

- How much are you willing to pay if you can achieve an income using water for productive uses?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ___________
  ☐ Stated limit: ____________

- How high does the daily income have to be in order for you to be willing to pay more for water?
  ☐ Under 2000 TSH
  ☐ 2000-6000 TSH
  ☐ 6001-10 000 TSH
  ☐ More than 10 000 TSH (please specify): _______________

- How much are you willing to pay if the water source is less than 5 minutes away, but can only be used for agriculture (because of the water quality)?
  ☐ 10 TSH
  ☐ 25 TSH
  ☐ 50 TSH
  ☐ 75 TSH
  ☐ 100 TSH
  ☐ 125 TSH
  ☐ 150 TSH
  ☐ More: ___________
  ☐ Stated limit: ____________

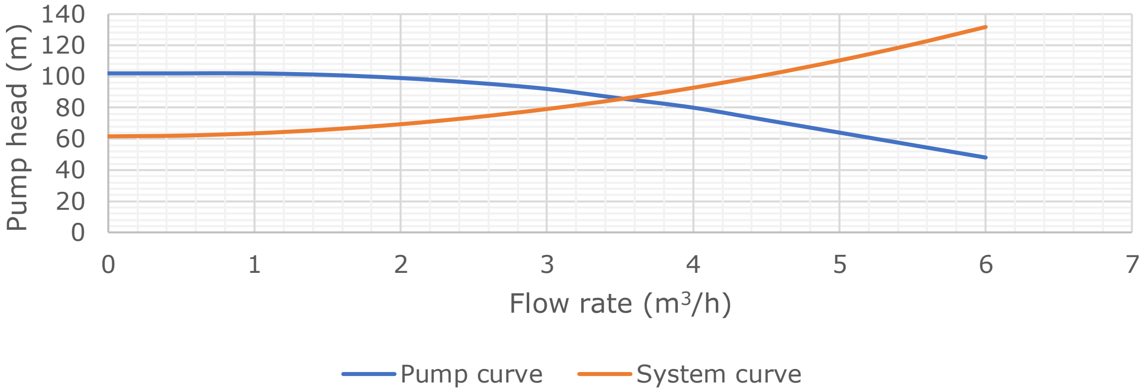
Appendix 13: Pump curves and system curves

Loss coefficients:

- Bend 90º (3): 1.5
- T-cross (1): 1

Basonyagwe village

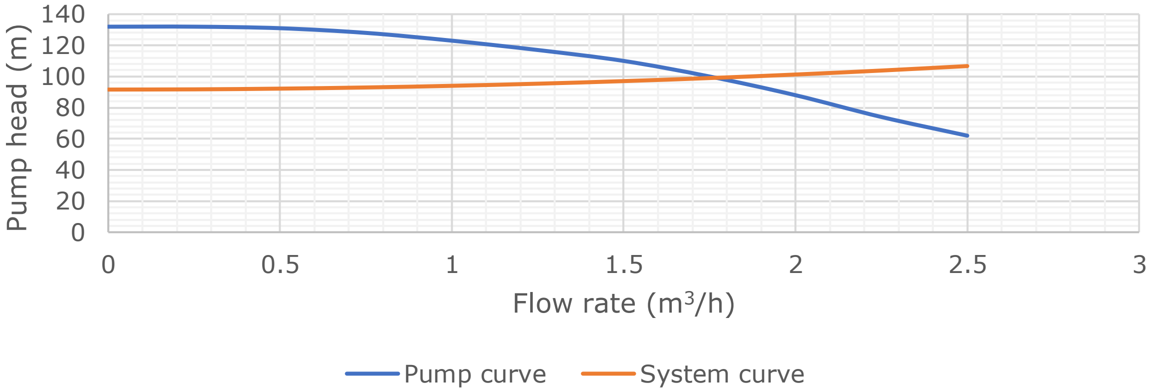
- DWL to inflow of the water tank: 61.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	100	3	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	38.1	38.1	15.6
Relative roughness k/D	0.005	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Diling’ang village

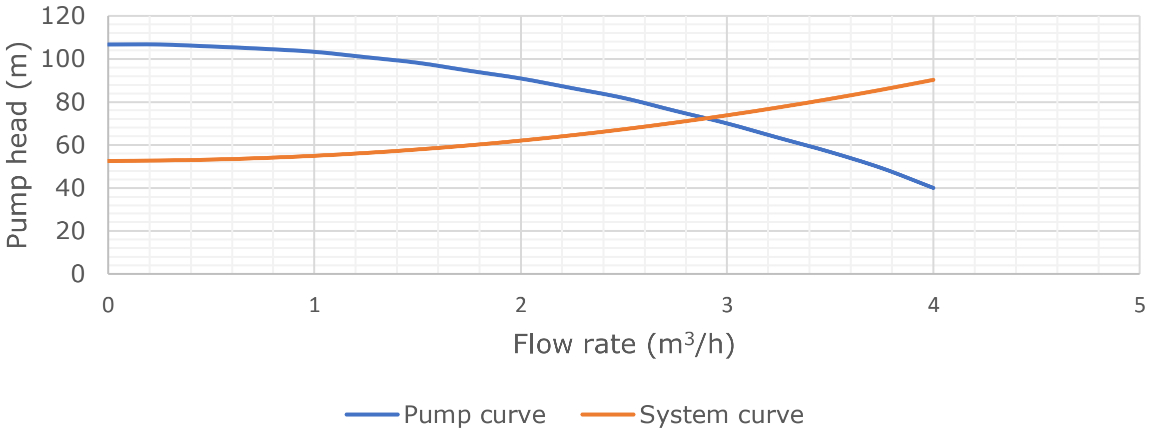
- DWL to inflow of the water tank: 91.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	110	6	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	31.75	31.75	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Gidbyo village

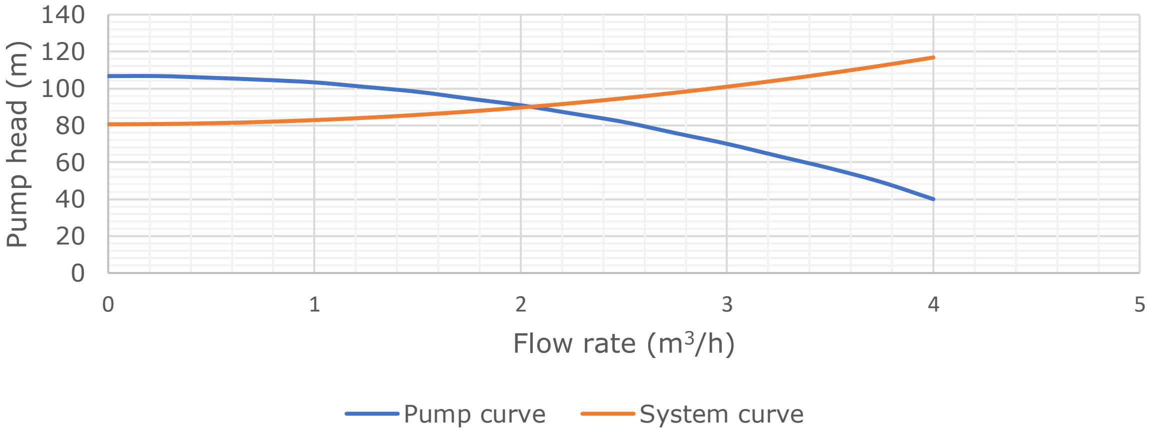
- DWL to inflow of the water tank: 52.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	100	6	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	31.75	31.75	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Gidurudagew

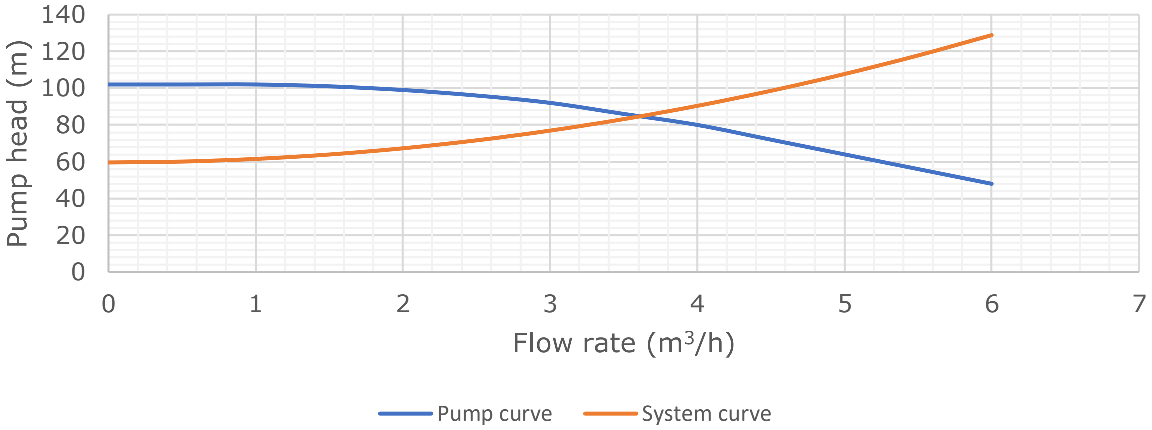
- DWL to inflow of the water tank: 80.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	85	6	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	31.75	31.75	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Harar village

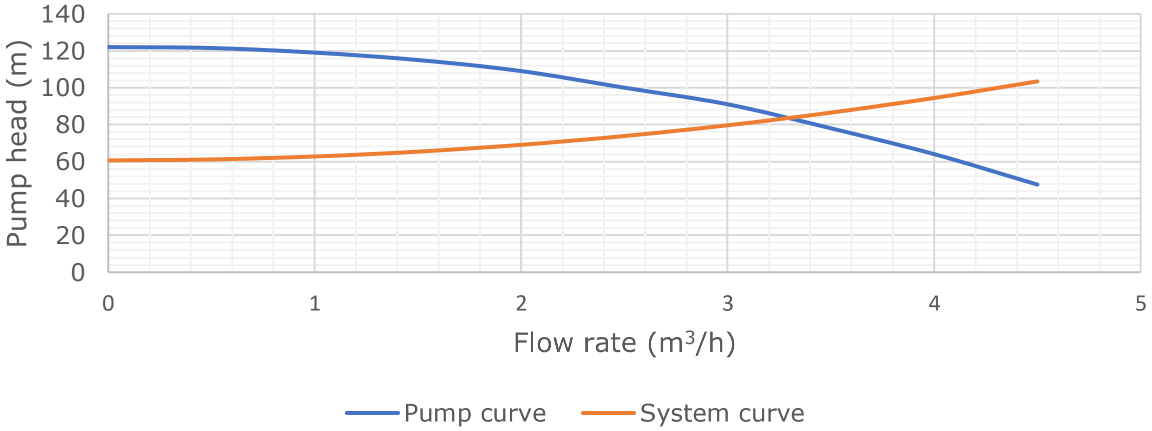
- DWL to inflow of the water tank: 59.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	90	3	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	38.1	38.1	15.6
Relative roughness k/D	0.005	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Hilamoto village

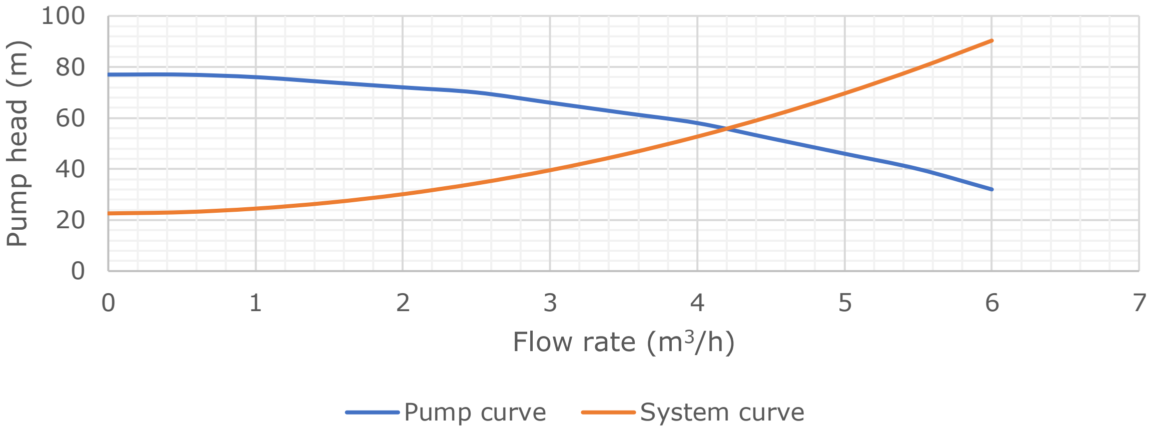
- DWL to inflow of the water tank: 60.6 metres.



Pressure loss param.	Borehole (a)	Pipe (b)	Pipe (c)
Length L (m)	65	2	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	31.75	31.75	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Isene village

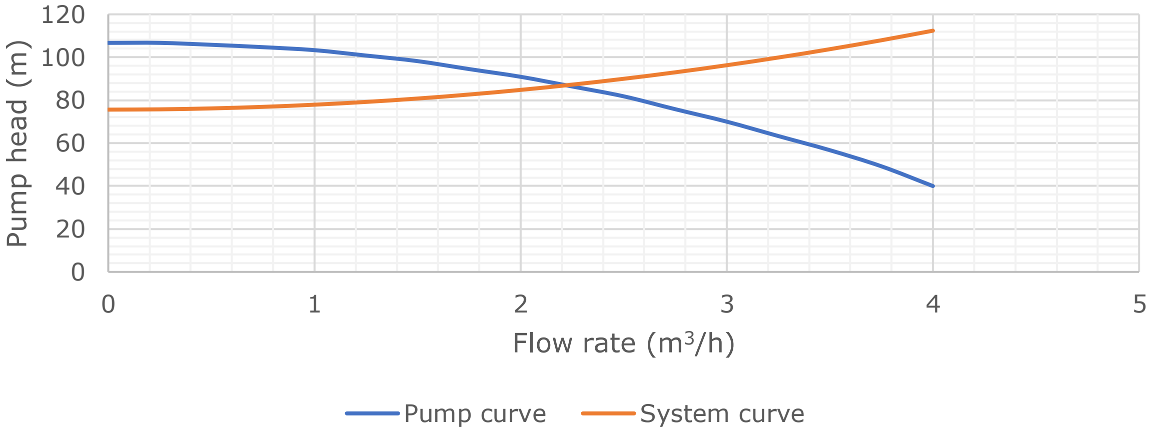
- DWL to inflow of the water tank: 22.6 metres.



Pressure loss param.	**Borehole (a)**	**Pipe (b)**	**Pipe (c)**
Length L (m)	70	6	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	38.1	38.1	15.6
Relative roughness k/D	0.005	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Mewadani village

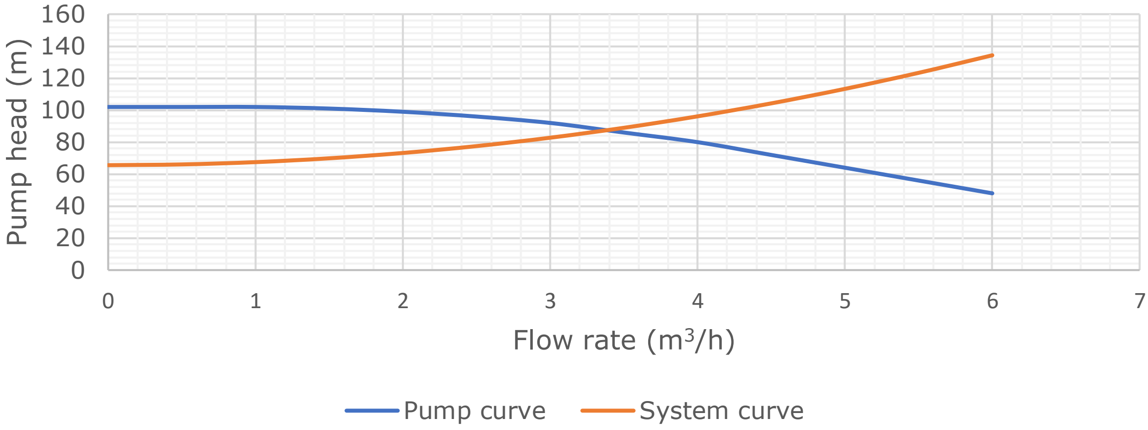
- DWL to inflow of the water tank: 75.6 metres.



Pressure loss param.	**Borehole (a)**	**Pipe (b)**	**Pipe (c)**
Length L (m)	90	7	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	31.75	31.75	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Murukuchida village

- DWL to inflow of the water tank: 65.6 metres.



Pressure loss param.	**Borehole (a)**	**Pipe (b)**	**Pipe (c)**
Length L (m)	80	7	5.4
Roughness k (mm)	0.2	0.2	0.2
Diameter D (mm)	38.1	38.1	15.6
Relative roughness k/D	0.006	0.005	0.013
Friction factor f (Moody)	0.031	0.031	0.038

Appendix 14: Readings from water metres in Basonyagwe village

Date	Water meter A	Water meter B	Difference A	Difference B	Water used A (l/d)	Water used B (l/d)	Water domestic (l/d)	Water veggie (l/d)	Water veggie (l/d*m$_2$)	Water per cattle (l/d)	Income A (TSh)	Income B (TSh)	Buckets domestic (20 l)	Buckets cattle (20 l)
01.09.2019	74	101												
02.09.2019	78	111	4	10	4000	10000				5,3				
03.09.2019	86	119	8	8	8000	8000	5633	2367	11.8	4,2	8450	10000	281,7	333,3
04.09.2019	92	129	6	10	6000	10000	5467	533	2.7	5,3	8200	10000	273,3	333,3
05.09.2019	100	136	8	7	8000	7000	6000	2000	10.0	3,7	9000	10000	300,0	333,3
06.09.2019	106	147	6	11	6000	11000	5000	1000	5.0	5,8	7500	13000	250,0	433,3
07.09.2019	113	157	7	10	7000	10000	7000	0		5,3	10500	1050	350,0	35,0
08.09.2019	118	166	5	9	5000	9000	4000	1000	5.0	4,7	6000	10000	200,0	333,3
09.09.2019	127	177	9	11	9000	11000	6000	3000	15.0	5,8	9000	11000	300,0	366,7
10.09.2019	138	187	11	10	11000	10000	6533	4467	22.3	5,3	9800	17300	326,7	576,7
11.09.2019	147	201	9	14	9000	14000	7000	2000	10.0	7,4	10500	19730	350,0	657,7
12.09.2019	158	218	11	17	11000	17000	867	10133	50.7	8,9	1300	1700	43,3	56,7
13.09.2019	169	230	11	12	11000	12000	8380	2620	13.1	6,3	12570	20180	419,0	672,7
14.09.2019	180	243	11	13	11000	13000	9047	1953	9.8	6,8	13570	15530	452,3	517,7
15.09.2019	191	256	11	13	11000	13000	7687	3313	16.6	6,8	11530	19620	384,3	654,0
16.09.2019	203	268	12	12	12000	12000	9907	2093	10.5	6,3	14860	16860	495,3	562,0
17.09.2019	213	280	10	12	10000	12000	7933	2067	10.3	6,3	11900	15270	396,7	509,0
18.09.2019	224	292	11	12	11000	12000	8967	2033	10.2	6,3	13450	16470	448,3	549,0
19.09.2019	234	306	10	14	10000	14000	7793	2207	11.0	7,4	11690	17230	389,7	574,3
20.09.2019	244	319	10	13	10000	13000	7473	2527	12.6	6,8	11210	15350	373,7	511,7
21.09.2019	256	331	12	12	12000	12000	8280	3720	18.6	6,3	12420	16000	414,0	533,3
22.09.2019	276	345	20	14	20000	14000	11673	8327	41.6	7,4	17510	18440	583,7	614,7
23.09.2019	281	357	5	12	5000	12000	9720	-4720	-	6,3	14580	15560	486,0	518,7
24.09.2019	290	371	9	14	9000	14000	7667	1333	6.7	7,4	11500	16190	383,3	539,7
25.09.2019	301	384	11	13	11000	13000	8700	2300	11.5	6,8	13050	15900	435,0	530,0
26.09.2019	310	399	9	15	9000	15000	6627	2373	11.9	7,9	9940	16350	331,3	545,0
27.09.2019	321	411	11	12	11000	12000	6533	4467	22.3	6,3	9800	17850	326,7	595,0
28.09.2019	332	424	11	13	11000	13000	8903	2097	10.5	6,8	13355	15100	445,2	503,3
29.09.2019	340	432	8	8	8000	8000	4833	3167	15.8	4,2	7250	11470	241,7	382,3
30.09.2019	355	449	15	17	15000	17000	10533	4467	22.3	8,9	15800	18480	526,7	616,0
				Average	9892.9	12071.4	7291.3	2601.5	10.6	6.4	24407.7	10937.0	14343.9	364.6
				Std.dev	3034.9	2433.2	2199.8	2554.5	14.9	1.3	8205.9	3299.7	4777.5	110.0

Appendix 15: Water supply demand for TCP

The following documents are provided by Zachayo Makobero from the NCA Tanzania.

SN	Name of Village	Total Depth (M)	Yield (Lt/Hr)	Pumping Hrs	# of Beneficiary	Other Consumptions	Domestic use	Total Demand per day	Remarks
1	Gidibyo	124	3200	8 to 10	2200	3+20 = 23 Litres	25 Lpcd	27500	Animals & Veggie
2	Hidet	100	7800	8 to 10	3120		25 Lpcd	39000	
3	Isale	156	2300	8 to 10	3200		25 Lpcd	40000	
4	Mamag	130	2800	8 to 10	2700	3+20 = 23 Litres	25 Lpcd	33750	Animals & Veggie
5	Endaharghadakt	150	1688	8 to 10	2300		25 Lpcd	28750	
6	Dinam	160	1500	8 to 10	1700		25 Lpcd	21250	
7	Matere	100	3500	8 to 10	2150		25 Lpcd	26875	
8	Endamilay	150	6000	8 to 10	2869	3+20 = 23 Litres	25 Lpcd	35863	Animals & Veggie
9	Endagulda	120	5800	8 to 10	1900		25 Lpcd	23750	
10	Murkuchida	100	6600	8 to 10	2300	3+20 = 23 Litres	25 Lpcd	28750	Animals & Veggie
11	Basonyagwe			8 to 10	2341	3+20 = 23 Litres	25 Lpcd	29263	Animals & Veggie - Under Constructions
12	Qhaloderer/Mewedan			8 to 10	3925		25 Lpcd	49063	Under Constructions
13	Guye			8 to 10	3387		25 Lpcd	42338	Under Constructions
14	Harar			8 to 10	2688		25 Lpcd	33600	Under Constructions
15	Qandach			8 to 10	3039		25 Lpcd	37988	Under Constructions
16	Sasumwega			8 to 10	3985	3+20 = 23 Litres	25 Lpcd	49813	Animals & Veggie - Under Constructions

Note

- 25 to 30 litres per capita per day in rural areas – lpcd as per Tanzania water policy
- 3 to 6 litres per m$_2$ for vegetable garden
- Animals 20 to 40 litres per head – lph
- Total demand per day depending on the number of animals and vegetable garden
- 30% to 50% beneficiary will access water within 400 metres

					SUPPLY				Demand			
SN	**Name of Village**	**Total Depth (M)**	**Yield (Lt/Hr)**	**Pumping Hrs**	**Solar pump water supply (litre) 8h pumping**	**Solar pump water supply (m3)**	**Electricity grid**	**# of potential Beneficiary**	**# of Beneficiary (50%)**	**Water consumption (m3)**	**Demand minus supply solar powered**	**Demand minus supply grid electricity**
1	Gidibyo	124	3200	8	25600	26		2200	1100	33	-7	
2	Hidet	100	7800	8	62400	62	47	3120	1560	47	16	0
3	Isale	156	2300	8	18400	18	48	3200	1600	48	-30	0
4	Mamag	130	2800	8	39200	39		2700	1350	41	-1	
5	Endaharghadakt	150	1688	8	13504	14	34	2300	1150	35	-21	-1
6	Dinam	160	1500	8	12000	12		1700	850	26	-14	
7	Matere	100	3500	8	28000	28		2150	1075	32	-4	
8	Endamilay	150	6000	8	48000	48		2869	1435	43	5	
9	Endagulda	120	5800	8	46400	46		1900	950	29	18	
10	Murkuchida	100	6600	8	52800	53		2300	1150	35	18	
11	Basonyagwe			8	0	0		2341	1171	35		
12	Qhaloderer/Mewedan			8	0	0		3925	1963	59		
13	Guye			8	0	0		3387	1694	51		
14	Harar			8	0	0		2688	1344	40		
15	Qandach			8	0	0		3039	1520	46		
16	Sasumwega			8	0	0		3985	1993	60		

SN	**Name of Village**	**# of Beneficiary (in 10 years)**	**Water consumption 30 lpd**	**Water consumption (m3)**	**Demand minus supply**	**Remarks 4CCP**	**Storage tank size today (m3)**	**Storage tank size in 10 years**
1	Gidibyo	1493	44790	44,79	-19,19	Animals & Veggie	15	second borehole
2	Hidet	2117	63510	63,51	-16,71		7,8	
3	Isale	2171	65130	65,13	-16,83		22,7	
4	Mamag	1832	54960	54,96	-15,76	Animals & Veggie	16,8	
5	Endaharghadakt	1561	46830	46,83	-33,326		13,7	
6	Dinam	1153	34590	34,59	-22,59		Handpump	
7	Matere	1459	43770	43,77	-15,77		16	
8	Endamilay	1947	58410	58,41	-10,41	Animals & Veggie	21	
9	Endagulda	1289	38670	38,67	7,73		15	
10	Murkuchida	1561	46830	46,83	5,97	Animals & Veggie	15	
11	Basonyagwe	1589	47670	47,67	-47,67	Animals & Veggie - Under Constructions		
12	Qhaloderer/Mewedan	2664	79920	79,92	-79,92	Under Constructions		
13	Guye	2299	68970	68,97	-68,97	Under Constructions		
14	Harar	1824	54720	54,72	-54,72	Under Constructions		
15	Qandach	2063	61890	61,89	-61,89	Under Constructions		
16	Sasumwega	2705	81150	81,15	-81,15	Animals & Veggie - Under Constructions		

Trine Ånestad Røer

Multiple-Use Water Services in Rural sub-Saharan Africa

NTNU
Norwegian University of
Science and Technology