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Sustainable water supply in the rural districts of Mbulu, Hanang and Mkalama, Tanzania

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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, spring 2018. It equals 30 ECTS and is the end of the five-year study program Civil and Environmental Engineering, with the course specialization Water and Wastewater Engineering. The research has been executed in cooperation with Norwegian Church Aid (NCA).

I first and foremost want to thank my supervisor Sveinung Sægrov for seeing the opportunities in a student who wanted to do something "out of the ordinary" and work with development projects. Without him this project would not have been started and I want to express my gratitude for all help and discussions both in Norway and Tanzania. I would also like to thank Erlend Våland Bø and the employees at the department's laboratory for essential help during the first couple of weeks with calibration of the sensor.

I am sending my gratitude to the people I worked with in NCA. Manfred Arlt and Håvard Aagesen have been utmost helpful, with everything from organizing the fieldwork, providing me with literary resources and being there under the implementation of NCA's sensors in Tanzania. Zachayo Makobero, as NCA's country representative, provided me with valuable support and company during long car rides. The same goes for the guys in 4CCP, Nelson Faustin and James Mmbando, who both served as translators, Swahili teachers, drivers at times, valuable sources of information and cheerful company during the many car rides to Munguli, Gidarudagaw and all the other villages.

NCA also supported me financially by covering the costs of the travel and stay at Haydom Lutheran Hospital. I am forever grateful for the opportunity to travel and stay there.

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Abstract

The lack of sustainability in rural water supply remains a demanding challenge, even after several decades with attention on causes and solutions. Numerous measures have been implemented, but water supply schemes are still left unused due to wrong technology choices, insufficient support from the donors towards communities and lack of repair and maintenance. Solutions that have been implemented may quickly experience problems and it often takes too long before functionality is recovered. Especially hand pumps are often easily broken, which is a major problem with the enormous amount of installed hand pump in sub-Saharan Africa (SSA) during the last few decades. The users of the scheme will be forced to use their old and often contaminated sources of water during this downtime. A growing awareness of the need for institutional and financial support after the implementation of a scheme has arisen, but how this is to be managed must be evaluated in relation to the relevant context and conditions.

To investigate this problem further, a fieldtrip to Haydom, Tanzania, was conducted in the period January to March 2018. This part of Tanzania has a major rural population, which lives with water related stress. Several interviews with local villagers and examinations of their water schemes were conducted to get an understanding of the challenges they are facing. Most of the interviewed villagers depended on hand pumps for water, which requires regular maintenance and repair. Lack of sustainability has thus been a problem here, and hand pumps that previously have been installed are now out of use. Four Corners Cultural Program (4CCP), Norwegian Church Aid's (NCA) partner organization in the area, is working with the water related challenges.

One of the suggested measures to reduce the downtime is to install a remote monitoring system. Several aid organizations have explored the possibilities within this field, which inspired NCA to do the same. They developed a system that can log and transfer water flow data via mobile networks thereby enabling stakeholders to view the consumption and discover if the system is not working. The idea is that this will reduce the downtime of the non-functional pumps and hence increase sustainability of rural water projects. Their system was installed on two pumps; one solar powered motorized pump and one India Mark II hand pump. Multiple challenges were discovered during the implementation and the system is not yet functional. Time will show if they are able to make it work and contribute to the remaining sustainability challenge.

During the interviews with the inhabitants of the villages, and by observing the issues in real life, several other factors affecting sustainability became apparent. These fit well with factors identified in relevant literature. Institutional, financial, social, technical and environmental factors can all be observed in this setting and measures can be implemented on several of these. Having a more efficient and available supply chain of spare parts combined with more skilled and locally available mechanics equipped with tools can reduce downtime. A reduction of downtime can also be achieved by being more aware of the technology choices made, especially concerning the choice of water scheme and the supplier of it. Making people

aware of the importance of a proper water scheme that delivers safe and clean water is also important as they more likely will take good care of it through well-managed operation and maintenance routines. This can be achieved through tariff settings and payment of water, or with enhanced focus on the health and society beneficial effects of an improved water source. Some of this is already common practice in 4CCP's work, but more can be done to further improve the sustainability of the projects. More work and effort has to be invested in identifying factors affecting sustainability in the relevant area and finding specific measures to reduce downtime.

Sammendrag

Verden i dag står ovenfor en betydelig utfordring når det kommer til bærekraften til vannprosjekter i utviklingsland. Tidligere har fokuset vært på å gi flest mulig tilgang på rent drikkevann, og det har blitt tatt lite hensyn til hvordan løsningene skal følges opp og vedlikeholdes etter de er blitt installert. Dette har ført til mangfoldige forlatte og ubrukelige løsninger og landsbyer som må returnere til de gamle, forurensede drikkevannskildene sine. Utallige håndpumper er installert i Afrika sør for Sahara de siste årene, da de sees på som både enkle å vedlikeholde og billige, men et stort antall av disse slutter å fungere etter kort tid. Mange forsøk har blitt prøvd ut for å bedre situasjonen, men fremdeles er bærekraft et betydelig problem. Man kan observere et økende fokus på institusjonell og finansiell støtte etter at prosjektene har blitt ferdigstilt, men dette må utarbeides for hver unike situasjon for å fungere best mulig.

Et feltarbeid ble utført i Haydom, Tanzania, for å undersøke disse utfordringene mer i detalj. Dette fant sted i tidsrommet januar til mars 2018. Befolkningen i denne delen av Tanzania bor spredt og under enkle kår. Vannsituasjonen er for det meste utfordrende, og mange må ta til takke med forurensede overflatekilder eller tradisjonelle brønner uten beskyttelse. For å få en dypere forståelse av de utfordringene denne befolkningen står ovenfor ble innbyggerne i ulike landsbyer intervjuet. I tillegg til disse intervjuene ble også vannforsyningen til landsbyene evaluert, der de aller fleste var avhengig av en håndpumpe som de delvis drifter selv. Flere har opplevd at håndpumpen slutter å fungere kort tid etter at den har blitt installert, og nedetiden kan bli så lang at andre vannkilder må tas i bruk. Kirkens Nødhjelp og deres partnerorganisasjon 4CCP er inne i området og jobber for å bedre bærekraften i vannrelaterte prosjekter.

Kirkens Nødhjelp har vurdert muligheten for å bedre bærekraften ved hjelp av et dataoverføringssystem som kan overføre vannføringsdata over mobilnettet. Mulighetene er store da det er flere som har tilgang på mobiler enn forbedret vannforsyning i området. Andre bistandsorganisasjoner har sett på slike løsninger tidligere, og tanken er at hvis man kan overvåke vannføringen i sanntid så kan man observere når den slutter å fungere. Tiltak kan da iverksettes med en gang og nedetiden vil reduseres. I tillegg vil det være et hjelpemiddel for å overvåke vannforbruket og gjøre det enklere å sette tariffnivåer for betaling av vannet. I installasjonen av Kirkens Nødhjelp sitt system ble det oppdaget flere utfordringer som setter en stopper for ideell funksjon. Disse må endres på for at systemet skal kunne bidra til bærekraftsutfordringene, og det blir opp til Kirkens Nødhjelp hvor mye de vil investere i systemet.

Gjennom informasjonen som kom frem i løpet av intervjuene og videre observasjoner ble mange ulike faktorer som påvirker bærekraft tydelige. Disse kan gjenkjennes ifra ulike kilder av relevant litteratur. Institusjonelle, sosiale, finansielle, tekniske og miljømessige faktorer kunne observeres og ulike tiltak er blitt, og kan, settes i verk innad i hver enkelt faktor for å bedre bærekraftssituasjonen. 4CCP har flere tiltak i sitt arbeid, blant annet oppstart og oppfølging av vannkomiteer som tar ansvar for å samle inn penger til vedlikehold og

reparasjoner og for selve reparasjonene. Andre tiltak som kan iverksettes er å ha lettere tilgjengelige reservedeler til håndpumper og mekanikere som har nok kunnskap til å reparere pumpene. Dette kan potensielt redusere nedetiden betraktelig. Det er også viktig å gjøre folk bevisste på hvilken betydning trygt og rent drikkevann har for dem, enten det er helse- eller samfunnsrelatert. Det er da mer sannsynlig at de vil hegne om vannforsyningen og reparere den hvis det oppstår problemer. Dette kan oppnås ved å ha ordentlige betalingsordninger for vannet, der pengene går til reparasjoner og vedlikehold, eller ved å gjennomføre holdningskampanjer der fokus blir satt på viktigheten av gode vannkilder. Mer fokus og innsats må legges i å finne årsakene for manglende bærekraft for disse spesifikke prosjektene, slik at nedetiden til håndpumpene kan reduseres.

Table of contents

List of tables

List of figures

List of abbreviations

4CCP – Four Corners Cultural Program

BRN – Big Results Now

CBM – Community Based Model

CMP – Community Management Plus

COWSO – Community Owned Water Supply Organization

DFID – Department of International Development

DRA – Demand Driven Approach

DWE – District Water Engineer

EiT – Eksperter i Team

HLH – Haydom Lutheran Hospital

IoT – Internet of Things

IRC – International Research Centre

JMP – Joint Monitoring Program

LGA – Local Government Authorities

L/p/d – Litre per person per day

MAL-ED – Malnutrition and Enteric Disease Study

MDG – Millennium Development Goals

MKUKTA – National Strategy for Growth and Reduction of Poverty

MoW – Ministry of Water

NCA – Norwegian Church Aid

NGO – Non-Governmental Organization

NOK – Norwegian Krone (1 TZS = 0.0036 NOK, as of 02.06.2018)

NTNU – Norges teknisk-naturvitenskapelige universitet (Norwegian University of Science and Technology)

O&M – Operation and Maintenance

PE – Polyethylene

PVC – Polyvinylchloride

RWSN – Rural Water Supply Network

SDG – Sustainable Development Goals

SSA – Sub-Saharan Africa

SWS – Smart Water Systems

TZS – Tanzanian Shilling (1 TZS = 0.00044 USD, as of 02.06.2018)

UNICEF – United Nations Children's Fund

URT – United Republic of Tanzania

USD – United States Dollar (1 USD = 2,280 TZS, as of 02.06.2018)

VLOM – Village Level Operation and Maintenance

WEDC – Water, Engineering and Development Centre

WHO – World Health Organization

WSDP – Water Sector Development Program

1 Introduction

Having sufficient and continuous access to safe and clean water is a human right as stated by the UN General assembly in 2010 (WHO, 2018). Still, 844 million people lack a basic drinking water service, meaning that they do not have access to an improved source of water within a round-trip of 30 minutes. 2,1 billion people are without a safely managed drinking water service, which should be located on their premises, available whenever needed and totally free of contamination. 41 countries have a situation where more than one fifth of the population use an unimproved source. Most of these countries are located in sub-Saharan Africa (SSA) (WHO & UNICEF, 2017b). 159 million people still collect their drinking water from surface waters. 58% of these live in SSA (WHO & UNICEF, 2017a). Still, 2,6 billion people got the access to an improved source between 1990 and 2015 (WHO & UNICEF, 2017b).

There are considerable differences caused by geographic, sociocultural and economic reasons. An example is the massive gap in service between urban and rural areas, or people living in low-income, informal or illegal settlements contra other citizens in urban areas. Globally, 80% of the people that are without an improved drinking water source live in rural areas (WHO & UNICEF, 2017b).

The Sustainable Development Goal (SDG) target 6.1 “by 2030, achieve universal and equitable access to safe and affordable drinking water for all” creates substantial implications for the water supply around the world. This target is highly ambitious and takes severe effort from governments and organizations dealing with water supply. Making progress on this target is also crucial to be able to achieve several of the other SDG targets. The SDG target is much more striving than the previous Millennium Development Goal (MDG) target, which was achieved by 147 countries (WHO & UNICEF, 2017b). Target 6.1 aims at achieving universal and equitable access, meaning that all people, no matter which subgroup they belong to, should have access to drinking water. The drinking water should also safe, affordable and accessible to all, including people with disabilities.

To be able to achieve target 6.1, several actions have to be taken to improve sustainability in water supply projects. Past failure by governments and development stakeholders to ensure sustained access to basic water supplies in rural areas is largely the result of inadequate investment to deliver infrastructure where needed. They have also been failing to ensure that infrastructure, once installed, continues to effectively provide the expected services over time. The rather impressive results from the MDG era remain fragile and at risk, with studies indicating high failure rates, especially on hand pumps (RWSN Executive Steering Committee, 2010).

1.1 Classification of drinking water service

People's access to drinking water and sanitation is among the best-monitored and discussed development issues in the world. The history of monitoring started with the UN Conference of Drinking Water Supply and Sanitation in Argentina in 1977, which culminated in a focused attention on global indicators during the MDG era. The MDGs left areas of improvement, leading to the SDGs (Bos, 2016).

The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) is monitoring the progress on target 6.1. After the creation of the SDG targets, the JMP developed a new classification of drinking water service. This is based on the previous source type classification from the MDG era, but also includes criteria on accessibility, availability and quality of the drinking water services provided. This classification is presented in the table below and in Figure 1-1.

Table 1-1: New classification of drinking water service (WHO & UNICEF, 2017b).

Service level	Explanation
Safely managed	Drinking water from an improved source, located on premises, available when needed and free of contamination from faeces or chemicals
Basic	Improved source where the collection time is not more than 30 minutes for a round trip including queues
Limited	Same as basic, but with a collection time exceeding 30 minutes
Unimproved	From an unprotected dug well or unprotected spring
No service	Water from surface water: rivers, dams, lakes, ponds, streams, canals or irrigation canals

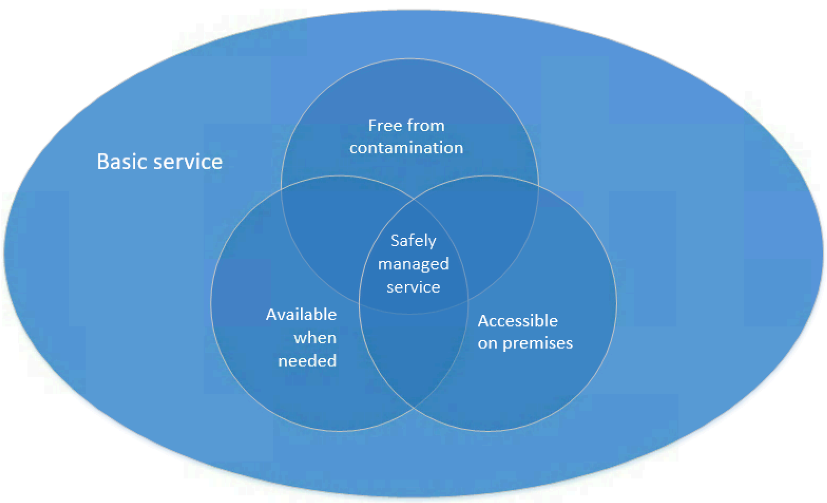

Figure 1-1: The new classification of water service (WHO & UNICEF, 2017a).

Improved sources refers to sources that can provide safe water because of their design and construction, such as boreholes/tubewells, protected dug wells, protected springs and rainwater. Unimproved sources include unprotected dug wells and unprotected springs. The use of surface water as a drinking water source is a great challenge in low- and middle-income countries, and it is a massive risk to the public health (WHO & UNICEF, 2017b).

1.2 History of rural water supply

1981-1990 is known as the International Drinking Water Supply and Sanitation Decade. The objective of this decade was to provide “safe water for all”. A new focus on rural water supply started together with speedy provisions of safe water supply. Governments, donors and NGOs have since then tended to focus on measurable goals and have put most of their efforts into constructing new water facilities. Little or no thought was given to the support of rural communities with finances and operation and maintenance (RWSN Executive Steering Committee, 2010). Problems appeared, unavoidably, fast. Already in the 1980s it became widely recognised that many rural water supply programs were performing poorly. Regardless of the technology implemented, systems were not repaired and thus left unused. There was minimal cost recovery and profits were often insufficient to cover even basic operation and maintenance of the water scheme, much less the initial costs of the project. There was no sense of ownership among the communities and little satisfaction with the water projects that had been handed over to them. Different groups blamed different reasons: engineers blamed poor construction quality, anthropologist meant it was due to lack of community participation, political scientists pointed at rent-seeking and poor governance structures, and economists blamed poor pricing and the tariff design (Whittington et al., 2008).

This lead to a consensus in the 1990s, stating that water supply programs should be more “demand-driven”. The necessary components of a demand-driven approach includes:

1. Involvement of the households in the choice of technology and in institutional and governance arrangements
2. A larger role for women in decision-making
3. Require households to pay for all operation and maintenance costs and a part of the initial costs (Whittington et al., 2008)

1.3 Rural water supply in Tanzania

In Tanzania, clean and safe water is included in every MKUKTA (National Strategy for Growth and Reduction of Poverty) round that has been held, Vision 2025, Big Results Now and election manifestos across all the major political parties. Even though it is commonly agreed upon, providing clean and safe drinking water to the whole population of Tanzania has proved to be difficult. The government and development partners have attempted to supply clean water through the Water Sector Development Program (WSDP) since 2006. More than 1.2 billion dollars have been used from 2006 to 2014. In the period of 2013-2016, this was supplemented by Big Results Now (BRN), which had rural water supply as one of the focus points. According to Twaweza (2017), only half of the households in Tanzania have access to an improved water source and the access in rural parts has not increased in the last 10 years.

The main challenges for the rural population are the distance to the water points, too few water points and contamination of the water. In rural areas the main sources for drinking water are unprotected wells (26%) and surface water (river, stream, dam: 20%). 17% receive water from a public taps and 16% from a protected well/tube well (Twaweza East Africa, 2017). 43% of the rural population use less than 30 minutes to collect water, 19% use between half an hour and an hour and 38% use more than an hour. The rural population itself has identified the distance to the water source as the largest challenge in assessing clean drinking water (39%), then an insufficient number of water points (35%) and dirty water (32%). Functionality of the water points is identified as one of the two main challenges by 14% of the participants (Twaweza East Africa, 2017).

It is not agreed upon if the access in rural parts of Tanzania has increased in the last years. The Ministry of Water (MoW) and the BRN initiative report a substantial increase, whereas the National Bureau of Statistics and Sauti za Wananchi (mobile survey) report no increase in the last ten years (Twaweza East Africa, 2017).

WHO & UNICEF (2017b), in the JMP report, operates with somewhat other numbers. They claim that 10% have water on premises, 44% use less than 30 minutes to fetch water, 25% use between 30 minutes and an hour and 21% use more than an hour. Not having water on premises is connected to another issue, namely that improved drinking water sources are more likely to be located on premises and unimproved are mostly located at a distance more than 30 minutes away from the household. Women and children will in most countries do the task of getting water and Tanzania is no different. This takes away a substantial part of their day, which could be spent differently. Walking for miles to get water can also be a dangerous task, as the women or children are left vulnerable (WHO & UNICEF, 2017b).

1.4 Purpose of the thesis

Sustainability is, as presented in the previous sub-chapters, a remaining challenge in low- and middle-income countries and especially in SSA. This includes Tanzania and measures have to be implemented to improve the sustainability of rural water projects in this area of the world. In SSA, which also has the lowest water supply coverage of any region in the world (WHO & UNICEF, 2017b), it is estimated that 36% of the hand pumps are out of service at any given time (Harvey, 2011). It is calculated that between 1.75 and 2 billion people use groundwater as their water source, either through motorized solutions or hand pumps (Lockwood & Smits, 2011). Between 600,000 and 800,000 hand pumps has been installed in SSA the last 20 years, but at least 30% of these pumps are not working at any given time. This accounts for a total investment of USD 1.2 to 1.5 billions (Baumann, 2009).

Several measures have been suggested since the International Drinking Water Supply and Sanitation Decade to better the sustainability. NCA wants to explore the possibilities within remote monitoring of rural water schemes to reduce the downtime of the hand pump and thus increasing sustainability. Downtime is the period from the pump stops working until it is functional again. Other potential solutions are presented in this thesis and discussed in relation to relevant literature and experiences from the fieldwork.

Specified tasks:

1. Describe the water supply situation in the region selected for the study including a brief historical overview.

2. Evaluate the different factors affecting sustainability of rural water supply and compare them with the findings and observations in the selected region.

3. Participate in the development of a control and monitoring system and collect information from the system installed at one solar powered pumping scheme and one hand pump.

1.5 Structure and limitations of the thesis

This thesis opens with an introduction, containing relevant background information that has lead to the design of the thesis. The purpose, structure and limitations are then presented. Chapter 2 covers more terms and structures that are important for the understanding of the reader. 4CCP and their work are described in Chapter 3, as it is their work that has been observed and as they work closely with sustainability issues. The concept of community owned water supply organizations (COWSO's) is also explained. This chapter is placed before the methodology because it is supposed to be seen in relation to Chapter 2 and the terms explained there. Chapter 4 describes the methodology used to get to the results and conclusions of the thesis, in addition to the choices and limitations relevant for the execution. The fieldwork completed is thoroughly described in Chapter 5, together with NCA's project.

Chapter 6 and 7 both include a theory and a results and discussion part. The reason for this is the great difference between the style of the two chapters, and it was found to be the tidiest way of structuring the thesis. Chapter 6 discusses the impact of water on a rural society and its connection to sustainability. Terms such as availability, accessibility and quality are used to explain indicators of sustainability both described in literature and observed. Chapter 7 deals with technical sustainability and factors affecting it in rural water projects. Lastly, Chapter 8 draws the most important points from these chapters into a conclusion, and further work is suggested.

The research project has been carried out in the period January to June 2018. It is built on project work from 2017 where a potential system for advance warning and failure detection based on failure tree analysis and present needs for monitoring in the context of failures was discussed. The project focuses on the districts Mbulu, Hanang and Mkalama in Tanzania. The project selected a low number of hand pumps and solar powered water schemes. Limitations are more thoroughly described in Chapter 4, Methodology.

2 Important terms for the understanding of the thesis

This chapter will introduce several terms essential for this thesis. All terms are widely used in development contexts. These include sustainability, operation and maintenance, the community based model and community ownership.

2.1 Sustainability

Sustainability became a term after the UN released its report "Our Common Future" in 1987. The term was applied to water supply in the 1990s. The Sustainable Development Goals, released in 2015, aim in target 6.1 at: "By 2030, achieve universal and equitable access to safe and affordable drinking water for all". This is an ambitious goal, and all members of the UN are committed to ensure this universal access; to close the gap between service levels in rural and urban settlements and to deliver higher service levels in terms of quality, accessibility and reliability. To be able to achieve this, the governments have to shift their policies and distribution of resources urgently, going beyond just delivering infrastructure. This means addressing long-term sustainable management and financing of rural water services. The SDGs pose a triple challenge for the responsible: to reach the unserved populations, to improve the levels of service and to sustain existing and future services. The sustainability issue in rural water service is not new and has been in focus since the International Decade on Water and Sanitation (1981-90). Initially the attention was on the community level, especially during the implementation of new schemes. Since the 2000s more emphasis has been placed on support in post-construction than on earlier processes (World Bank, 2017).

2.1.1 A sustainable water supply

The term sustainability can be defined in several different ways. The focus in this thesis will be a definition that is suitable for the topic of rural water supply. Davis & Brikké (1995) stated that a water supply is sustainable if:

- The water supply services are maintained such that a reliable and adequate safe water supply is ensured.
- The water source is not overexploited but naturally refilled.
- The water supply benefits continue to be realized over an extended period of time.

The first bullet point mentions maintenance; to be able to have a sustainable water supply, an effective operation and maintenance (O&M) system has to be in place. Another aspect, connected to the two latter bullet points, is the environmental sustainability. The use and outtake of water needs to be balanced with the natural recharge, keeping it from being dried out permanently (Davis & Brikké, 1995).

2.1.2 Sustainability factors

The concept "sustainable water schemes" has evolved over the decades. By the end of the 1990s it was considered that community managed water supply had five dimensions, which are technical, environmental, financial, institutional and social sustainability (Mukherjee & Wijk, 2003). These dimensions are by many referred to as factors and they are agreed upon by several organizations and authors, among them Parry-Jones (1999) and Harvey & Reid (2004). The latter carried out research on the sustainability factors mentioned above, with a special focus on hand pumps. The different factors are described as follows:

- Institutional/organizational factors refer mainly to the maintenance system that provides on-going financing of recurrent costs and maintenance and repair of the water scheme. One of the central parts is a local organization, e.g. a water committee, which takes care of organizing preventive maintenance and repair and also financing of costs.
- Financial factors denote the funding used to cover recurrent costs for keeping the hand pump functional. In addition to this comes tariffs, tariff collection and finance management.
- Social factors refer to matters such as user satisfaction with the delivered service. It is measured in how easily the service can be accessed and if it is considered worth paying for. This factor also includes social equity, and all individuals of a community should be able to access the water source.
- Technical factors include a reliable functionality of the hand pump, while delivering enough water of an adequate quality. Hand pump technology might not be the determining factor for hand pump sustainability, as issues like hardware problems, spare part access, preventive maintenance and pump usage and durability are just as important.
- Environmental factors are referring to the water source, which should not be over-exploited or polluted. It also includes issues such as chemical and microbiological quality of the groundwater (Harvey & Reed, 2004).

These factors are interweaved and will vary considerably depending on the context the water scheme is in, which may explain why measuring sustainability is such a tough challenge. The factors will be used later in this thesis as a tool to explain sustainability challenges of rural water supply by hand pumps.

2.1.3 Critical criteria for sustainability

Lockwood, Bakalian, & Wakeman (n.d.) identified several critical criteria for sustainability. These will have an affect in the post-project phase. They concluded that the criteria are forming a hierarchy ranked by their effect on sustainability. The most critical criteria among the 20 evaluated are "adequate tariff collection for recurrent costs" and "external follow-up support". Other important criteria are preventive maintenance, availability of spare parts, community management capacity, user satisfaction and willingness to pay, training and support to education within sanitation and hygiene and water source production, quality and preservation.

2.1.4 Problems with sustainability

Parry-Jones, Reed, & Skinner (2001) identified three issues concerning sustainability as a concept. These three issues have to be dealt with properly in order to have a long lasting sustainable water scheme:

- Minimal external assistance in the long term
- Users should finance operation and maintenance with regular contributions
- Continued flow of benefits over a long period

Having as little external support as possible has been a priority for several years, where stakeholders have aimed for communities that are able to run the water scheme on their own (Harvey & Reid, 2004). This has proven to be difficult, resulting in the proposed Community Management Plus (CMP) solution from Baumann (2006), which is explained in the section below. CMP is just one of the improvements towards sustainable rural water supply. Other examples include the "Triple-S", also called "Sustainable Services at Scale", which is an initiative from the International Resources Centre (IRC). Triple-S encourages a paradigm shift from the operational level to decentralized service delivery (IRC, 2018). The combination of technical solutions such as remote monitoring and changes in O&M are another examples of improvement.

2.2 Community based model

The International Decade on Water and Sanitation marked a shift from the earlier centralized, supply-driven and engineer-led programs to the community based model (CBM). New principles were introduced, among them the demand driven approach (DRA), community management and village level operation and maintenance (VLOM) of hand pumps. The CBM is a way of management that enables communities to have the responsibility of ownership and O&M of their water supply using their own resources, that being human, material and financial. Community members are meant to contribute at different stages in the water supply project, formation of management structures and capacity building (Matamula, 2008).

It has been recognized that many communities are not able to fully manage the water supply scheme on their own. They are therefore dependant on support from stakeholders outside the community. Baumann (2006) therefore introduced the concept Community Management Plus (CMP), where a central aspect is that O&M is a shared responsibility between communities, local authorities and central government, thus needing a comprehensive O&M policy.

2.3 Operation and maintenance

"Operation and maintenance" is used in this report as a term referring to all activities needed to run a water (or sanitation) scheme, leaving out the initial construction of the scheme. The overall goal of O&M is to ensure efficiency, effectiveness and sustainability of water and sanitation facilities (Castro, Msuya, & Makoye, 2009). Operation and maintenance are two actions that differ in their own nature. Operation refers to the direct use of the system performed by the users, tasks of any operational staff and rules valid for operation. Maintenance is directly connected to technical actions, either planned or reactive, which is required to keep the system functional. Skills, tools and spare parts are necessary to be able to perform adequate maintenance (Carter, 2009). Maintenance can, after Castro et al. (2009), be classified as follows:

- Preventive maintenance: This includes work that is planned and implemented before a malfunctioning of the system. Such maintenance should be carried out on a regular basis to keep the infrastructure in good condition. It can also include small repairs and replacements as stated by routine inspections.
- Corrective maintenance: Replacing or repairing something done incorrectly or that's in need of being changed.
- Reactive maintenance: This can be explained as a reaction to an emergency or complaints from the public, which normally occurs as a result of failure and the following malfunctioning or breakdown of the system. This type of maintenance can mostly be eliminated by proper preventive maintenance, thus reducing the risk of costly repairs.

A well functioning O&M system depends on factors such as strong institutions, supportive attitudes, expertise and skill, financial matters and the presence of an appropriate service level and technology. Possible constraints for the achievement of such a system might be an unsuitable political environment, the low profile and thus low priority given or lack of community involvement (Davis & Brikké, 1995).

2.3.1 Problems with O&M

Water and sanitation projects do, in general, face their most serious problems with O&M and with cost recovery projects. There are countless examples of how recently built water schemes fail to function shortly after the project has been completed (Liddle & Fenner, 2017; RWSN, 2009). A proper O&M is therefore crucial. O&M activities do not only cover technical matter, but also managerial, social, financial and institutional ones. These activities have to be organized so that constraints, which prevent the accomplishment of sustainable projects, are mostly eliminated or reduced (Brikké, 2000). O&M is an element closely linked to sustainability and a common reason to the lack of sustainability in water projects all over the world. Several of the failures are not technical, and might be a result of poor planning, insufficient cost recovery or outreach shortcomings of centralized agents (DFID, 1998). O&M

has previously been neglected, alternatively only discussed or though about after the projects have been implemented. This neglect has led to an exacerbate credibility of the investments made, the functionality of services, the welfare of rural populations and development of future projects. Luckily, the significance of O&M has been getting increasingly attention. Policy-makers and project engineers seem to be more conscious of the link between sustainable projects and O&M, and the need of incorporating post-construction activities as well as design and construction (Brikké, 2000).

2.4 Ownership

The term ownership is frequently used among organizations dealing with rural water supply. It may seem like ownership is a requirement for community management and a key factor for sustainability. The idea is that if a community has a sense of ownership towards the water supply facility, they will take responsibility of its management, which will lead to willingness to manage and further willingness to meet the on-going O&M costs. Harvey & Reed (2004) reports that this not always the case. A community does not necessarily have a sense of responsibility for the management or a willingness to pay for O&M costs of a water scheme just because they own it. This is important to be aware of as a water scheme implementer (Harvey & Reid, 2004).

3 Creating a community managed sustainable water supply

This chapter is dealing with the process of creating a community-managed water supply, which by many is perceived as the sustainable solution. Having a strong community with an ownership to the water scheme is important for sustainability, even though it does not automatically lead to sustainability. One should also bear in mind that external support is most likely needed. To achieve a community managed water supply in Tanzania, COWSOs are often established and community training is performed. 4CCP's role and work is to be explained in this chapter, concerning water supply both directly and indirectly.

3.1 COWSOs

Community owned water supply organizations (COWSOs) are, by the Ministry of Water in Tanzania, defined as the main accountable for sustaining rural water supply and sanitation services on behalf of the communities (URT (MoW), 2015). The COWSOs are regulated by part VII in the Water Supply and Sanitation Act of 2009. COWSOs have a number of roles, including operation and maintenance of the water schemes, customer care, tariff collection (financial management), health, hygiene and sanitation, monitoring and reporting the trend of the water schemes (Mwendamseke, 2016).

The government decided that from 2009, rural water supply and management should be decentralized to the communities. This has made the COWSOs the responsible legal bodies. Establishment procedures and registering of COWSOs are described in the Water Supply and Sanitation Act, together with an explanation of how communities can participate in owning, planning, maintaining and operating water supply projects. The establishment and registration of COWSOs has been transferred to the Local Government Authorities (LGAs) as an attempt to increase the performance. These also have the responsibility of providing technical support and ensure a well functioning spare part supply chain. The regions are supporting the LGAs and assist in monitoring. The Ministry of Water are to provide strategic support, which will help with the monitoring, report generation and ensuring accountability for reaching targets (URT (MoW), 2015).

3.1.1 Establishment and registration of COWSOs

There are government prepared guidelines for the establishment and registration of COWSOs. These are describing the steps for implementation and which actors that should be involved. The process consists of five steps: introduction of the idea, organization of the community meeting and selection of an interim committee, constitution drafting, registration and technical training and backstopping. The directive on COWSO establishment and registration is described as unclear by Mwendamseke (2016). Each district has then been forced to modify and adapt their own strategies. The establishment and registration process is reported to take too much time and there are several COWSOs operating unregistered. Other problems might be lack of funds to facilitate the process, poor planning and low awareness among the communities (Mwendamseke, 2016).

The COWSO system works effectively and efficient when properly established and composed. It is participatory, which increase the sense of ownership and brings an extra authority to the community in order to manage their own water schemes in a sustainable way. Still, there is a need for monitoring and supervision of the COWSOs in order to keep them accountable for the functionality of the scheme (Mwendamseke, 2016). One needs to make sure that each COWSO consists of conscious men and women who want to contribute to the best for the village.

3.2 4CCP and their role

4CCP stands for "four corners cultural program". 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, 2018). It is based in the city of Haydom and works with the rural community in the districts of Mbulu, Hanang and Mkalama. 4CCP is owned by Haydom Lutheran Hospital (HLH) and has five full-time employees. This area is unique, as it is the only place in Africa where the four major language groups of Africa meet and live side by side. 4CCP has been cooperating with and receiving funds from NCA since 2009 (Nelson Faustin, personal communication, February 2018).

3.2.1 The process

In Chapter 7, Technical sustainability, the initial steps needed to establish a sustainable rural water scheme will be explained in more detail. A village in need of an improved scheme has to be located, the demand has to be assessed, suitable location for the water supply must be found and a suiting technology must be chosen before implementing any scheme. Before starting on the assessment, 4CCP demands that a legally registered COWSO is present in the village and that the community contributes financially and are willing to participate in technical training. After a village is found suitable and has met the requirements, 4CCP might hire an engineering company to do hydrogeological surveys in the area, drill a borehole in a suitable location and install the hand pump (or another chosen solution). When the implementation is done, 4CCP can be a consultant and supporter in O&M or financial matters.

3.2.2 Financial matters

If a village has a well functioning, legally registered COWSO, and a demand for an improved water supply, 4CCP asks them to contribute with a certain amount of the total cost before a further assessment of the opportunities for water supply. This amount is e.g. 30%, like it is in the Dinamu village. 4CCP has this as a demand to ensure that there will be a sense of ownership in the community. The idea is that a scheme that is just handed over to the community will be of less worth than a scheme they have contributed financially to. This amount must be put in a separate bank account before a village is evaluated as an adequate receiver of support from 4CCP (Nelson Faustin, personal communication, February and March 2018).

3.2.3 Technical training

4CCP wishes that all receiving villages find one or several members of the community that can be trained in O&M. These should be able to perform at least routine operation and preventive and easy corrective maintenance. This is, as previously mentioned in Chapter 2, essential for the water scheme sustainability. Their need for help from 4CCP or from the district water engineers decreases drastically if the community is able to do most things themselves.

3.3 Other work done by 4CCP

Figure 3-1: Veggie garden watered with water from a newly installed hand pump.

Water projects are one of the main focus areas of 4CCP's work, and they are incorporating many of their focus points when providing improved water supply to villages. As they are demanding community ownership and participation through COWSOs, financial contributions and technical training, they are empowering the community, which leads to development and social welfare. More water also means the possibility for small-scale agriculture, such as the "veggie garden" project they just started testing. This garden will provide a small variety of vegetables to a household or for sale in the community. Women and children will especially benefit from the water projects, as they are the ones that mostly are given the task of collecting water. This is further explained in Chapter 6, Impact of water. Other work they do include economic empowerment of poor villages, peace building among the different people groups, resolving gender issues and youth leadership programs.

3.4 Ending remarks

"Our findings suggest that the demand-driven, community management model, coupled with access to spare parts and some technical expertise, has come a long way toward unravelling the puzzle of how to best design and implement rural water supply programs in developing countries" (Whittington et al., 2008).

Just as Whittington et al. (2008) discovered, it is evident that the most well functioning projects are the ones that are demand-driven, managed by the community and have access to spare parts and technical expertise. 4CCP can be a facilitator in all of these aspects, and has been so for several villages. They are in addition someone who is supervising the villages and COWSOs, keeping them accountable for their results and functionality of the scheme. This is an example of Baumann's (2006) Community Management Plus. The result is more sustainable rural water schemes and increased development and social welfare for the communities surrounding Haydom.

4 Methodology

This chapter presents an overview over the methods used to gather information during the work with this thesis and how it was executed.

Olsson (2011) presents the following seven methods to gather information:

- Document review
- Use of existing data from systems, reports and similar sources
- Case study
- Interviews with key stakeholders
- Participating observation
- Direct observation/measurements
- Survey

In this report, all the methods have been used except from number 7 (survey). Figure 4-1 illustrates the process of the thesis, where the first two bullet points have been merged into one, called literature review. A case study is used to describe a unit in depth, or to give insight whether a phenomena leads to something else (Wæhle & Dahlum, 2018). The methods in the middle section of Figure 4-1 are all used to achieve this, and are therefore grouped into "case study" as an overall method. When several methods are used, as in this report, it is called triangulation. This compensates for weaknesses in the different methods (Olsson, 2011).

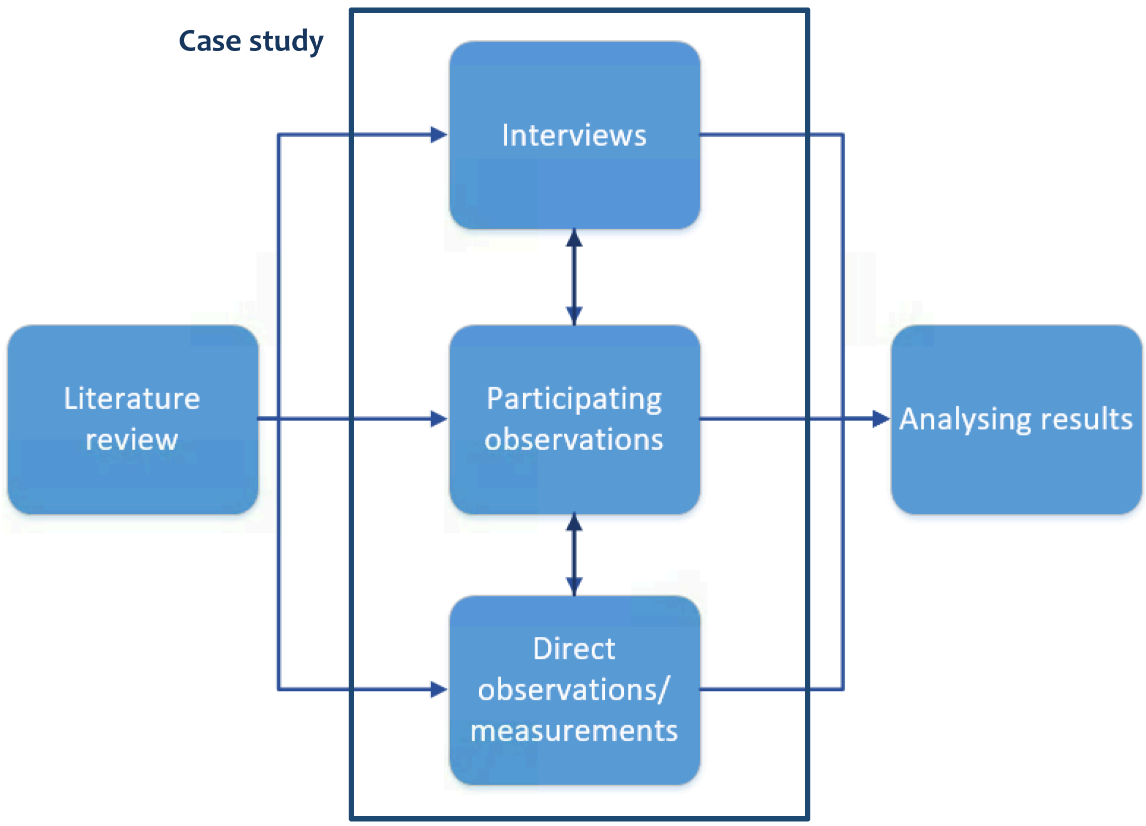

Figure 4-1: Implementation process of the Master's thesis.

The methods of this Master's thesis are mainly qualitative, which is why most of the results presented are qualitative. Qualitative methods are based on oral or written information, where the focus is on few study objects, but with numerous and varied information. Quantitative methods, on the other hand, are based on numbers and measurable parameters. The performed interviews or the participating measurements are examples on qualitative methods, whereas the calibration or the measurements of water flow are quantitative methods (Olsson, 2011).

The reliability of qualitative studies is often challenging, as they are based on a small number of study objects and occasionally subjective responses or information. Quantitative methods are often showing a higher degree of reliability. Reliability can be seen in relation with verifiability and is a control of proper measurements and implementation. If one performs the same measurement several times and gets the approximately same results each time, the reliability would be evaluated as good (Olsson, 2011).

4.1 Literature review

The literature review is performed to provide knowledge, which will enable the solution of the stated problems and provide the theoretical framework for the assignment. This thesis is based on the found and reviewed literature and is discussing it in relation to the problem statement. The material used is mostly available online, enabling anyone interested to easily locate the same information.

The theory presented in the background information and in the beginning of Chapter 6 and 7 is mainly retrieved from the World Bank, UNICEF, RWSN, WHO and relevant aid organizations dealing with rural water supply. Other sources are journal articles written on different subjects related to this thesis. Several of the cited sources were found due to the good work Manfred Arlt has done, both in his own Master's thesis and during the project preparation.

The strategy for finding existing literature was executed as both a systematic search and a chain search. Systematic search means to search after literature in databases through subject-specific words, whereas chain search is to find new sources in the reference list of the primary source (Rienecker, Jørgensen, & Skov, 2013). The databases used here are Web of Knowledge and Google Scholar. Google Scholar is available for free and accessible to everybody. Web of Knowledge was accessed through a NTNU licence, as it is an online subscription-based scientific citation indexing service. The most relevant keywords were: *sustainable development, rural water supply, hand pumps, sustainability assessment, downtime, community management and participation,* and *sustainability indicators.*

It is important to have a critical perspective when evaluating articles, reports and other sources of information. Only this way, a certain scientific quality will be achieved, through evaluation of the objectivity, credibility and accuracy of the source. It is therefore crucial to ascertain if the information is suited for today's conditions and assumptions in relation to technology and research (Rienecker et al., 2013). The following properties were examined during the literature review:

- Content – Is the content relevant for the assignment? Is it just a general overview or is it described in detail? Is the information conflicting with other sources? What are the limitations and assumptions? Are there knowledge gaps?
- Year of publication – Is this the newest information or research on the topic? Is it still valid?
- Place published – Are there any local conditions that must be considered and/or altered to better fit this study?
- Author – What is the author's background and education? What has the author published earlier? What university, institution or organization does the information belong to?
- Citations – Is it a source of information that others trust and have used in their work? Does the source cite other reliable sources? This must be seen in relation with the year of publication.

4.2 Interviews with key stakeholders

4.2.1 Purpose

The purpose of interviewing inhabitants of different villages is to get an insight in the problems the communities are facing on a daily basis in relation to water supply. Through gathering of the water committees and village leaders in a community, a unique chance to gain insight in their ways of coping with water related challenges appeared. Challenges concerning both unimproved sources and improved sources such as hand pumps could be explored. The feedback from the different communities served as an important source of information to this thesis.

4.2.2 Participants

Representatives from water committees in 10 different villages were interviewed during the fieldwork. These were all connected to the catchment area of 4CCP's work. 4CCP arranged the meetings and provided additional information and translation. Ideally, the whole water committee and village leaders should attend the meeting, but in some cases some of them were hindered. Once because of a sudden death in the village, but mostly due to work that needed to be done. In addition to the villages, the district water engineer of Mbulu and two of his technicians were interviewed. This was done to get their view on the issues that the villagers had described, and receive more specific technical information.

It was valuable to have both the water committee members and the village leaders attending the meeting as they work together to manage the water schemes connected to the village. The water committee is responsible, but the leaders of the village are the ones who take any significant decisions concerning the village and its population. Meeting with them together gave a more complementary picture of the situation.

Table 4-1 is presenting the interviewed villages together with some key information about them.

Table 4-1: Name of interviewed villages with essential information.

Village	Number of households	COWSO	Primary water source (secondary source)
Endagaw Chini	1200	Yes	Hand pump (and river)
Hayeda	250	Yes	Hand pump (and traditional well)
Gidarudagaw	87	Yes	Hand pump (and seasonal river)
Munguli	102	Yes (2 committees)	Solar powered driven pump and rainwater harvest for school
Hilamoto	400	Yes	Hand pump (seasonal river and traditional wells)
Hang'Wa	17.000 inhabitants	Yes	21 water points connected to an electric pump + two hand pumps
Mtamba	500	Yes	Diesel driven pump with 12 water points
Dinamu	316	Yes	Self-dug dams to collect rainwater
Endamilay	313	Yes	Hand pump and traditional wells
Mazingiri	336	Yes	Four hand pumps and rainwater harvesting tank at the school (and four traditional wells)

4.2.3 Question design

The questions were formed to best obtain information relevant for this thesis, particularly specific information enabling discussion around the problem statement. The interview questions are listed in Appendix A1. During the interviews some spontaneous alterations were made to complement the information that appeared. The questions are divided into four main groups:

- Initial questions, which are assessing the number of households and structure of the water committee.
- Water situation, which is the largest and most relevant part. Here, questions about what type of water sources they have, repair and maintenance routines and the connected issues and challenges are explored.

- Impact, which started out as a point mostly because of interest, but ended up being relevant for the thesis. Questions about health impact, school attendance and changed life situations are included.
- Financing, which includes questions on the amount paid, how it is collected and if it is enough for maintenance and repair costs.

4.2.4 Interview execution and evaluation

Before conducting any interviews, Nelson Faustin, project coordinator at 4CCP, would call and arrange the meeting with the villages. All the villages did gladly accept being interviewed and summoned most of the relevant members of the community. Nelson Faustin had read the questions in advance and had given some comments on them. The survey was altered accordingly. Information from each interview was written down directly in a notebook and rewritten on the computer when returning from the interviews. The rewritten interviews are presented in Appendix A2.

A total of 11 interviews were held, where 10 were with villagers and one with the district water engineer in Mbulu. The interviews were conducted between the 13th of February 2018 and the 5th of March 2018. Each of them lasted between half and hour and an hour, depending on the participants' willingness and ability to answer, their questions to 4CCP and 4CCP's need to give them additional information. Some villages also got additional questions as interesting information appeared during the interviews. Each interview started with a presentation of all the participants of the meeting and the reason for them being there. Most of the interviews ended with an examination of their water sources, either improved or unimproved.

It was seen as important to interview groups instead of individuals. This made the interviews more efficient and there were always someone present who could answer the questions. As it was necessary to both have transportation to and translation in every interview, and as the villages were often located up to an hour away from HLH, it was required to be efficient. The different members of the committees and village boards completed each other. If someone did not quite understand the question, or did not have the sufficient knowledge, another member could answer.

The findings from the interviews are mainly presented in Chapter 6 and 7, but some of the information has been used as examples elsewhere as well. The results from the interviews are compared with information found in relevant literature.

4.2.5 Weaknesses and limitations

Because of a relatively limited selection of villages, one might question the validity of the results and whether it is sensible to draw conclusions from them. More interviews, especially with villages that have not received improved water supplies yet, would have given more validity to the results. Further, the results are based on subjective experiences and responses. It is therefore difficult to examine the quality of the results. Especially numbers on walking distance and time to water sources and downtime should be taken with a pinch of salt. Some of the villagers also have a limited understanding of technical matters concerning the water solutions, and might have given incorrect information.

Since the interviews were performed in a foreign environment and culture, there are challenges that would not be present if they were conducted in Norway. One is the constant need for translation between Swahili and English. Questions might have been altered in the translation, probably giving a different answer than if everything had been done in the same language. Different language, culture and way of living give different associations to different words or ways of expression. This means that even though it was believed that everyone understood both questions and answers, talking past each other might have happened. The questions could also have been discussed more in detail with a social anthropologist with knowledge about the area and people. However, 4CCP was very helpful with developing the questions.

In some of the villages there were only certain people who spoke. Especially women remained silent. It would be interesting to have performed interviews where only women were present, as they are the ones feeling the burden of insufficient water sources the most. This was not possible during these interview rounds. Lastly, to be able to better compare the results, it would have been better to stick more to the initial questions. This would, on the other hand, leave out useful information that emerged and that have been used in the work of this thesis.

To summarize the weaknesses and limitations:

- Limited selection of villages
- Based on their subjective experiences, not on objective information
- Limited knowledge of technical matters
- Language difficulties and talking past each other
- Could have discussed more with a social anthropologist, but 4CCP was valuable
- Interviews with only female village members could have given other responses
- Sticking more to the initial questions would have made it easier to compare the different villages

4.3 Participating observations

4.3.1 Purpose

This method was used in the beginning of the fieldwork. This was useful for learning how to approach the different communities, how and which questions to ask and to get an initial understanding of the water challenges the communities are facing. It also gave a unique and valuable impression of how aid organizations work together with local partners to get better results.

4.3.2 Execution and evaluation

The first week of the fieldwork, when Manfred Arlt was there, several villages and projects were visited to assess what kind of solutions that can be implemented and where the best location would be. When visiting a village, the first step is to meet with one of the leaders in the village to inform him about the purpose of your visit. During these visits, questions about their water supply, either improved or unimproved, were asked. The existing water schemes were visited and their condition were assessed, based on their appearances and information received from the village. To be able to observe the water schemes and the questions asked by Manfred Arlt was a valuable experience before starting with the interviews. The information received from this method served as inspiration and preparation for the following week's work.

4.3.3 Weaknesses and limitations

None of the presented results rely heavily on this method, as the interviews and literature review are the main sources of information. The information received from this method mostly confirms the information from the interviews and literature. It could still have been useful to participate more actively in these sessions, so that the information that emerged would be more relevant for this thesis.

4.4 Direct observations/measurements

Three different kinds of direct observations were performed during this work: calibration of the water flow sensor, reading of the water meters in Munguli and collection and analysis of the data from the NCA water meter.

4.4.1 Purpose

The purpose of the calibration was to compare the values given by the water flow meter belonging to NCA with conventional water meters, which are certainly giving reliable values, and then to adjust the code belonging to the NCA water flow meter so that it too would present reliable values. This had to be done before the fieldwork and implementation of the water flow meter on pumps.

The purpose of the reading of the water meters was to compare these values to the NCA water meter, to be able to calculate the consumption per day per person in Munguli and to have a back-up solution in case the NCA solution did not measure. The purpose of the data gathering from the NCA meter was to see if they were functional, if they gave values that could be trusted and, if not, to try to figure out what could be done to solve the problems.

4.4.2 Execution and evaluation

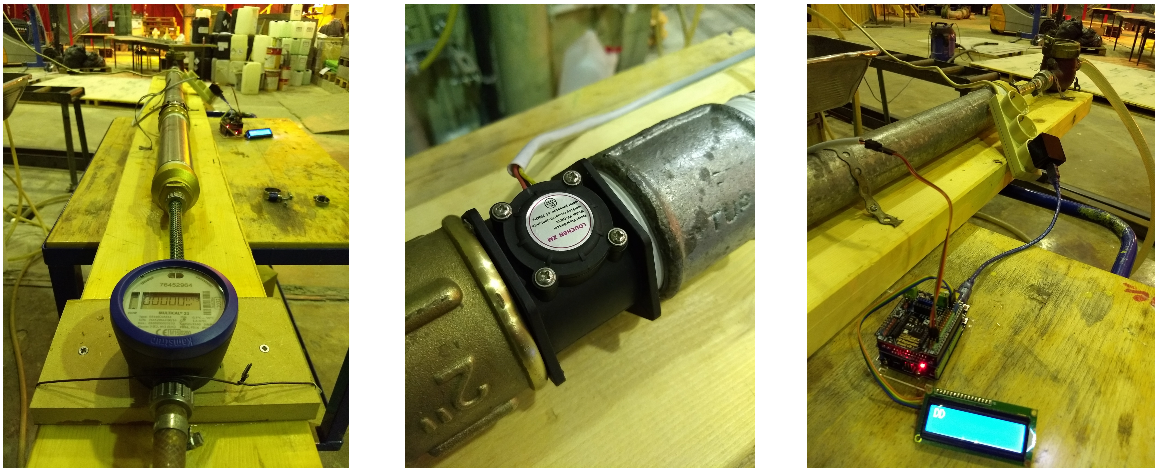

Figure 4-2: 1: The horizontal pipe fitted with a conventional water meter. 2: The NCA sensor. 3: The module for storing and transferring data & screen for displaying the water flow.

The calibration was executed during one day in the middle of January 2018 before the fieldwork had started. It was performed in the laboratory of Civil and Environmental Engineering at NTNU. The calibration structure had a horizontal pipe fitted with three water flow sensors: one provided by Kamstrup, displaying water amount directly on the meter; the NCA sensor and a mechanical flow meter belonging to the laboratory. The last one was not functional, so the calibration was only based on the Kamstrup meter's values. Water was sent through the pipes, and both the Kamstrup meter and the NCA sensor measured the amount. The water was turned off after some time and the amount displayed on the Kamstrup meter was written down. This value was compared to the stored values on the memory card, which differed a great deal on the first try. The value in the code was changed to a better value and this procedure was repeated until the two sensors measured the same amount of water. This value was then communicated to Håvard Aagesen at the NCA office, in order to ensure that all the systems that were going to be used in Tanzania were calibrated to display correct values.

The readings of the conventional water meters in Munguli were done approximately once a week. One of the teachers at the school was given the task of doing readings two times each day, once before they started the pump and once after they stopped it. The readings were recorded in a notebook, and this was photographed each week. The book with all the readings done by the teacher is shown in Figure 4-3. After the return from the trips to Munguli, these values were written in Excel and analysed. Errors were spotted and the average and standard deviation on consumption were calculated. This is presented in Chapter 7 Technical sustainability.

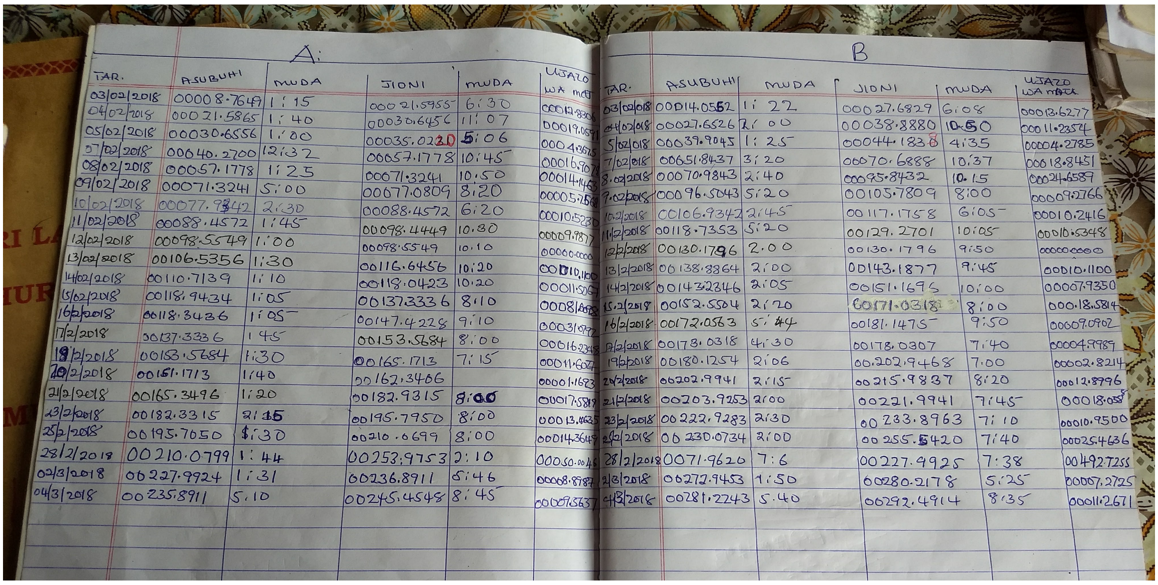

Figure 4-3: Book with readings twice a day.

The readings from the NCA sensor were likewise gathered approximately once a week. These are stored on a memory card that can be read on a normal computer, and this was done after the return from the trips. The data were analysed, mostly to see if the sensor measured anything of value. This will be further explored in the Chapter 7.

4.4.3 Weaknesses and limitations

Concerning calibration it would have been better to have two functional water meters. Two meters for reference would have improved the accuracy of the calibration. To get better water flow data from the sensor mounted on the hand pump, it would have been useful to perform a calibration after the instalment. This could be done by pumping a certain number of buckets with a known volume and comparing this to the measured values.

The teacher who read the meters twice each day did several mistakes, some which were easily visible and correctable and some were it is almost impossible to know the real value. This leads to more uncertain consumption values for Munguli. This is dealt with later, when the standard deviation is calculated. Sometimes the pump was running when the measurements were to be taken, and it was not possible to check if the latest value was read correctly. Even though instructions and training were given on each visit, errors still occurred. The meter can be perceived as hard to read, especially without any

Figure 4-4: Conventional water meter used in Munguli.

prior knowledge or experience with data reading and water meters. More intensive training and follow-up is needed to get reliable results.

4.5 Graphic and design tools

The following software tools were used to create this Master's thesis document:

- Microsoft Word and Excel for Mac 2011: Reporting, calculations, tables and graphics
- Microsoft Visio Drawing: Creating figures
- Google My Maps: Creating maps

All pictures used in the thesis are taken by me, or by Sveinung Sægrov and his wife Randi Sægrov.

5 Fieldwork in Tanzania

A substantial part of this Master's thesis is the fieldwork carried out in Tanzania. It will be presented in detail in this chapter, as will NCA's remote monitoring project. Future possibilities of the NCA project are shortly discussed. The chapter ends with a personal account of the impressions, as it is impossible to be a part of a project like this without being affected.

5.1 Introduction to remote monitoring

There has been a global mobile communication revolution in the world the last couple of years thus providing new chances to address water security and poverty reduction challenges. The number of people with access to a GSM signal in Africa overtook the number with an improved water supply already in 2011. It was estimated that by 2012 mobile subscription numbers would pass the same yardstick. This marks a new technological era, which can transform the way water services are paid for, operated, regulated and maintained, especially for low-income countries. The industrialized world are rapidly applying the use of smart water metering, which can be used to detect systematic operational inefficiencies and to administer and assign water resources more efficiently in developing areas (Hope et al., 2011).

Uncertain and significant risks, such as rapid population growth, hydrological variability and more frequent extreme events, and increased stress on different water distribution demands, are more evident than previously. Smart Water Systems (SWS) present a new approach to advertise water security and dealing with the mentioned risks. Water resource decision-making needs to be both strategic and transparent to be able to achieve water security. This achievement depends on accurate, timely and reliable collection and communication of data, which can be captured and transferred with SWS. SWS can create a secure, transparent and low-cost flow of capital and information between consumer, water service provider and delivery system, when combined with mobile banking. This can open up possibilities for the rural poor, making it easier to be connected to an improved water source (Hope et al., 2011).

A number of innovative projects have been implemented by NGO's trying to accomplish better sustainability in rural water projects, where one of the most successful projects has been implemented by Oxford University in Kwale county, Kenya. They used an accelerator sensor on the handle of the hand pump, making them able to calculate the amount of water pumped. A pre-payment system for water improved the maintenance and repair system; with results such as a ten-fold reduction in pump downtime and 98% of pumps functioning when the project was finished (Hope, et al., 2014).

5.2 Description of NCA's project

Norwegian Church Aid wants to better the sustainability of rural water schemes, especially for hand pumps, through remote monitoring. They have, like other aid organizations, discovered the opportunities of remote monitoring in water projects. Having innovation as one of their main focus points have made them positive towards giving Håvard Aagesen and Alexander Klein the task of exploring the possibilities. It was mainly a project executed on their spare time during the autumn of 2017, but after receiving financial support from Innovation Norway they were able to use a part of their professional time at NCA.

Their system is made out of Ardiuno elements that are able to read, store locally and send the signals measured in the water flow sensor. Ardiuno is one of the world's leading open-source hardware and software ecosystems, offering a large variety of software tools, hardware platforms and documentation. It enables almost anybody to be creative within Internet of Things (IoT) development. The NCA module consists of two microcontroller boards, one that has the ability to receive signals from the sensor and store them locally on a SD card, and one that can transfer the data using a SIM card. The code used in the system is inspired by the online Arduino community and edited for NCA's purpose by Håvard Aagesen and Alexander Klein. In addition to this, there is a power bank or battery, which receive power from a solar panel and provides the system with power when the sun is not there, and a screen that displays the measured values. The sensor used is a simple turbine meter, which registers each propeller rotation created by the water flow. The whole system is easy to obtain and relatively cheap, no matter if living in Norway or Tanzania. It is, on the other hand, not very robust and is therefore placed inside a plastic box, providing protection against vandalism and the surrounding environment. With the local storage of data, one has the ability to collect the data through frequent visits to the site and reading of the memory card. These data can be viewed in an Excel sheet where the time date and water amount pumped are stored. The water amount is stored and each new value is added to the previous value, therefore the number will strictly increase until the system is turned off. The transferred data can be viewed on a web site, which relevant stakeholders should have access to.

5.3 Work connected to the Master's thesis

5.3.1 Preparation/calibration

During the autumn of 2017, a pre-study of the project was completed. It was not until this project was finished that Håvard Aagesen and Alexander Klein were able to work on the project outside their own personal time. January 2018 was therefore a hectic month, trying to discuss and agree on both the technical solution and practical matters of the field trip. One physical meeting at NTNU in Trondheim was held, where the system was discussed and evaluated to the best of the participant's abilities. After a closer look at the code it was evident that there was a need for calibration of the sensor before field-testing the whole system in

Tanzania. Only one value in the written code was necessary to alter. The calibration has been described in Chapter 4, Methodology.

5.3.2 Fieldwork

Figure 5-1: Map of Tanzania with the location of Haydom (made with Google Maps).

A field trip to the city of Haydom, Tanzania, was conducted from 30.01.2018 to 08.03.2018 to install the sensor and transfer system on two pumps, perform surveillance of the system and data reading, and to visit and interview different villages in the area, asking them about their water schemes and maintenance routines. Haydom is a remote town in the north-central part of Tanzania, marked with a green point in Figure 5-1. The nearest urban area is Arusha, which takes about 7 hours by road to get to (Mduma et al., n.d.). The community is build up around Haydom Lutheran Hospital (HLH), which receive support from NCA among others. The guesthouse at HLH is the best option for staying in Haydom, visited by several voluntary workers and students each year.

Figure 5-2: View over the city of Haydom from Mount Haydom.

The first week consisted of visiting water projects in different villages, together with Manfred Arlt and Nelson Faustin, to get an impression of the challenges and possible solutions. Håvard

Aagesen worked together with Zachayo Makobero, the NCA country coordinator in Tanzania, and Paulus, the hospital mechanic, to install the system at the solar powered pumping scheme in Munguli. The sensor was placed on a bypass connected to the inlet pipe leading to the storage tanks. The box containing the components was placed on the metal structure supporting the tanks.

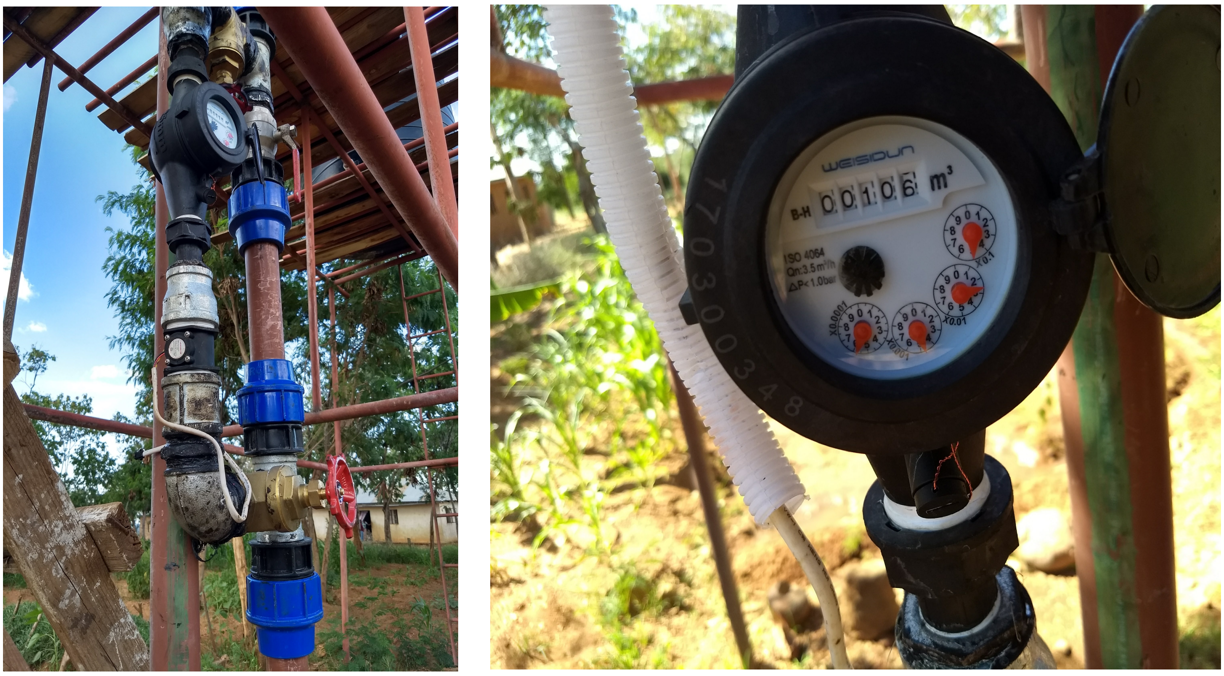

Figure 5-3: 1: Bypass with conventional water meter and sensor. 2: One of the installed conventional water meters.

All the components were placed at an elevated spot for safety, because it is located on school grounds. The system receives power from a small solar panel, installed on an elevated spot with a favourable angle sun-wise. In addition to the instalment of the bypass, a conventional water meter was installed at the outlet of the pump. This enabled measurements at two different parts of the system, which was used to compare values. After the completion of this instalment the work on the hand pump in Gidarudagaw was next. The sensor was installed on the sprout of the hand pump, and the whole middle section had to be replaced. This work was also done by Paulus, together with several members of the village community. The box containing the reading and transmitting system was placed close by, in a metal box that can be locked. The solar panel was placed on top of a long vertical metal pipe, keeping it out of reach for most people.

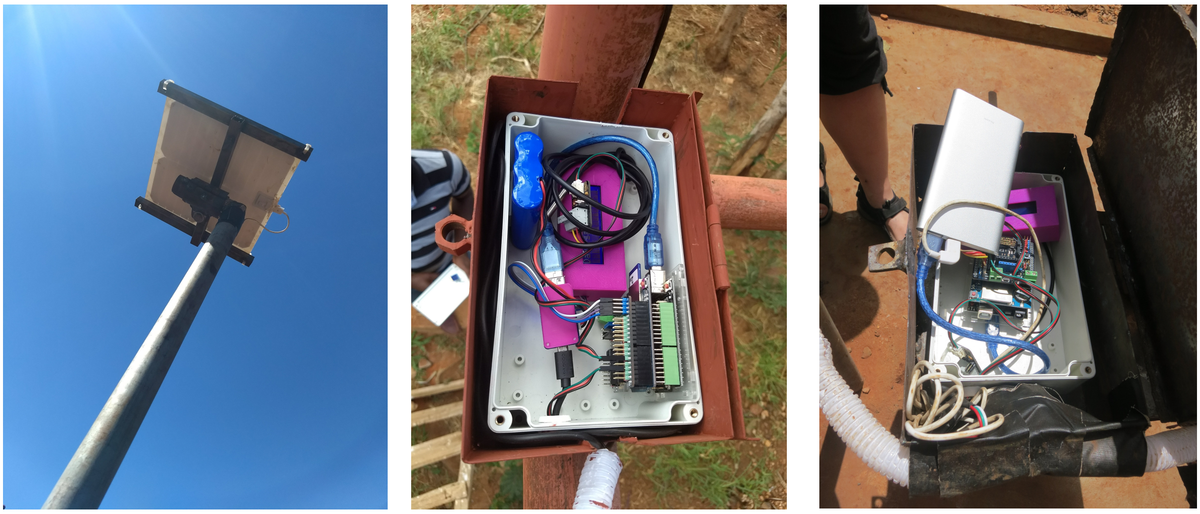

Figure 5-4: 1: Solar panel providing electricity to the system. 2 & 3: the whole system inside a protective metal box.

The remaining four weeks were spent on data collection from the sensors, analysing this data, interviewing local water committees in different villages, looking at their water schemes and visiting other projects 4CCP is managing.

5.3.3 Challenges and further work

The instalment of the two sensors worked seemingly fine at first. It was nevertheless soon discovered that the system in Munguli only logged and transferred water flow data with the value zero, even though water was flowing through. The system in Gidarudagaw did not transfer at all, but were logging and storing data locally. These problems were not rectifiable while Håvard Aagesen was there and it was decided to replace the modules with ones that only store the data locally. Weekly visits to Munguli and Gidarudagaw to collect data manually was therefore necessary. One of the problems that need to be solved is the problem of coverage and mobile networks. Both Gidarudagaw and Munguli are rurally located, making the choice of a mobile service provider difficult. Placing the whole system inside two boxes, where one is made out of metal, is not favourable for the transferral of data. The metal box is required for protection of the system, but an external antenna might help eliminating the coverage problem. Equally, the high temperatures in this area can be a problem, forcing the system to shut itself down. A solution might be to install a fan component, which can cool the system.

The system in Munguli only showed zero as a water flow value, even when the data was collected manually. This suggests that there is something wrong, either with the sensor itself or with the connection between the sensor and the reading and transfer system. The system in Gidarudagaw delivered values locally, but the date and time is not right. Every reading is reported as being stored 01.01.2000 with the time 01.00. This makes it difficult to know when the pump has been used. The sensor at the hand pump might provide slightly incorrect values, as there is not full pipe flow at all times in a hand pump and the installed sensor at the sprout can disturb the flow (Thomson, Hope, & Foster, 2012). This will lead to different values in the stored data than the actual pumped water amount. To ensure that the sensor is displaying as correct values as possible, calibrations should be performed. One needs to keep in mind that different people pump differently; some take slow and large strokes and some small and fast. This will affect the amount the sensor is able to read.

Table 5-1: Example of data series from Gidarudagaw.

Year	Month	Day	Hour	Minute	Water flow (L)
2000	1	1	1	0	5,41
2000	1	1	1	0	14,06
2000	1	1	1	0	22,78
2000	1	1	1	0	27,67
2000	1	1	1	0	27,67
2000	1	1	1	0	27,67
2000	1	1	1	0	28,8
2000	1	1	1	0	34,21
2000	1	1	1	0	40,3
2000	1	1	1	0	47,59
2000	1	1	1	0	55,11

Table 5-2: Example of data series from Munguli.

Year	Month	Day	Hour	Minute	Water flow (L)
2018	2	12	14	1	0
2018	2	12	14	1	0
2018	2	12	14	2	0
2018	2	12	14	2	0
2018	2	12	14	2	0
2018	2	12	14	3	0
2018	2	12	14	3	0
2018	2	12	14	3	0
2018	2	12	14	3	0
2018	2	12	14	4	0
2018	2	12	14	4	0
2018	2	12	14	4	0
2018	2	12	14	4	0
2018	2	12	14	5	0
2018	2	12	14	5	0
2018	2	12	14	5	0

NCA has up until June to come up with a solution to these problems. The solution should be more stable and able to work under conditions where the coverage is inadequate. Then they may apply for more support from Innovation Norway to further develop their remote monitoring solution.

Alexander Klein in NCA performed another field trip to Haydom in May 2018, attempting to implement a new version of the system. This version has a built-in GSM module and the possibility of having an external antenna outside the box. New problems arose, and due to weather difficulties and delays there are uncertainties concerning the reason for the problems. One hypothesis is that a combination of the hardware and software cause the system to hang. There was no sign of improvement in transferral of data when they left the box open. The next step is to investigate whether a better solution might be to not connect the system directly to the Internet, but have a system where a SMS is sent to a gateway phone. Further work is to be done by NCA, but they are dependant on more funding (Håvard Aagesen, personal communication, 31st of May 2018).

5.4 Personal account

Even though I thought I was prepared for a rural community in a developing country, there was still quite a shock to arrive in Tanzania after 30 hours of travelling from snowy Trondheim. Nothing felt like home: roads were mostly what I would describe as terrible, but which I learned to appreciate as the "Tanzanian massage", the temperature was well above my comfort level and everything were perceived as "exotic". Haydom Lutheran Hospital felt like a safe haven at times, as several Norwegians lived, worked and did their hospital training there. As the only known place with proper indoor-faucets and "western" toilets, one could easily forget that the water situation was completely different outside the hospital gates. New people arrived and left the hospital's guesthouse every week and our living conditions reflected the numerous Europeans, Americans and Canadians who have been staying and investing in the place. I felt more than once spoiled when I left the hospital knowing that we the same morning had complained about the lack of hot water in the shower. Visible poverty makes one reflect; at least it is the case for me.

My work was divided into two main parts: to participate in NCA's project and oversee it after Manfred Arlt and Håvard Aagesen left, and interview villagers to get an understanding and identify their issues with sustainability, downtime and water supply. Even though NCA's sensor and transmitting system did not work as planned, it was still valuable to be a part of the project and to be the one overseeing it. All the data I collected from the two NCA sensors could not be used, other than to realize that there were problems with both.

Performing the interviews and visiting villages that have severe challenges with water supply were definitely the most rewarding part of the whole experience. The way people greeted us when we arrived, the helpfulness in answering questions and showing us their water sources and the cheerfulness, even though we discussed serious matters, made an impact on me. I wish that I were able to do more than just ask questions about repair, maintenance and walking distances and then write a report about it. It is so easy to feel useless after an experience like this, as nothing seemingly has changed. My hope is therefore that this thesis can be used to inspire further work than can accumulate in brilliant and lasting changes in the communities. Hopefully it will inspire other students to engage in development work, both in their student projects and in their career life. It has leastwise inspired me.

Figure 5-5: Neema (one of the teachers at Munguli primary school), me and Randi Sægrov with a chicken we received after a visit to Munguli.

6 Impact of water on a rural society

The following chapter discusses the different ways water may impact a rural society, using terms from the thematic report of JMP. Financial, social and environmental factors affect sustainability, as described in Chapter 2, and these are all included here. Evaluating these factors and how the observed projects are performing accordingly can be helpful to reduce downtime and increase sustainability. The first part of this chapter describes literature found on the subject, whereas the second part discusses topics from the literature together with observations made during the fieldwork.

6.1 Theory

Water is one of the most crucial substances for life on earth and one of the backbones of society. Water is essential for human living and a necessity for development. If water is non-existing or only found in small quantities, a number of problems arise. According to Reed & Reed (2013) the absolute minimum of water required is per person per day 7.5 L, including only enough for survival and basic hygiene. To include more thorough hygiene, washing of laundry and home, small-scale agriculture and sanitation, a much larger quantity is needed (Reed & Reed, 2013). Quality is another aspect of water and bad quality causes millions to fall ill each year. JMP's thematic report on drinking water uses the following indicators to determine if a water service is safely managed: accessibility, availability and quality (WHO & UNICEF, 2017b). These indicators will be used in this chapter to identify the impact a water service has on a rural society, as they are key factors for achieving an improved and sustainable water supply.

6.1.1 Availability and accessibility

Availability can be translated into sufficient quantities of water and reliability of services. Reliability is associated with continuity, which are closely linked with sustainability, system robustness and resilience (Bos, 2016). The water should be available in sufficient amounts for drinking, personal hygiene, cooking, food preparation, dish and laundry washing and cleaning. Any excess water can be used for irrigation purposes or livestock. The quantity available or used over a given time can be used as an indicator for availability. One might also use indicators such as a certain amount of days with service throughout a year or frequency of breakdowns and the time it takes before it is operational again (WHO & UNICEF, 2017b).

Accessibility can be explained as the distance or travel time to a reliable water supply and whether different groups can access the source, such as people with disabilities, children and elderly. The distance to the water source from the household, school or work place should be within everyone's reach (Bos, 2016).

There is a close connection to the quantity available water and the distance to the source, and the longer the walk the smaller the amount available. WHO has provided a guidance that shows the relationship between service levels, the distance to the source and which needs that will be met by the supply. This relationship is presented in Table 6-1.

Table 6-1: Requirement for water service level to promote health (Howard & Bartram, 2003).

Service level	Access measure	Needs met
No access (amount usually less than 5 L/p/d)	More than 1000 metres or 30 minutes collection time	Consumption cannot be assured and hygiene is not possible unless practiced at source
Basic access (amount unlikely to exceed 20 L/p/d)	Between 100 metres and 1000 metres or 5-30 minutes total collection time	Consumption should be assured. Hand washing and basic food hygiene possible, laundry and bathing difficult without doing it at the source
Intermediate access (average amount about 50 L/p/d)	Water delivered through one tap on premises or within 100 metres/5 minutes collection time	Consumption is assured, personal and food hygiene assured, laundry and bathing should be assured
Optimal access (average amount 100 L/p/d)	Water supplied through multiple taps continuously	Consumption is met and all hygiene needs should be met

A service on the intermediate level should be achieved (Bos, 2016). This might not be possible in areas with water scarcity or in areas where the water source is located far from the households. Water for human consumption and domestic use have to be prioritized when there is a shortage. If an intermediate access, or even a basic access, is not possible, the low amounts of water available will be a threat to human health as proper hygiene practices is not prioritized or possible. Further, and indirectly, the lack of water can cause pressure on agricultural productivity, crop failure, malnutrition, starvation, population displacement, and resource conflict (National Institue of Environmental Health Sciences, 2017).

According to Esrey (1996) it is actually more efficient to increase the amount of water when aiming at preventing disease than to better the quality of it. The population will then have the chance to perform better personal hygiene and reduce the risk of contaminating initially clean and safe water (Esrey, 1996). This does not at all mean that the original quality is to be forgotten; it should still be free from contaminants when used for human consumption.

6.1.1.1 Availability and accessibility in Tanzania

In Tanzania, only 10% of the population have water located on their premises, placing them in the optimal or, more likely, in the intermediate access group. 44% spend less than 30 minutes, 25 % between 30 minutes and an hour and 21% spend more than an hour collecting drinking water (WHO & UNICEF, 2017b), meaning that 46% are classified as having no access to water services. The same report that presents these numbers concludes that improved drinking water sources are more likely to be found on premises and unimproved sources are normally located more than 30 minutes away. This means that if you have access to clean and safe water, it is most likely located close to your house, work or school, but if you have to go far to collect drinking water it is most likely contaminated. Tanzania's National Bureau of Statistics has more data on this, which is presented in Table 6-2. It indicates the same as the JMP report: a large percentage of people in rural parts of Tanzania have water located outside premises with varying distances. The distance increases significantly during the dry season, as small-scale rainwater harvesting is not an option and boreholes and seasonal rivers might dry out.

Table 6-2: Percentage of Tanzanian population having varying distances from household to water source in rural areas (National Bureau of Statistics, 2014).

Distance	% of population in rural areas	
	Rainy season	Dry season
At home	16.9	2.5
Outside home, but less than 500 m	42.3	37.8
500 m – 1 km	20.9	24.0
Greater than 1 km	19.9	35.6
1-2 km	13.5	20.4
2-5 km	5.7	11.5
5-8 km	0.6	3.2
Greater than 8 km	0.1	0.5

The burden of fetching water will, in 8 out of 10 households with water outside premises, fall on women and girls (WHO & UNICEF, 2017b). In rural parts of Tanzania women (over 15 years) are responsible for fetching water in 79% of the households and girls (under 15) in 5.5% (National Bureau of Statistics, 2014).

6.1.1.2 Water service charge

To be able to maintain the solution, and have a sense of ownership to the water source, it is common practice to pay fees, either per bucket or per month. The cost should contribute to financial resources, so that the operation can run smoothly and so that maintenance and replacement of assets can be done in a timely manner. Monthly fees might be challenging for households in a tight economic spot and in rural communities paying per bucket up front might be the only achievable solution. There is no absolute measure for the affordability of water, but some development agencies use an estimate of 3-5% of household income, which originates in World Bank practice (Bos, 2016). From the JMP report, which is based on the

Tanzanian household budget survey, it is evident that unless one has access to tanker/vendor water, piped water on premises or a public standpipe, it is likely that one would spend less than 2% of the household expenditure on water (WHO & UNICEF, 2017b). Most do not pay at all, which can be a challenge when implementing new solutions where payment is mandatory.

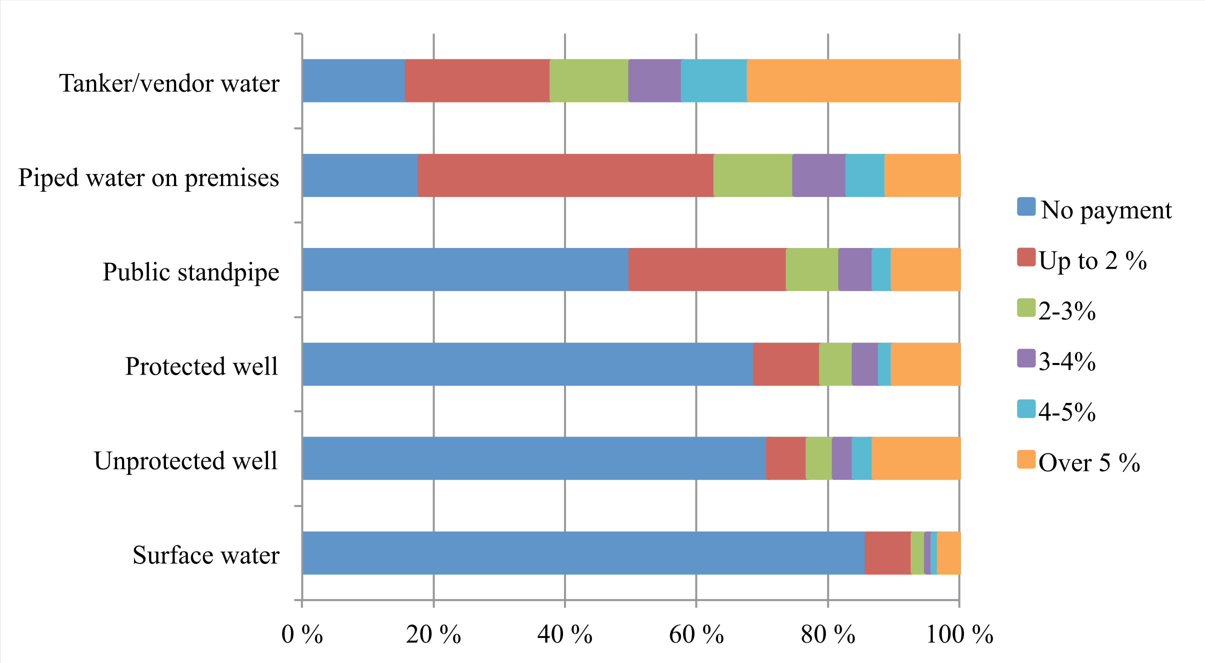

Figure 6-1: Proportion of household expenditure on water services, by source, type and residence (%) (WHO & UNICEF, 2017b).

There are two important components related to water service charge: the access to the water supply network (connection charge) and the water consumption (water price). The connection cost or the installation cost of a scheme might be a high one-off expenditure that several of the members of a community or village cannot afford, making it even more expensive for the remaining households (Bos, 2016).

6.1.2 Quality

To be considered safe, drinking water must be free from pathogens and higher levels of harmful substances at all times. The water quality parameter with the highest priority globally is the contamination of drinking water with faecal matter. This type of contamination is usually detected through surveillance of indicator bacteria such as Escherichia coli (E.coli) in a 100 mL sample. The presence of E.coli in drinking water indicates faecal contamination, but the absence of it does not guarantee safety (WHO & UNICEF, 2017b). The sample might have been taken during a period without contamination and a small or passing event could easily be overlooked.

6.1.2.1 Water-related diseases

Water is connected to several kinds of diseases, some waterborne or water-washed, others water-based or caused by insects living close to the water. Increasing the quality and quantity of water can prevent waterborne and water-washed diseases respectively. Waterborne diseases are therefore a consequence of bad water quality and water-washed diseases of insufficient amount of water available, restraining proper hygiene. Examples of waterborne diseases are diarrhoea (cholera), enteric fevers (typhoid) and hepatitis A, whereas water-washed diseases are e.g. diarrhoea (amoebic dysentery), trachoma and scabies (WEDC, 2017).

Diarrhoea is the second leading cause of deaths among children under five, even though it is both preventable and treatable. According to WHO, approximately 520.000 children under five are killed by this disease every year. It is also the leading cause of malnutrition in children under five and globally there are almost 1.7 billion causes of childhood diarrhoeal disease each year (WHO, 2017).

In addition to causing a great number of children to fall ill and, in worst case, die, diarrhoea will be a burden financially for the households suffering from it (Rheingans et al., 2012) and for cognitive delays in children (Walker et al., 2012). Households might experience great expenses related to treatment, transportation to a health facility and lost time at work. This might have an impact on both the economics of the family and the health. The cost connected to diarrhoea might reduce the money initially saved for investment, education, food or hygiene. It might also effect to what extent poor households seek care, leaving the children more exposed to mortality. Given the high frequency of diarrhoea among children in developing countries, where children under three years old have on average three episodes of diarrhoea each year (WHO, 2017), households are continuously balancing the health risks and economic costs (Rheingans et al., 2012).

Child mortality caused by diarrhoea is easily quantifiable, especially compared to indirect effects like subsequent risk of infection, growth limitations and cognitive delays. It is estimated that each episode of diarrhoea in early childhood increases the odds by five of being stunted at the age of two. This is followed by the fact that early childhood stunting cause cognitive weakening. In addition to this, evidence is stating that there is a difference in caretaker behaviour towards children that are sick. Children that are experiencing regular diarrhoea incidents will be less stimulated by their own activities or caretakers, as they are spending a lot of time in the acute or recovery phase of the illness (Walker et al., 2012).

One solution could be to implement some sort of treatment at home if the water source is contaminated. There are, unfortunately, only small parts of the rural Tanzanian population who take measures to treat the water. 59.8% does not perform any treatment at all, whereas 16.2% boil the water and 13.9% strain it through a cloth. Other measures such as water filters or chemicals are only used sporadically. The numbers on storage of water are better, as 49.5% store water in buckets with lids and 20.6% in clay pots with cover, both methods recommended as the best options for storing water (National Bureau of Statistics, 2014). Proper storing will prevent contamination of initially clean water before being used.

Assessing these indicators shows that water of sufficient quantity and quality located close to or on premises is crucial for everyday life. It affects the amount of water available, which further affects health, hygiene, the empowerment of women, children's school attendance and therefore results and economics in the household, just to mention some aspects. The lack of safe and clean water is a hindrance to the development process, depriving humans of the opportunity to use the resources, that being time, money or health, they have.

6.2 Results and discussion

6.2.1 Availability and accessibility

Travel time or walking distances are immense in rural parts of Tanzania. The population are dispersed, and getting to a water source to collect water can take up a considerable amount of the day. As mentioned earlier in this chapter, this task does mostly fall upon women and children, and the case is seemingly no different in this area. There were without exception women or children, who therefore were absent from school, who fetched water. The unsafe water sources are also here, seemingly, located far from the settlements. This is confirmed through the interviews: the villagers had to walk from 3 up to 10 km depending on the village and the source. Seasonal rivers seem to be located further away than traditional wells that have been made by the villagers themselves. The villages that now have received improved sources, mostly hand pumps, have shorter walking distances than before. However, it is still not sufficient to receive status as intermediate access for the majority of the villagers. The placement of the pump depends more on groundwater conditions than on people's whereabouts. In addition, the settlements are so dispersed that a majority of the village will get some distance to the pump anyhow.

6.2.1.1 Walking distance and waiting at the pump

Pumping a bucket of 20 L full of water takes time, and if the pump is serving a village of 500 or 1000 people, where everybody needs at least 20 L each, one will get long lines. The hand pumps are only available certain hours a day, as the accountant have to be there to keep records of who and how much water is being pumped so that the right households are billed for the right amount of water. Some villages reported queues over 3 hours, which get even worse during the dry season. When the lines get bad, school children are allowed to go first in some villages, creating even more waiting time for the others. Some villages experience that people from other nearby villages come and use their hand pump, even though they have not contributed to the initial costs.

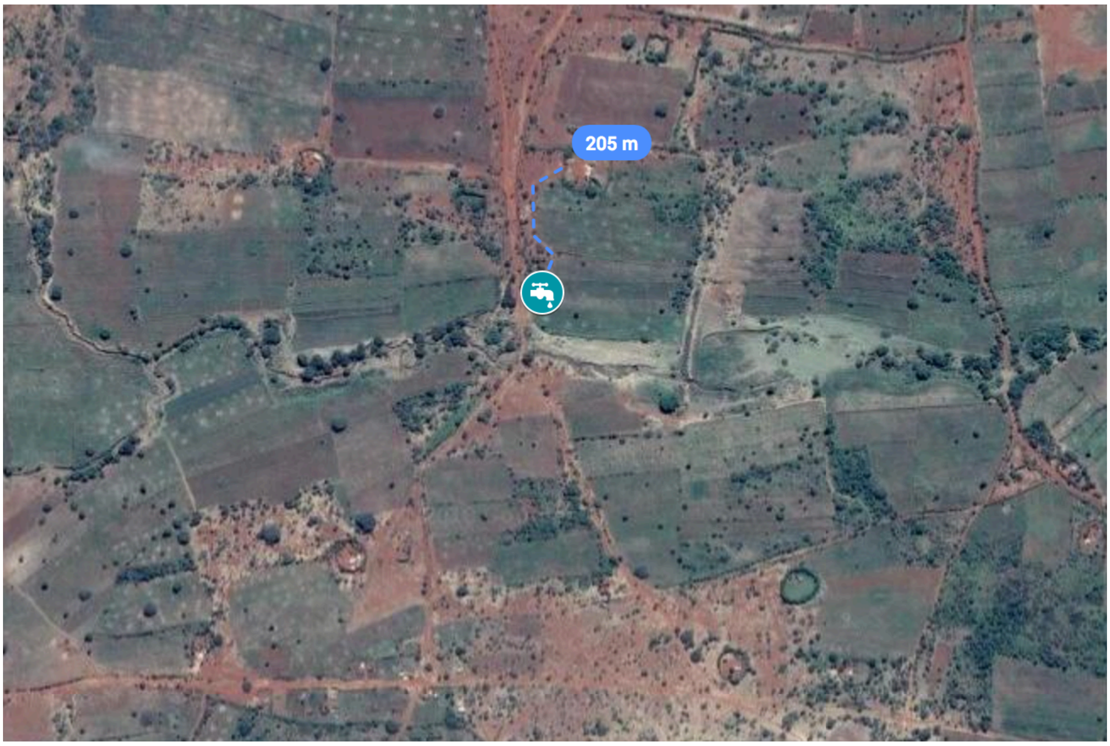

Figure 6-2: Map over the village Gidarudagaw with markings displaying the distance from the hand pump to the closest household (made with Google Maps).

The map is an example from the village Gidarudagaw, located in the Mbulu district. This village contains 87 households, which equals about 552 individuals (one household equals six individuals). As one can see, the closest compound is located about 200 metres from the hand pump, placing it in the basic access group.

6.2.1.2 Secondary sources

Fetching enough water to fulfil the needs of the whole household can be a challenge when the walking distance is fairly long, there are queues and the pumping by hand takes time. The solution might be to go to the secondary sources after all, even when they know that the hand pump deliver safer water. Having multiple sources of water is common in many parts of the world, and it can be because of frequent problems with the primary source, a matter of convenience or preference or because of financial matters (WHO & UNICEF, 2017b). All of these have been reported through the interviews. The downtime is reported to be anything from a week to a month for the hand pumps. It depends on the location of the village, the roads at the time, if there is a trained village technician or somebody else assigned to fix the problem, the availability of spare parts, the seriousness of the problem and the cost to fix it. The secondary or previous source is the only alternative during the downtime, leaving people in the same situation as earlier. Some of the villages also experienced that the pump is dry during the dry season and that they have to find alternative sources, often located far away from the village. Some households are located closer to an unprotected source, making them prefer that as their primary source of water. One of the most common secondary sources, rainwater harvesting, is used to supplement the water from the primary source during rain season. Schools might have rainwater-harvesting tanks, but households normally collect water in buckets, water drums or other small containers. This can be a considerable contribution to the water needs of a household, but is dependant on rain events, which can be relatively rare even during the rain season.

6.2.1.3 Financial matters

When a village wants to receive financial support from 4CCP, they are imposed to contribute at least 30% of the total cost. This is about 15 million TZS for the project in the Dinamu village. There are 316 households in this village, but 4CCP estimate that only about 80% are able to contribute to this cost. This leaves 250 households, which have to pay about 60.000 TZS each (which equals a good goat, 216 NOK or 26,4 USD). 4CCP has not yet decided upon what to do with the 20% that are not able to pay the initial cost for the water scheme. Water policy directs everybody to pay for water use, including the part of a village that, in reality, is too poor.

Having monthly fees might be too expensive for a poor rural population. In the majority of the visited villages there were fees for each bucket; each bucket containing 20 L.

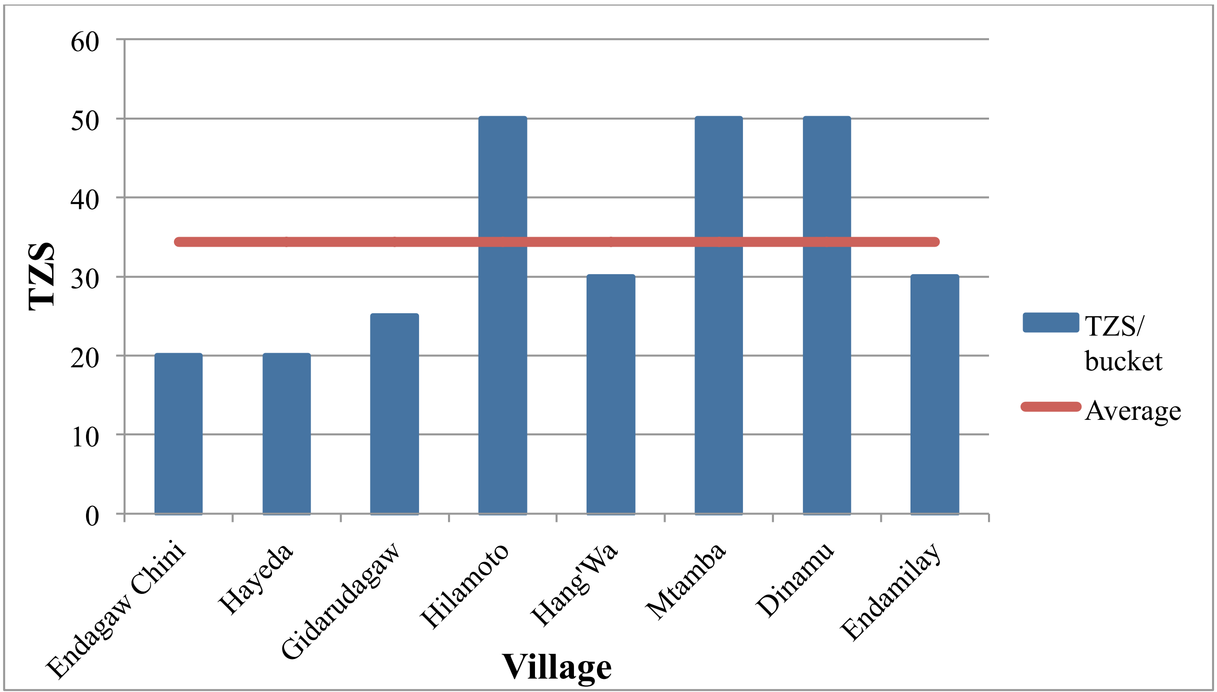

Figure 6-3: Overview of the size of the fees paid per bucket.

The calculated average amount is 34.375 TZS, where the smallest amount is 20 TZS and the largest 50 TZS. Two villages pay monthly fees: in Mazingiri does each household pay 3000 TZS/month and in Munguli 2000 TZS/month. Mazingiri recently increased their fee, as they saw that it was not sufficient for maintaining the hand pumps they have. The amount was previously 2000 TZS/month for a household during the dry season and 1000 TZS/month during the rain season. The overall feedback from the villages is that the collected fees are not enough for maintenance and repair, even when it is properly collected and stored in a bank account. When a problem of larger character appears, with a cost of more than they have available at the time, they will have to collect money from the villagers, ask the village government for money or ask 4CCP or other organizations for help. This increases the downtime of the pump drastically. One possible solution could be to increase the fees even more, increasing the pressure on household expenditure.

Calculation example 1

The mean household consumption in the rural areas of Tanzania is TZS 212,599.97 (National Bureau of Statistics, 2014). The proportion of household expenditure on water for the different fees in the interviewed villages, assuming an average household size of 6 and a consumption of 20 L/p/d from the improved source:

Table 6-3: Proportion of household expenditure with different water fees.

Amount	Amount per month	Proportion of household expenditure
TZS 20/bucket	TZS 3600	1,7%
TZS 25/bucket	TZS 4500	2,1%
TZS 30/bucket	TZS 5400	2,5%
TZS 50/bucket	TZS 9000	4,2%
TZS 2000/month	TZS 2000	0,9%
TZS 3000/month	TZS 3000	1,4%

As shown in Table 6-3, fees of TZS 50/bucket equals to 4.2% of the total monthly household expenditure. In periods without rain, or if the household uses more than the assumed amount, the percentages will naturally be higher. This may make it difficult to increase the fees, especially in the villages already having relatively high fees. It can also cause people to choose different sources of water due to too high costs. One might also observe that it is actually cheaper to pay monthly fees than per bucket, which is relatable to e.g. paying for a monthly ticket contra a one-way ticket on public transportation. This affects the poorest most, as they might not be able to pay monthly and therefore will have to use more money in total on water expenses. One should also keep in mind that these numbers are calculated based on the average household consumption and a substantial part of the population have less to spend on basic needs such as food and water. 33.3% are below the basic poverty line in rural parts of Tanzania, meaning that they have not enough income to satisfy basic needs for long-term physical well-being. 11.3% are below the food poverty line, also described as living in extreme poverty (National Bureau of Statistics, 2014). These groups of people might have a hard time paying the set fees, forcing them to seek other, often contaminated, sources of water.

Calculation example 2

During the same semester as this thesis have been written, a group in the course TVM4850 – Eksperter i Team – Waterworld developed a tool to calculate tariff suggestion based on numbers from NCA and Tanzania. They divided the costs in direct costs (maintenance costs), institutional costs (monitoring, assistance, follow-up and training), rehabilitation costs and investment costs. They have used a life cycle cost analysis, with a lifetime of 25 years, which was suggested by NCA (Fyllingen et al., 2018). Some input value alterations have been made in this calculation example:

- The number of people who are served by the pump is changed from 300 to 2000. This is based on a calculated average of people served by a single hand pump in the interviewed villages (2700 people/hand pump). Only 80% is estimated to be able to pay and the value is therefore set to 2000.
- Rehabilitation and investment costs covered are set to 70% instead of 80% and 100% respectively. This is due to 4CCP's requirement to have the villages contribute financially.
- The rest of the input parameters are left as they originally were, as there are not indications on them being different.

With the new input parameters, the tariff suggestion is 0.05 USD per person per month. Still assuming that each household consists of 6 persons, this equals a total of 0.30 USD per household per month. 0.3 USD equals 684 TZS per household per month, which is far less than the monthly amounts calculated in *Calculation example 1.* The previously calculated monthly costs, based both on monthly tariffs and payment per bucket, are actual values reported from the interviewed villages. When the tariff tool gives a significantly lower tariff suggestion than actual tariff levels, one starts to wonder – why are not the amounts the COWSOs are collecting sufficient for maintenance?

One reason might be the long lifetime Fyllingen et al. (2018) have used in the tariff calculation tool, both as duration for the whole analysis and for some of the components. As will be discussed later in Chapter 7, the cylinder has several times been reported to last shorter than the lifetime of five years used in the analysis. This is also the most expensive component, and more frequent changes of this will affect costs drastically. Another reason might be that people are not paying what they are supposed to according to the tariff. Alternatively, the institutional costs or some of the material costs might not reflect the true costs.

This tool is just applied as an example in this thesis, as it is an interesting way of calculating tariff levels. More thorough thought has to be placed in the different input parameters, and the parameters should, as far as possible, concur with the conditions in the relevant study area. Although it was interesting to discover that the tariff suggestions were, to such a great extent, lower than values found in the fieldwork, where a need for higher tariffs has been expressed.

6.2.2 Quality

According to the Tanzanian MAL-ED cohort, the following sources of water are used in the area surrounding HLH (Mduma et al., n.d.):

- Unprotected well/spring: 42.7%

- Surface water: 25.2%
- Public tap/standpipe: 12.4%

Leaving the city of Haydom, one will find that people use hand pump instead of public taps, but the percentage is low in comparison with the unimproved sources. Unprotected wells or traditional wells are widespread and easily contaminated. The same goes for surface water, which presumably are mostly seasonal rivers. Just a small portion of the population is boiling their water, 17% according to the MAL-ED cohort, and even less are filtering it through fabric. The majority, 69%, let it stand to let particles settle (Mduma et al., n.d.). This means that if the unimproved sources are contaminated, which they almost definitely are, then the majority will be exposed to contaminants.

6.2.2.1 Groundwater quality

Groundwater is normally of good quality. It is abstracted through hand-dug wells, hand pump operated shallow-wells or submersible pump-operated deep wells or boreholes. Groundwater might have a mineral content such as magnesium and calcium salts or iron and manganese, depending on the composition of the stratum through which the rock flows (Ojo, Otieno, & Ochieng, 2012). The results from the water quality report provided by Trust Engineering shows that the groundwater quality in the area around Munguli is suited for human consumption. There are no drastically elevated concentrations of minerals or metals and the physical characteristics are well within the norms. There has not been a test on microbiological parameters, which could be a problem if the well is placed in an area of porous rock with “direct” channels to the groundwater. This is a problem related to more shallow wells than the one in Munguli, and where cattle are grazing directly on top of the aquifer

There are apparently high levels of fluoride in the groundwater in the area surrounding HLH. High fluoride values are a global concern, and high levels have also been found in the Rift Valley (WHO & UNICEF, 2017b), which is located close to the study area. Fluoride, while being essential for humans, may cause dental and skeletal fluorosis. Dental fluorosis happens at concentrations just above WHO’s recommendation of 1.5 mg/L and is visible by stains on the teeth of the affected. Higher concentrations can lead to skeletal fluorosis, that being adverse changes in the bone structure that can end in crippling (WHO, 2004). Tests that previously have been conducted in the area by the Norwegian company Eurofins report fluoride concentrations exceeding the recommended values. These, together with the value from Munguli given by Trust Engineering, are presented in Table 6-4. The values from Eurofins should be viewed with a critical look. The tests were two weeks old when they arrived the laboratory, which might have affected the results. The fluoride concentrations presented in the table, except at the Yotam pump, are high enough to create visible stains on teeth, especially with children. These can be unsightly, but are not damaging otherwise (Eurofins, 2014).

Table 6-4: Fluoride concentrations in different wells in the area surrounding Haydom (Eurofins, 2014; Trust Engineering Co.Ltd, 2015).

Test location	Fluoride level	Tested by
Munguli	1.2 mg/L	Trust Engineering
Endagulda	1.7 mg/L	Eurofins
Haydom (Yotam pump)	0.72 mg/L	Eurofins
Haydom (Basonyagwe pump)	2.9 mg/L	Eurofins

6.2.2.2 Rainwater quality

Rainwater may contain different types of contaminants, because dust, ash, pathogenic bacteria from bird droppings, heavy metals from dust in industrialized areas or from the roof itself and mosquito larvae are present on roofs (Mosley, 2005). The area is rural and will not have problems with industrialized heavy metals, but 48.8% of the roofs are made out of corrugated tin (Mduma et al., n.d.), but one would most likely also find corrugated galvanized steel sheets, coated with zinc or aluminium. Metal roofs are both smooth, meaning they will be less likely to retain contamination than more rough surfaces, and they can get hot enough to be partly sterilising. Mosley evaluates the risk of contamination from heavy metals from roofs to be of low risk, as long as the rain is not acidic (Mosley, 2005). There is a considerable risk of dust particles and microbiological contamination from bird droppings on the roofs and therefore should rainwater not be used for human consumption without treatment. The treatment is preferably boiling in addition to simply settling of particles. Bearing in mind the low percentages of water boiling as treatment among the villagers, rainwater is best used for cleaning and washing purposes. Rainwater may, nevertheless, be the best option for drinking water, as other sources might be even more contaminated (Meera & Ahammed, 2006). It was both observed and explained in the interviews that fewer people use the improved sources when there have been rain events, leading to shorter queues at the pumps. It is therefore likely that some households use rainwater as drinking water without treating it sufficiently.

6.2.2.3 Water-related illnesses

In the area surrounding Haydom Lutheran Hospital stunting is a common phenomenon. At one month of age 17% is stunted, at 6 months 25% and at 24 months it is 70%. This is presumably due to dietary insufficiency, poor water quality and attendant enteropathogens. The most common pathogens detected are different kinds of E.coli, Campylobacter and Cryptosporidium, all which can give diarrhoea. It was found that diarrhoea was relatively rare in the area, and mostly associated with rotavirus, an intestinal infection and the lead cause of severe diarrhoea in small children; and E.coli. The hospital has been providing rotavirus vaccines since 2013 (Mduma et al., n.d.) and a permanent reduction in episodes in the area will, hopefully, be detected in the years to come. After having visited the parasitology department at the hospital's laboratory, it was evident that the parasites Giardia, Entamoeba histolytica (amoeba dysentery) and hookworm are the most common parasites in the area.

These parasites can come from drinking unsafe water, but also because of insufficient hygiene or walking barefoot (hookworm).

6.2.2.4 Reported improvements after project implementation

All the interviewed villages with improved water supply claim to be experiencing better general health than before they got the pump solution. Waterborne diseases episodes have decreased, where the village Gidarudagaw mentioned specifically cholera and amoebas in addition to just diarrhoea. School attendance are reported to be improving, because the children have more time on their hands when they do not have to use several hours on fetching water, either from home or from the school grounds. The village Mtamba expressed the importance of having the water supply close to the school, as they have seen how it affects school attendance. The Dinamu village argued strongly for placing the pump on school premises. 4CCP has a policy of not placing solutions directly on the grounds of an institution. Further, the school was placed on a hill, making it more unsuitable for a borehole than further down in the valley. Still, this shows that the villagers have a deep understanding of the importance of a good and safe water supply and the importance of education. This village also reported having more cases of waterborne diseases after a heavy rain event, as was suspected based on the amount of faecal material surrounding water sources due to grazing cattle. Several of the other villages communicated that having clean water closer to schools enables the children to cook in the school, causing them to stay there longer. This, combined with less time used on getting water for both students and teachers, give better school results. The hygiene, both in schools and in households, is better because of a larger quantity available. Results provided by 4CCP, which are presented in Figure 6-4, demonstrates that school performance, measured in the amount of students passing, has increased significantly since implementation of the water scheme in 2015. This confirms what the other villages have communicated, that access to water is crucial for staying in school and performing on a sufficient level.

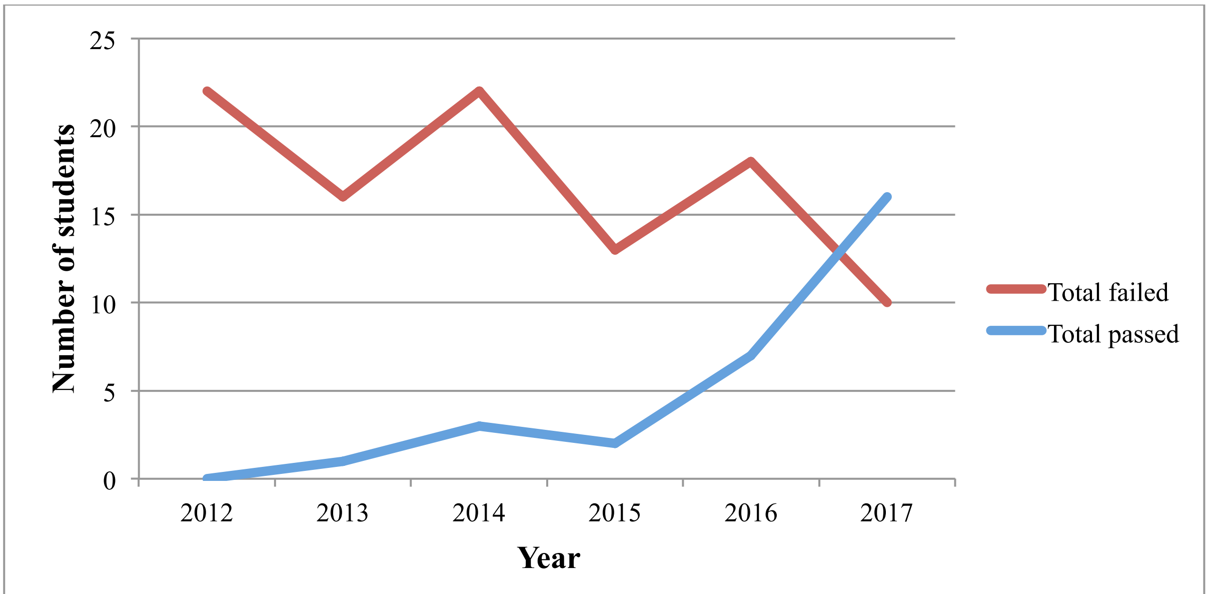

Figure 6-4: Distribution of pass and fail at the school in Munguli (Faustin, 2017).

6.3 Ending remarks

Both theory and observations show that water is affecting all aspects of rural life. It is pretty much impossible to develop as a community without water of sufficient quality and quantity, as there will be less available work force, less overall education in the community, poorer health and more deaths, less female participation in decision-making and worse economic conditions. Water should ideally be located on premises in unlimited amounts available for all, but this is, for now, wishful thinking for a dispersed rural population. One has to focus on improvement where it is possible to achieve it. This will be to bring water closer to the population and making sure that it is safe, either initially or through treatment.

Ensuring a sustainable water supply depends on several factors and at least three of them have been presented in this chapter; financial, social and environmental factors. Evaluating these factors further for the specific study area, either separate or combined, might increase sustainability and reduce downtime for the projects. Assessing walking distances, tariffs and willingness to pay, waiting time and quality and the associated health effects, will give interesting results in relation to sustainability.

7 Technical sustainability

As a soon-to-be engineer writing an engineering Master’s thesis, technology choices easily become the main focus. It is important to remember that this is far from the only issue affecting sustainability. Far too many water scheme projects have failed because they have been perceived as only that; engineering projects that can be handed over and then abandoned by the initiative taker of the project. This chapter will discuss the role of technology, some of the available options and technology issues that were observed during the fieldwork. It is wise to remember that technical factors are identified as crucial for sustainability (Harvey & Reid, 2004)

7.1 Theory

7.1.1 The role of technology

Despite an increased awareness of the importance of social and community aspects of water supply, technology still plays a vital part. The more sustainable options are low-cost, easy to understand and learn and easy to repair and maintain, in contrast to solutions that require specialized equipment or personnel. Even though technology does not alone determine sustainability, it can have a great impact, especially concerning on-going O&M (Harvey & Reid, 2004).

7.1.1.1 Choice of technology

There are several different solutions for water schemes, which need to be selected based on environmental conditions, affordability and social acceptance. The main focus of this thesis will be the hand pump, as it has been, and still is, the first choice of NCA and 4CCP. Some other solutions will be mentioned because they have been observed used in the study area or, if possible, is to be implemented by 4CCP. A water supply scheme should be acceptable to the community, both in relation to convenience and health and environmental perspectives; feasible and sustainable. When a community has been identified as in need of an improved water supply, it is crucial to assess:

- Existing water supplies
- Community demand, capabilities and priorities
- Potential water sources (Harvey & Reid, 2004)

This assessment, together with the other steps needed to create a sustainable water scheme, was explained in Chapter 3.

Davis & Brikké (1995) have listed these following critical technical requirements, which need to be addressed to be able to choose the most suitable water supply technology:

- Skills: The chosen technology must fit the existing skills in the village. Should the appropriate skills not exist, then skills training should be arranged or the choice of technology should be revised.
- Tools: O&M tasks should be carried out using tools, which are easily available and can be used by the people responsible for O&M. If there is a need for specialist tools they must be provided or possibly reproduced locally. It is not sustainable to be dependant on unavailable highly specialized tools.
- Standardization: This leads to expertise among users and maintenance personnel and is helpful in relation to spare parts, training and maintenance. Standardization enables spare parts to be ordered, stored locally and shared between different communities. Training in installation, operation and maintenance can be standardized and thus very detailed. Maintenance tool kits can be standardized and therefore limited to only the essential tools needed.
- Spare parts: This is so important to sustainability of a water scheme that it is discussed separately in the following section.
- Consumables: Such as chemicals and fuel – need to be available, affordable and of an adequate quality (Davis & Brikké, 1995).

The issue of spare parts

The lack of spare parts has been, and still is, a key limitation to the sustainability of water schemes. There are examples of it being the cause of complete abandonment of schemes. A part of the problem is connected to the choice of technology. The hardware might be purchased from donor countries, without examining if there are suppliers of spare parts in the receiving community or country. Some donors might have provided a small stock of spares, but this is not a long-term solution. Spare parts availability and supply is an important consideration when implementing a water scheme that is meant to be sustainable and suitable for community management (Davis & Brikké, 1995).

The term "spare parts" includes all materials and goods that are needed for an efficient and sustainable operation of the technical components of a water supply. This incorporates mechanical and electrical parts, but also tools, fuel, lubricants and chemicals. Before deciding on a scheme, one must investigate the availability of spare parts. Choosing a well-known technology that is locally obtainable is therefore essential. The supply of spare parts is considerably enhanced if the manufacturing is located within the country of use, given that the quality is ensured. However, the concern for spare part often arises after the technology has been chosen and implemented. This puts sustainability at risk (Davis & Brikké, 1995).

An important aspect of spare parts is the distribution system, which transfers the parts from supplier to user. When establishing an efficient system, a thorough identification of potential suppliers is required. A supply system will also contain stocks of spare parts at different levels to meet an uneven demand. Stocks at village level are both cost efficient and desirable, and should be implemented if possible. Monitoring of both purchase and use of spare parts is another significant aspect. It can provide useful information on the performance of systems. The system is most likely out of function if spare parts are not being bought (Davis & Brikké, 1995).

7.1.2 Hand pumps

The hand pump is one of the major water supply technologies in rural Africa. This is supposedly because of its ease and low-cost O&M compared to other available technologies, the ability of pumping groundwater from considerable depths and widespread acceptability among users. It is important to keep in mind the balance between durability and ease of maintenance, because all hand pumps will eventually break down. It is little use in a high-tech hand pump that no one is able to maintain and repair.

7.1.2.1 Selection of hand pumps

According to Harvey & Reed (2004), there are three main aspects that must be contemplated if sustainability is to be guaranteed:

- Operating condition of the pump, such as depth of operation, usage level and groundwater pH
- Ease and cost of maintenance
- Spare parts availability and accessibility

The first of these aspects is evaluated as the most important one by Harvey & Reed (2004). Several of the available hand pumps only operate on shallow depth, which limits the options for deep groundwater.

7.1.2.2 Types of hand pumps

There are different types of hand pumps being used by 4CCP and other organizations operating in the area. India Mark II has been the type used in the first phase of the projects done by 4CCP and will therefore be explained more thoroughly. The district engineers in Mbulu use Afridev and a short description is provided here. Several other types of hand pumps are available on the market, but it is outside the scope of this thesis to evaluate them.

India Mark II hand pump
The Rural Water Supply Network (2018b) writes that the India Mark II is a robust conventional lever action pump designed for serving communities of about 300 people. It can be provided with a lifting height of 80 m (Harvey & Reid, 2004). It is mostly made out of galvanised steel and with some components of cast iron and brass. It is not corrosion resistant and should not be used where the pH is less than 6.5. India Mark II needs to be installed by technicians with proper training and a mobile team with a lifting tackle (RWSN, 2018b).

Davis & Brikke (1995) write that this hand pumps proves to be durable but is not easy to maintain. Experience from India showed that it relied heavily on a centralized mobile maintenance team that had access to a vehicle with special tools, heavy spares (pipes and connecting rods) and three or four somewhat trained fitters. A technical drawing of India Mark II can be found in Appendix B1.

Afridev
The Afridev is a conventional lever action pump, also designed to supply communities of 300 people with water. It has a somewhat lower recommended lift than India Mark II and is easier to both maintain and install. The piston can be removed from the cylinder without dismantling the rising main, which makes maintenance easier. The pump is made of galvanized steel, stainless steel PVC-U, fibre glass reinforced plastic and plastic components, thus making it corrosion resistant. All the steel parts have the possibility of being locally manufactured (RWSN, 2018a).

Reciprocating and public domain pumps
Both India Mark II and Afridev are described by Harvey & Reed (2004) as deepwell reciprocating pumps and are common all over Africa. A generic drawing of this kind of pump is given in Figure 7-1. The principle behind these pumps is that water flows from areas of high pressure to areas of lower pressure. Reciprocating pumps create an area of adequately low pressure above the water body, hence causing it to flow upwards (Baumann, 2000). Also, they are both public domain pumps, meaning that any company or individual are allowed to manufacture them. This is seen as a way of inspiring manufacture of pumps within the country or, alternatively, encouraging competition between international suppliers. In Africa this has been less successful than expected due to cheap and easy import from Asia (Harvey & Reid, 2004).

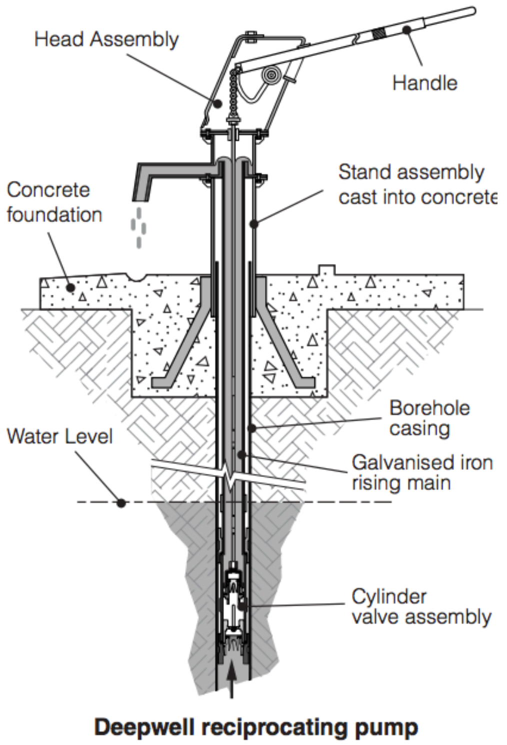

Figure 7-1: Generic deepwell reciprocating pump (Harvey & Reed, 2004).

7.1.2.3 Boreholes

Hand pumps are normally placed above boreholes, but this is not the only possible solution. Depending on the hydrogeological conditions, hand-dug wells or hand-augered boreholes can be better alternatives. These three have their own set of advantages and disadvantages, but the main constraints are:

- Limited depth and a risk of pollution for hand-dug wells
- Limited depth and suitable environmental conditions for hand-augered boreholes
- High costs and limited access for a machine-drilled borehole

India Mark II can also be placed on top of a hand-dug well, and when hand-dug wells are fully protected, they might have water quality comparable to drilled boreholes. Wells are, by far, cheaper than boreholes as well, and cost is undoubtedly one of the most important factors to be evaluated (Harvey & Reid, 2004).

The siting is crucial, regardless of the choice of water scheme technology. It should be sited central in the community, where it promotes equity, accessibility and community ownership. Hydrogeological conditions, on-site sanitation, community preferences and land ownership are other aspects that have to be taken into account. Poor siting will affect the sustainability as it might lead to insufficient yield, pollution, abandoned boreholes, necessary re-drilling and increased costs.

The main factor that decides sustainability of a borehole is its yield. It is normally measured in litres per minute or cubic metres per day. To find the maximum yield, one finds the maximum flow rate where the water does not drop below the level of the pump intake. One should bear in mind that maximum yield is not necessarily sustainable. It is important to be aware of the hydrogeological conditions and the rate of re-filling of the aquifer. Placing a hand pump on the wrong site may lead to a dry borehole because of insufficient yield, either because there was too little water in the aquifer in the first or because of exploitation. Harvey & Reed (2004) report a yield of minimum 10 l/min to support a hand pump.

Sustainability could be at risk due to bad design even for a borehole with a suitable siting and adequate yield. The most important aspects to borehole design are its casing and screens, borehole development, gravel packs or other filters and protection (Harvey & Reid, 2004).

7.2 Results and discussion

This part will connect the observed technical solutions and problems in Tanzania with the theory described in the section above. Other aspects that were found during the field trip are also included. The division is based on the needs that have to be assessed to be able to achieve a sustainable water supply, as mentioned in the start of this chapter.

7.2.1 Existing water supplies

One of the first questions asked during the interviews was what kind of water source the village depended upon prior to the improved supply. The most common answer was either surface waters (mostly seasonal rivers located far from the settlement) or traditional wells. Traditional wells are open hand-dug wells in areas where the groundwater level is high.

Figure 7-2: 1: Traditional well. 2: Dam dug to collect rainwater.

The main problem with these sources is the risk of contamination. This water is in close contact with faeces, both human and animal. People using the water for drinking or cooking risk getting ill, especially after a rainfall where faeces might have ended up in the water. Still, as mentioned in the previous section, a hand-dug well can have about the same water quality as a borehole, if it is properly protected. The example of a traditional well in Figure 7-2: 1: above is lacking any kind of protection. It is not visible on the picture, but faeces are completely surrounding this well. This is also true for the dug dam. Additionally, these wells are easily accessible for all kinds of animals and thus contamination.

These sources would not have been all that bad if it were not for the lack of protection of the sources. A simple coverage over the well or a fence surrounding the dam could reduce the risk substantially. These sources are still used, either by communities without an improved source, or as a secondary source as explained in Chapter 6. The option of improving these sources, instead of just creating new ones, might be a better choice. Simple treatment, like sieving or boiling, to improve water quality when protection has failed, is at least a good practice for when the improved source is out of function or non-existing.

7.2.2 Community demand, capabilities and priorities

The engineering approach to demand is usually the amount of water needed to supply the population. To calculate this, engineers need to collect data on consumption patterns, the amount and what kind of facilities O&M arrangements, demand if upgrading and so on (Parry-Jones, 1999). However, demand can be so much more than this. Even more important than just assessing the amount of water needed is the community wish. Do they wish for traditional solutions or modern ones? Gidarudagaw expressed their wish for a solar powered scheme, even though they already had received a hand pump. They were grateful for the help with the implementation of this, but experienced that it was not quite enough. Stories of solar powered schemes in other villages are also inspiring. There are more people living in the village than the recommended 300 people served by each pump and queues are therefore inevitable. A solar powered scheme could provide the village with more water, given that the yield of the borehole is great enough to prevent exploitation. Having access to more water will reduce the waiting time and eliminate some of the need to use secondary water sources. On the other hand, having a motorized pump delivering water will increase the amount used per person, as it takes less time and effort to get water. This has to be considered when looking at a sustainable yield from the borehole. The village Munguli uses approximately 60 L/p/d with their solar powered scheme, which also was said to be the average in Tanzania (Nelson Faustin, personal communication, February 2018). People depending on hand pumps are more likely to be using less, perhaps as little as 20 – 25 L/p/d (Lockwood & Smits, 2011).

Calculation example Munguli
There are several easily noticeable mistakes in the received readings from the teacher in Munguli. Calculating the average and standard deviation is nevertheless a useful exercise and serves to get an impression of the consumption and the dispersion in the data set.

The water distribution system in Munguli is made of a solar driven electric pump, which pumps water to three elevated storage tanks located inside the primary school. Water is distributed to seven points, but 4CCP has recently closed off three of the points, as they were not properly maintained. One water meter is placed with the storage tanks (A) and one with the pump outlet (B). The letters A and B refer to the book with the readings shown in Figure 4-3.

There was a total of 29 days between the implementation of the water meters to the last reading. It is estimated that 150 people use water from the pump (Nelson Faustin, personal communication). The Excel sheet containing the readings and calculations is located in Appendix C1.

<u>Tank (A):</u>

Average over the whole period: 245,45 m^3.
Consumption per person per day: 56,43 L.

Standard deviation:
Standard deviation is calculated using the consumption data from each reading period. There are 6 periods. The calculation itself has been done using Microsoft Excel and the final tables

for both water meters containing the results are presented here. For the full calculation and tables with the readings and comments, see Appendix C1.

Table 7-1: Standard deviation for water meter at tank bypass.

Period	x	x-x	(x-x)^2
1	58,35	2,24	5,03
2	63,69	7,59	57,57
3	71,98	15,87	251,97
4	59,63	3,53	12,47
5	54,33	-1,77	3,14
6	28,64	-27,46	754,26
	Average of x (x)		56,10
	Sum of (x-x)^2		1084,45
	Standard deviation		**13,44**

As can be seen here, the calculated average from the consumption in the six period are 56.1 L and the standard deviation is 13.44 L. This gives the following dispersion:

$$\underline{x} - S = 56.10 - 13.44 = 42.66$$

and

$$\underline{x} + S = 56.10 + 13.44 = 69.54$$

This is quite a large dispersion, but it gives a certain idea of how high the consumption is per person per day. The consumption might vary due to several factors, such as rainfall and less use of the pump, incorrect readings by the teachers and readings after the pump has been switched on and meter has started running.

Pump (B):

Average over the whole period: 292,49 m^3.
Consumption per person per day: 67,24 L.

The consumption is seemingly higher at this meter. A reason for this can be reading errors on some of the digits counting one or ten cubic. Another suggestion is that there might a distribution point that receives water directly from the pump without going by the storage tanks. The calculation process is the same as above.

Table 7-2: Standard deviation for water meter at pump outlet.

Period	x	x-x	(x-x)^2
1	64,76	-9,19	84,45
2	81,95	8,00	64,02
3	79,35	5,40	29,19
4	69,31	-4,64	21,52
5	61,66	-12,29	151,04
6	86,67	12,71	161,66
	Average of x (x)		73,95
	Sum of (x-x)^2		511,88
	Standard deviation		**9,24**

The dispersion here is considerably smaller than with the water meter at the tank. The following dispersion appears:

$$\underline{x} - S = 73.95 - 9.24 = 64.71$$

and

$$\underline{x} + S = 73.95 + 9.24 = 83.19$$

The consumption is significantly higher at this water meter than at the one installed on the storage tanks, and the standard deviation only emphasises this. To have consumption values as high as 83 L per person per day seems unrealistic, but it might be true in periods of drought.

Naturally, the community wants to have access to more water with an adequate quality and which is located close to their homes. This has to be considered when implementing a water scheme. Dispersed settlements make it hard to please everybody with regards to site selection and hydrogeological conditions, which, in the end, are the determining factor. A high-tech mechanical solution might provide a village with more water than a hand pump, but both initial and maintenance costs are much higher. The community has to evaluate if the increased costs are something they are able and willing to pay. The amount of maintenance and level of expertise needed are also higher. To sum up, before implementing any technical water solution, it is important to have a good dialog with the village community where their needs and wished have been heard and considered. Otherwise, a perfectly good solution might be planned and built, but no one wants to use it or take care of it after implementation.

7.2.3 Potential water sources


Figure 7-3: 1: India Mark II hand pump. 2: Rainwater harvesting tank in Munguli primary school.

As mentioned in the theory part, placing a hand pump on a borehole is not the only solution for a sustainable and safe water supply, even though it has been the preferred choice in rural Africa for decades. The options that 4CCP is involved in are boreholes fitted with hand pumps or solar-driven mechanical pumps and rainwater harvesting tanks.
These solutions are well known in the area, and successful when proper maintenance is performed. Drilling boreholes is costly and drilling a dry borehole creates a significant financial loss to the organization. Even though a hydrogeological survey has been completed at the sites, villages experience dry boreholes due to seasonal fluctuations. Rainwater collection is also not an option during this season. As an option, it might be an idea to teach the rural communities how to improve the sources they have. They are then able to use the source safely while waiting for their chance to receive help with the implementation of a hand pump or a solar-powered scheme, or, during periods when their primary sources are unavailable.

7.2.4 Observed hand pump issues

7.2.4.1 Quality

Apart from the limited capacity addressed, both earlier and later in this thesis, the hand pumps observed during the fieldwork suffered from several problems. Some of the visited villages experienced that the pumps stopped working shortly after implementation and were in need of severe repair. After conversations with both 4CCP and the villages, it seems like the problems are mainly connected to the cylinder. As no investigations had been performed to figure out what kind of damage this was, it was difficult to get more information about the problem. One suggestion was that it is due to the manufacturer of the pump and hence bad quality of the product. This might very well be the reason as a proper supplier of the product is crucial to having a long-lasting product. Another reason might be corrosion. India Mark II is prone to corrosion, and the fully immersed parts are the most vulnerable. The whole rising main might be exposed to rust as it is made out of cast iron. It is constantly submerged and it might not take long before rust appears. One alternative is to replace it with a PVC rising main. This is an alternative that is cheaper, lighter and easier to work with. This option may, on the other hand, be prone to cracking. A raising main of stainless steel may also be an alternative, as it will not be as vulnerable to corrosion. No matter what solution is chosen, good preventive maintenance routines and skilled mechanics are essential for a long-lasting pump.

Before installing new hand pumps, 4CCP should be certain that the supplier is trustable and is delivering adequate products. Problems with the cylinder and rising main are expensive and difficult to repair and should be avoided whenever possible. pH tests should also be conducted before instalment to assess if PVC or stainless steel rising mains might be a better option.

7.2.4.2 Spare parts

In all the interviewed villages there were knowledge about were to find spare parts for the pump. All the 4CCP villages are using India Mark II, and spare parts are found in the closest main cities. This can nevertheless be located far from the village and it can take a long time getting there, especially during the rain season. If the village did not have knowledge about spare parts, 4CCP had. The two districts water engineers (DWE) who were asked, in Mbulu and Mkalama, both confirmed that there was not a stock of spare parts in their offices. The DWE in Mbulu said that they are getting spare parts from suppliers in Dar es Salaam, where it takes two to three days to retrieve the parts, or Dodoma, where it takes one day. The downtime is illustrated in Figure 7-4, where the availability of spare parts affects the last three steps before a well-functioning pump.

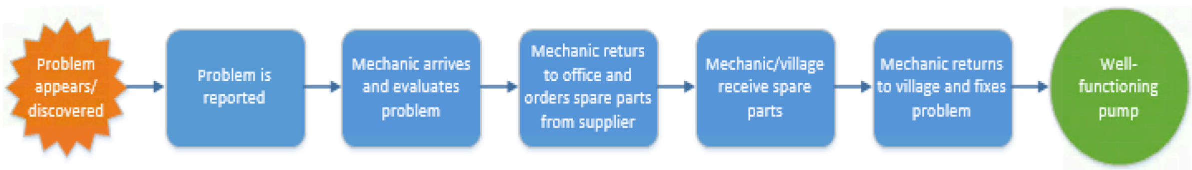

Figure 7-4: The different stages of downtime.

If there was a stock of spare parts, either or both in the villages and with the DWE, downtime could be reduced with up to several days. Where to place the stock depends on the skill in the villages, but one solution is to have common parts, which can be more easily replaced, in the villages and more valuable parts at the DWE's office.

7.2.4.3 Mechanics (skills and tools)

An extensive problem in rural water supply in this particular area is the lack of manpower at the DWE. One example is the Mbulu district, where they have four district technicians, but just one who is responsible for the pumps. Further they have the responsibility for 386 water points scattered over large distances with challenging road conditions. They claim that they get by with the support from village technicians. Training of such technicians is therefore essential for the sustainability of the rural water schemes. Centralized district technicians have limited capacity, so investing in the training of locals to perform regular maintenance and some repairs are valuable. This task can be, and is in some cases, performed by 4CCP as a way of taking some of the pressure of the DWE's.

Figure 7-5: Trained technicians and villagers installing sensor in 1: Munguli and 2: Gidarudagaw.

In addition to have the needed skills in a village, there is also a need for tools to perform the maintenance and repair. One idea that was mentioned during the fieldwork was to have several area mechanics supported by 4CCP or the local government. These would have been provided with proper training, a means of transportation (motor cycle) and a standardized tool kit for India Mark II. Not only would this be of great support to the DWE and his technician, and to reduce the downtime of hand pumps, but it would also offer work opportunities in the community. This fits right into the bullet points on critical technical requirements for sustainable water supply presented in the theory section of this chapter.

7.2.5 Other observed technical issues

7.2.5.1 Pipelines

Figure 7-6: PVC pipe lying unprotected after several years of project delay.

One of the observed technical problems during the fieldwork was uncovered and unprotected pipelines lying around. Some due to delayed projects and other due to suddenly occurring problems with the pipes. There were several examples of pipes lying fully exposed in the sun or the occurrence of bits of a remaining pipe after a pipe burst. The pipe bursts might have several reasons, anything from bad manufacturing to improper handling of the pipes. Both PVC and PE pipes were observed, and these plastic pipes will experience weathering when exposed to sunlight. The ultraviolet radiation in the sunbeams causes a series of complex reactions to occur, which results in degradation of the polymers and hence the pipe itself (Whittle, 2010). The exposure to solar radiation may, in the case of plastics, lead to loss of impact strength, resistance to slow crack growth and thermal stability (Stahmer & Micic, 2003).

As long as 4CCP mainly works with hand pumps, pipelines are not a great concern. Though, there is a rising call for other solutions among the villages, where pipelines might be necessary. The examples of observed problems are taken from the city of Haydom and the village of Mtamba, where 4CCP has been involved. If a growing number of projects needs to use pipelines, the following has to be considered: finding proper manufacturers and suppliers, protection of the pipelines before they are dug down and proper handling of pipes.

7.3 Ending remarks

Achieving technical sustainability depends on several aspects, not just choosing the right product or the best manufacturer of said product. Spare parts, right tools and local skills are needed to keep a rural water scheme running sustainably. 4CCP has done several things right here, but during the fieldwork some areas of improvement were spotted. Having a stock of spare parts, either in villages, at the 4CCP office or at the DWE office will reduce the downtime. Continuing with the search for better manufacturers, suppliers and training of technicians will improve sustainability of their projects, combined with standardization of both hand pumps and tool kits.

8 Discussion, conclusions and further work

8.1 Discussion

NCA's system was said to have the potential of reducing downtime by enabling district technicians, engineers or others responsible for repair and maintenance to discover problems more quickly. If it had worked perfectly, one could imagine it leading to results similar to what Hope et al. (2014) achieved, which was mentioned in Chapter 5.1. It is still a long way to go to make NCA's system work properly. Problems concerning mobile coverage and the temperature of the systems need to be addressed, together with an evaluation of the system and its robustness. As it is now, concerns rise whether it is sturdy enough to function over a long time in the rural Tanzanian environment. The system is supposed to be both simple and cheap, making it possible to order spare parts and fix it locally if it is out of function. Several well-known problems will likely arise, which have been mentioned multiple times in this thesis:

- The availability of spare parts
- The skills among the responsible
- The willingness to maintain the system

It seems like the sustainability of this solution will suffer like the sustainability of rural water projects has done the last couple of decades. Before implementing more systems and developing the projects further, these challenges should be assessed.

Even though the remote monitoring system did not work as planned, it can still be of use to the local communities in Gidarudagaw and Munguli. It is now possible to calculate the consumption, which gives a better foundation for setting tariff levels, and one can get an impression of consumption patterns. This is, naturally, dependant on NCA's ability to fix the problems with the output data. The system in Munguli would have to show values besides zero and the system in Gidarudagaw must display the correct time and date for the water flow data.

As of my opinion, the NCA system will not reduce downtime drastically, even when it is working optimal. There are several other factors affecting downtime and sustainability that, seemingly, will have a much greater impact. Even if a district engineer has access to real time readings, he would still have to go through the same stages of downtime that was described in Figure 7.4. This system would be of greater value if it was placed in a community without mobile phones and villagers that could notify the engineer or organizations as 4CCP about problems with the functionality of the pumps. It appears that the majority of villagers have access to phones and people are ready to report problems when they emerge. Other measures to reduce downtime appear to be more effective, such as having a more efficient spare part supply chain, adequate tariff collection to cover maintenance and repair costs and a sufficient amount of skilled manpower and tools that are easily available throughout the year.

8.2 Conclusions

The purpose of this Master's thesis was to participate in the development, installation and testing of the NCA remote monitoring system and to evaluate the sustainability of rural water projects in this region with special focus on maintenance and repair. This was achieved through a six-week fieldwork in Tanzania, where both the remote monitoring system was installed and the overall sustainability of rural water projects were assessed through interviews and observations. It provided this Master's thesis with varied findings, containing both personal and objective answers. The answers and observations enabled suggestions on how to reduce downtime and increase sustainability.

The identified and interconnected factors affecting sustainability in rural water projects in the area are:

<u>Institutional/organizational:</u>

- The establishment and support of well-functioning COWSOs (Community Management Plus)

<u>Financial:</u>

- Adequate tariff collection to cover maintenance costs and other recurring costs

<u>Social:</u>

- User satisfaction with the water supply, which is affected by e.g. walking distances, waiting time, experienced health effects or performance in school

<u>Technical:</u>

- Choice of supplier, manufacturer, hand pump type and materials
- Spare part accessibility
- Skilled mechanics with an adequate tool kit

<u>Environmental:</u>

- Quality of groundwater, concerning microbiological parameters and other substances present (such as fluoride)
- Quantity of groundwater, especially during the dry season or when installing motorized pumps

Most of these factors have been affected by 4CCP's work and promising results have been observed. The work with the COWSOs and 4CCP's support towards them is particularly encouraging. A close cooperation between organizations such as 4CCP and COWSOs leads to quicker responses when something happens with the pumps, financial support to poor communities and technical assistance with installation, training and maintenance.

There are, however, observed areas of improvement. A more evaluated choice concerning hand pumps and their manufacturer and materials are needed, as several of the hand pumps were out of function shortly after installation. 4CCP could need someone with more technical expertise in its staff, in addition to people from NCA who visit once in a while. An increased focus on spare parts and easier access to them together with training of area mechanics will increase the sustainability of these projects substantially. The area mechanics must be equipped with the necessary tools, and must arrive quickly to the site of the malfunctioning pump.

If NCA's project should be continued, more time and resources have to be invested in its development to make it entirely functional. All errors have to be eliminated and one should be certain that it delivers reliable and continuous values on water flow. A proper routine of what to do if something happens to the system needs to be developed and explained to the responsible, with special focus on where and how to get spare parts and how to repair it. If the system is fully developed and functional, it will be a valuable tool to calculate consumption and use these data to better estimate tariff levels, and to detect errors in the system earlier.

In conclusion: the findings from interviews, observations and additional fieldwork together with relevant literature show that several interconnected factors affecting sustainability are present also in the local rural water supply projects. It is a remaining challenge to reduce downtime in a way that lasts and one must assess all factors to understand what is and is not working. NCA and 4CCP are well on their way to achieve sustainable projects, but several factors are still not entirely considered or implemented. It will be exiting to see if resources and new ideas are sufficient to make progress on sustainability in the years to come.

8.3 Further work

It would be interesting to see how the NCA system is working when fully developed and functioning and if it can contribute to the reduction of downtime. It is natural that NCA is the developer of this system, but if they do not have the resources to achieve this they should delegate it to students at e.g. NTNU. Students at the cybernetics or electronic courses should have sufficient knowledge and resources to develop it further. If the development of the system is successful, other sensors might be relevant to install, such as sensors measuring groundwater level, functionality of different parts of a pump or water quality sensors.

Further exploration of tariff levels and willingness to pay is also noteworthy. A continuation of the work in the EiT report, which Calculation example 2 in Chapter 6 is based on, might reveal that the current tariff levels should be adequate and help identify why they are not.

Lastly, students from the Civil and Environmental Department at NTNU might support with technical knowledge about pumps and pipelines in the upcoming years. It could either be solar powered pumping schemes and the accompanying pipelines, or further evaluation of technical choices in relation to pump technology, material choice or installation of schemes. Other solutions than pumps should be assessed together with an evaluation of water quality and simple, yet sufficient, cleansing of surface water. Further investigations of the quality and performance of the India Mark II are also valuable for the reduction of downtime. Having a list of acceptable manufacturers and suppliers of the pumps, which have been thoroughly examined, will prevent future problems with bad pump quality. This, together with a systematic investigation of pump failures and the associated reason, will lead to an even better performance and more sustainable rural water projects.

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Appendix

Appendix A1: Interview questions.

Appendix A2: Rewritten notes from interviews.

Appendix B1: Technical drawings of India Mark II.

Appendix C1: Readings from Munguli with calculations.

B

Appendix A1

Focus group questions

Initial questions
-How many households are there in this village/connected to the pump?
-How is the water committee organized? Who is a part of it (male/female)? How were they chosen?

Water situation
-Can you tell me a little bit about the water situation in the village? How many water points do you have?
-Where do you get water today/throughout the year? Do you go to other villages?
-How has the water situation evolved over the years?
-What do you use the water for? (Drinking water only, all-purpose household and/or livestock).
-Where did you get water earlier/before the improved water source? Pump, surface water, rainwater harvest etc.?
-Were there problems with the previous source? Health issues, breakdowns, droughts etc.
-If it got broken, would it be repaired? If so: by whom?
-How long time would it take?
-Where do you get water today?
-Who has the responsibility of the water source and its repair and maintenance?
-If it breaks down, will it be followed up?
-Has it broken down/had troubles yet? Who repaired it? How long time did it take (from breakdown)?
-Are you able to fix small problems yourself or do you have to contact 4CCP/a mechanic?

For villages without improved source:
-Are there sources in the area where water can be found all year around?
-If no: What do you during the dry season?
-Why should an improved water system be implemented?
-Have you done anything to try to improve the situation yourself?
-Are there any wells in the area, in other villages close by? If so, is there water all year around? How deep are they? Who built them and how?

Impact
-Have you gotten more time to do other things after the source was implemented? What do you do with it?
-Has the new scheme changed the structure of the society? Are the children more at school, do women work more elsewhere etc.?
-Has the new water source changed the health of the villagers? If so: in what way?

Financing
-How is the system's maintenance financed?
-What are you paying to the water committee to ensure maintenance of the source? Is this amount sufficient?
-How is the money collected?
-What are you willing to pay for an improved water system (for villages without)? How much is your limit for what you want/can pay for the source?
-Do you have confidence in that the money is actually used for repair and maintenance? If not, why?

D

Appendix A2

Interviews

Endagaw Chini (13.02)

1200 households (about 7200 people) connected to the borehole. It is a deep borehole (100 m). COWSO consist of 12 people, of whom 10 showed up to the meeting (6 male and 4 female). Also present were 3 elders/advisors. The accountant is a woman, whereas the chair/leader is a man. Previous water source was poor; a river located 8-10 km away. They got the hand pump from 4CCP in August 2017 and this is now the only/main source of water. They use the water for everything: cleaning, drinking, washing, cooking, irrigation and for cattle. They recently had a problem with the cylinder of the pump, causing it to be out of use for one and a half week. They called 4CCP who then contacted mechanics at HLH who then again fixed the problem. They have not experienced small problems that possibly can be fixed by them, and it didn't seem like they had a plan for a case like that. When the pump was out of function, they went back to the river and used buckets to collect rainwater for each household. 4CCP took the cost of the repair, but they are collecting money that is supposed to go to the maintenance and repair of the pump. They pay 20 shillings/bucket, which is far too little to cover the costs. Someone from the committee keeps a list of the villagers that gets water and how much they are getting. They are considering increasing the price to be able to cover the costs. They are reporting improved lives, more time (kids can be more at school) and better health.

Hayeda (13.02)

250 households + a school of 400 students. COWSO consists of 12 people (8 male and 4 female). They have the sole responsibility of the water supply and they are picked by the village (randomly). They used to collect water in traditional wells earlier (3-5 km away). They received an improved water source in October 2017. In December they had a problem with the cylinder (also a deep well). They were 3 weeks without water from the borehole (last December), and got water from the traditional wells and contaminated surface water close by. They called 4CCP, which fixed the pump. During the rain season they also collect water in buckets at their houses. The water from the pump is used for all their needs. There are trained people in the neighbouring village, which they can call during small breakdowns. They have their own borehole. They also collect money for each bucket, 20 shillings. They have discovered that this is not a sufficient amount and are considering increasing the amount. By now they have 20.000 shilling (80 NOK). 4CCP paid for the costs when the cylinder had to be changed. They are planning to increase the amount, either by increasing the fee/bucket or by collecting 10.000 shillings from each household for damage repair. They will discuss this with the village before implementing a solution. In addition to a far greater collecting distance for the old water source, they also had to both boil and sieve the water before using it. They are experiencing that the people do not suffer from water-borne diseases anymore. The children have time to go to school, and the parents have time for other activities or for working more. They see that other villages nearby are coming to fetch water from their pump, causing long lines of up to 3 hours. They therefore want more boreholes in the villages

nearby. An idea is also to install rainwater harvesting tanks at the school, so that the students are not increasing the waiting time and so that they do not have to go to the pump. Could also be used as a back-up if the pump breaks down. During the dry season may the borehole have problems supplying all the villagers with water, and they might go to the traditional wells.

The initial cost is a collaboration between 4CCP and the village.

Gidarudagaw/Mbulu (15.02)
87 households + 375 students at a school. COWSO consists of 10 members (5 male and 5 female). They have been elected by the village council. They use the village government and 4CCP as advice. Earlier did they use a river that was 3-5 km away (Endabash) or the river Endashangwe, which is located 3-4 km away. Depended on which part of the village one was living in. These are rivers that flow all year around. Now goes everybody to the pump to get water, but the people living the furthest away from the pump use traditional wells in the neighbouring village. They have had no problems with the pump since it was erected in 2016. It is also a deep borehole (106 m). The traditional wells are supposedly filled with water also during the dry season. They have trained 3 villagers to fix the pump if there are problems, and they should also be able to fix more severe problems. They will call 4CCP for spare parts. They experience queues during the dry season, and the students have priority in the morning and in the evening. Some collect RW in big buckets/small tanks for domestic use, but nothing organized. Some boil the RW and others not. They take 20 shillings/bucket, but after the meter is put up they have increased to 25 shillings/bucket. They will use the money for O&M and are putting the money into a bank account. They will increase the amount if there is a problem and if the amount is too high will they ask 4CCP for financial support. They open the pump from 5-10 and 14-18. After they received the pump have the amount of water-borne deceases decreased (cholera, diarrhea, amoeba). Some have more time on their hands now and some have not because of the long distance. They are thinking about getting a new pump at another location, because this one is not enough. They have to decide at the committee level, then village council and then 4CCP. Perhaps they can also implement a solar where the existing solution is now. They also find it challenging to pump and want another solution. They think they use 400 buckets in a day, because they receive 6000 – 8000 shillings.

Munguli (15.02)
102 households (including teachers) + 482 students (186 girls & 294 boys). They have two water committees, both having 5 members. One consists of 3 male and 2 female, the other 2 male and 3 female. They have chosen this approach to be able to provide good service to the whole area. They went earlier to a river and traditional wells located about 10 km from the school. They got the new solution in January 2016. The school also uses rainwater-harvesting tanks. The village may harvest RW in small amounts. Previously were there several water points in the village (7 in total), but because of lacking maintenance did 4CCP close four of them. The taps broke down and the water was running continuously. They would call 4CCP for spare parts and they should be able to fix things themselves. They have one that is trained. It took a week before 4CCP fixed the taps and closed some of the water points. If they have a serious problem they would call 4CCP, consult the water committee and contact the DWE in

Mkalama. They have not had any problems with the solar system and have a guard that takes care of the area. It is not much maintenance that is done; expect cleaning of the area and dusting of the solar panel. They pay per month (1000 shilling for a household, 2000 shilling for the school and 1000 shilling for the dispensary). They put the money in a bank account. The students have a lot more time to be at school since the pumping station was implemented. W-b. diseases have decreased, better performance at the school, more time for studies, the hygiene is better as water is more easily available and attendance is far better.

Hilamoto (16.02)
400 households and a school with 450 students. Cowso: 11 (5 male and 6 female). They are selected from the village ensemble. Earlier there was water source a river located 10 km from the village. Now they have a borehole for the whole village and they have had it since 2004. It was a company that was drilling in the villages close by that drilled it there. They have an India Mark II HP (120 m deep). This is their main water supply (collects small scale RW). This is not enough and it happens that the borehole is empty for several days. Then will they close the HP and go to traditional wells located in the neighbouring villages (10-12 km away). They have experienced problems with the HP, and the maintenance is now done by 4CCP. It can take 2-3 weeks (up to a month) before a failure is fixed. They receive spare parts from 4CCP. 3-4 years ago could it take 2 months before it was fixed, because nobody is trained to fix it (probably before cooperation with 4CCP. The problems have been inside the pump (probably cylinder). They identify over-usage as a reason for breakdowns. Nobody in the village is trained to do maintenance. The last problem was I September 2017. Queues can be very long and students are given priority. If the lines are very long will they share the water with each other. People still go to traditional wells because it isn't enough water for everybody and the lines can be long. They take 50 shillings/bucket and are using this for maintenance. This is not enough, so if something happens that requires more money will they call the village ensemble and make the village contribute or share the problem with other development stakeholders that can help. They have seen a reduction of w-b diseases and increase in school performance. They can also cook at the school now and it makes the students perform better and stay longer. If there is no water do the teachers need to go and get water instead of teaching. Their plan for a new borehole is almost implemented. They have raised 2 million shilling and used it to bore a new hole, but the machine was too small. They are now waiting for them to return with a new machine. They want to place it where people are. They do not know when it will happen, but they feel that they have a good dialog with the DWE/DEO in Mkalama about it and that the company will return. If not will they get their money back and get a new company. The village will have the full responsibility of the maintenance, but will have help from 4CCP (they will train people). **They want a new borehole to reduce the time it takes to collect water to stop the limitations on development.**

Hang'Wa (Haydom + another village) (20.02)
They serve 17.000 inhabitants. The HP serves 50 HH. COWSO is put together from two original COWSOs, one from each village. There are six members from each village. They are chosen from the village assembly meeting. They are 50% female, as it suggested by law. The

treasurer should be a woman, according to the law. There are 21 DP in the area, which gets water from an electric pump + two HP. The HPs are easily emptied and not that much in use. There have been several problems with the pump/source – three times the last year. There are also problems on the DPs. Pipes are also sometimes exposed and can burst. The leakages stay there until you are able to see them on the surface. COWSO is responsible for repair, and Paulus is one if the members. They also use another technician from the hospital; if they do not have enough capacity they will outsource the work. The source provides enough water in the rain season, but not in the dry season. The alternative is private sellers or to go to a nearby village. The responsible for security takes care of criminal issues (damage, stealing) and report problems and makes people responsible for taking care of the system. It is their responsibility to assure reliability, together with the technicians. The responsible for health protect the water source and do hygiene promotion, teach people about boiling and cleaning of the water + water treatment. They normally do not have diseases with the people having new sources, but with the people using traditional wells. They had a cholera epidemic in 2016, and have had diahirrea and typhoid. They charge 30 shilling/bucket. It is bought at the DP and money is collected in the evening. Institutions have water meters. They pay per litre each month. The money is used for maintenance and repair. It is enough for now, but will not be enough when they increase the system. Big projects are funded by someone else. The relationship with the DWE is good and he is the overall supervisor. He is responsible for all damage and new projects and they are to be trusted. There has been a smooth transition between two COWSOs to one. Using diesel or electricity from the grid is expensive and unreliable, so they are thinking of transition into solar. They want support with the HH taps project. Then would the consumption increase and people would have to pay. One would also need to know the yield from the source, how people would pay and have a map. The operation of the DP is expensive, but it is not possible to increase the price.

DWE Mbulu (20.02)

They have all kinds of water sources in Mbulu. They have 386 WP, where 276 are functional. Some are not yet finished and some are out of function. They are supplying 46% availability, which is very low. They are working on improving this together with water sector development programs (government, 10 projects). Then it will increase to 58%. These ten projects will be 3 gravity and 7 boreholes. They are scaling up some existing sources and implementing some new ones. Some of the sources are rivers, then they are sieving it and using chlorine. They have 88 HP, Afridev, SWN, Neera & India Mark II. With the India Mark II, chains can get damaged and they find it hard to get spare parts. Maintenance is difficult and there is a need for specialization. Afridev does also have challenges. The rising main is made out of PVC and can be prone to damage and leakage. It is easier to fix when broken. Up to 45 m depth. It seems like the India Mark II can get damages at the bottom of the cylinder, with the valve and with the rubber. If they want to get spare parts they buy it from Dar el Salaam (2-3 days) or Dodoma (1 day). They have 4 district technicians, where 1 has the responsibility for the pumps. They are asking the government for means to employ 4 more. They are only main supervisors, and they are using area mechanics for smaller damages. With the help of area mechanics are they able to cope with the workload. They are imagining that the sensor will let them know if the water point is functional or not and help them with the monthly report of the water points. They have gotten support from an EU program called Direct Foreign Investment, that helps them with the maintenance. The downtime depends on the message from the village and the type of damage. The COWSO are mostly capable of explaining the problem, so that the technician only needs one trip to the site. The COWSO is there under the installation so that they are able to identify the problems. Their main problem is the lack of staff. They have to outsource jobs to technicians elsewhere. They want to have more solar solutions. They have 3 projects, but no planned routines for maintenance. They are also supervising distribution systems (Dogobesh, where 326 have indoor supply). They also want to have a sensor in the rising main/cylinder, so one can detect where the problem is in the pump.

Mtamba (21.02)
Legally registered COWSO with 11 members (5 female and 6 male). 500 HH and 600 students at school. They used traditional well, dams/ponds and seasonal rivers earlier. Now is this the back-up solution. These are located about an hour away. They have RW harvest at the school, but little in the village. The world bank solution got broken in 2013 and has been repaired by the government after the villagers made them aware and responsible of the problem. They have 2 km of pipes, a water tower and 12 DP (taps). The start of the project was good, but the contractor left the project and took the money. When they asked the government about it (after a 4CCP initiative), it was finalized. Their repaired the pump and pipes that were broken. The elevation from the pump to the water tower is about 50 m. They told us that they used PVC pipes, but the pipes are PE. Pipe breaks/bursts are a problem – bad material quality? They contact the DWE is something isn't working. It takes 3-4 h to fill the tank. The yield is sufficient, but the supply system isn't. They are planning to have a distribution system in all the sub-villages. They have started with the mapping of the distribution points. They collect 50 shilling/bucket. They use the money to buy fuel for the pump + small maintenance. They collect extra money if something large happens. Sometimes they do not have enough money for fuel, change to solar? They can fix smaller problems themselves. They do not boil the water, not even the surface water → lack of awareness. The water affect school attendance, so safe water has to be available in the school.

Dinamu (28.02)
316 HH and 352 students at the school. The water situation is very bad and they use almost 3 h/day to fetch water. They use dug dams, and they are very contaminated, especially after a rain event. Some people boil water and some do not. The students use the same contaminated water. There is some rainwater collection, but it is not enough to fulfil the needs. There are also no pumps nearby that can be used. To improve their own water situation they created groups of people to take action. They dug dams that collect rainwater. They got more water, but it is still contaminated. The local government try to create awareness of the contamination of water; tell people that they have to boil. They are looking for funds from stakeholders, so that they can drill for water. The COWSO is strong and has an active bank account (without money). To be able to get help from 4CCP, they need 30% of the costs in the bank account. That is about 15 M shilling. They were recruited to the project last November, but still have not collected the money from the village. They also need to sort out some logistical problems

concerning the bank account. They are planning to collect money from each HH and are counting on that 250 HH are able to pay –> 60.000 shillings each (equivalent of a good goat). People are ready to pay for the water supply, and they are thinking about 50 shilling/bucket. The school is also contributing, but the parents take the cost. It is their first time with a solution like this. They do not have a village technician, but 4CCP will train someone. Mbulu and the DWE is not far away and it is fairly easy to get spare parts. They are expecting that the water fetching will take less time when they get the improved solution, and it will help the kids stay at school and they will be healthier and cleaner. The veggie program will help them get an income and with nutrition. They have seen some cases of water-borne diseases, students that have to go to hospital. They also see more sickness in December (start of rain season). They are preparing for problems with the water solution by having money in the bank account. They have not planned for queues yet – find a solution if that happens. They are planning a solar solution with taps locally, so there might not be that many lines. The water should only be used for human consumption; the animals should use the old source. They want the solution inside the school, but 4CCP does not place water sources inside institutions, just nearby if possible. The school lies on a hilltop so it is not an option. The borehole has to be placed further down and away from the school. They have some difficulties with where to place the borehole. They might get funding for another pump from someone else, and the pumps have to be placed in a reasonable distance from each other. There will be no pipes or distribution network now, but the project will be easily scalable if the yield is great enough and they have enough money.

Endamilay (02.03)
They have several non-sustainable ones, and only one sustainable. That is a natural spring that is located 10 km away. They have traditional wells and a HP, but this dries out regularly. The COWSO is not registered and trained, but was formed in Octorber 2017. It was only trained for two days, and they should have had a year of training. They are 12 members, 6 of each gender, but should be 7 female and 5 male. Nelson Faustin said that they have to change the structure before implementation of the project. They have 100.000,- shillings in the bank and they need 16.200.000,-, because that is 30% of the project costs. They need to have these money before they get the funds from 4CCP. In the village are there 313 HH, which can contribute (52.000,- shillings/HH). The board said that this would be possible, but they need to discuss it at the village assembly meeting. The price is now 50 shillings/bucket. The biggest challenge is leaders that do not give information about income and expenses. The only health problem they have experienced is diarrhoea. They get 20 buckets/day from the hand pump, which is far too little. They had Afridev earlier, but have now changed to India Mark II (in 2016), but the yield is too low. They also said that they have another HP that has the same problem.

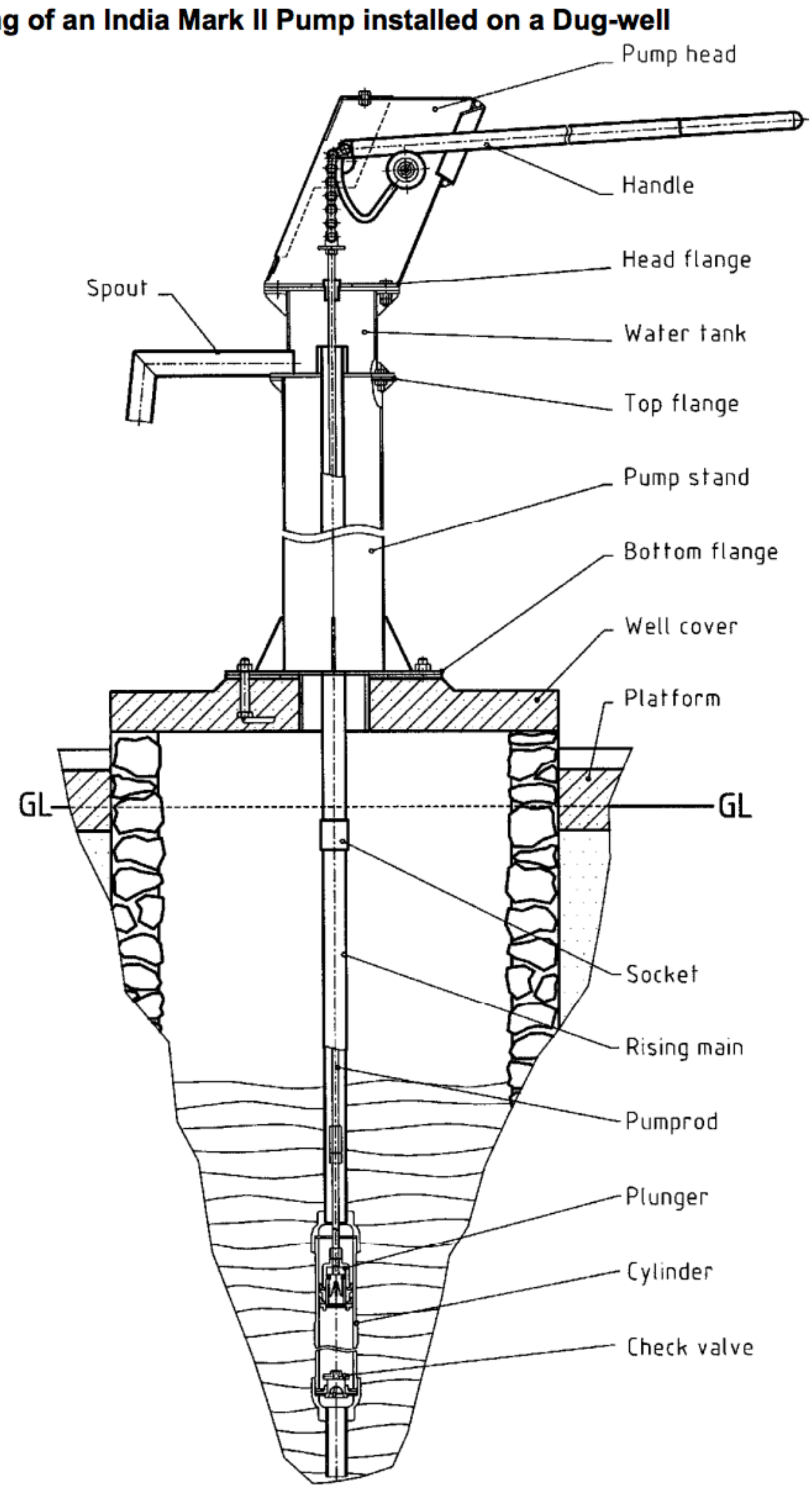
Mazingiri (05.03)
The number of households is 336. There is also a primary school with 630 students. The COWSO has 8 members, four men and four women. Before they got the pumps (2010) they had a traditional well in each of the sub-villages (4). These wells are about 4 km away. The school has a RW harvesting tank built by 4CCP, and people are collection RW in buckets at

home. The water from the HP is not sufficient, especially in the dry season. They have therefore made a regulation that each HH gets 4 buckets of water for drinking. This water is not to be used for animals. If they need more water they have to go to the traditional wells. They have experienced problems with the rods and with the cylinder. They are using India Mark II, with depths of 52, 53, 43 and 43 meters. The village government does the maintenance, and some people in the village are trained to do it. They get the spare parts from Singida. 4CCP has no role in the maintenance in this village. The tank they put up have a storage capacity of 500 m^3 (according to the villagers). They pay monthly, 2000/HH and 1000/HH during the rain season. This has not been enough for maintenance and they have increased the amount to 3000/HH for the entire year. They will increase it even more if it is necessary, after a discussion in the village. The villagers have agreed on the raise of cost this time. The normal downtime is 1 week, but it depends on the problem. If the problem is serious, they have to ask the village government for money and they have to wait 3,4 or 7 days extra. If one of the HP is broken, they will share the other pumps. It is therefore not that critical. There are lines, 3 hours or more in the dry season (4-5), but people will rather wait than go somewhere else. If there is no water in the school are the students given priority at the HPs. They have experienced that the health is better. It is easier to keep clean, and they can prepare food in the school. Last year the school was the best school in the ward.

L

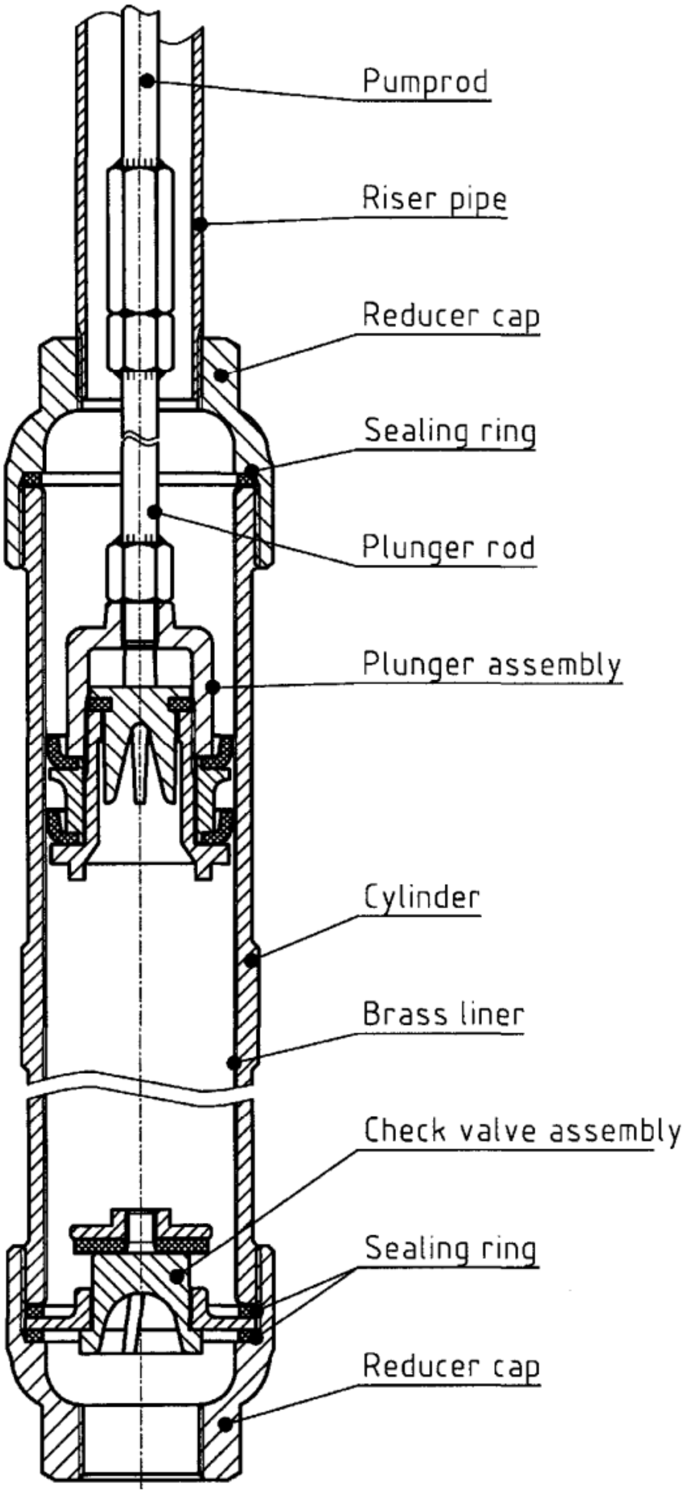
Appendix B1

Drawing of the India Mark II Hand Pump on a dug-well (SKAT & RWSN, 2008)



Drawing of the India Mark II Hand Pump Cylinder (SKAT & RWSN, 2008).

Drawing of the India Mark II Pump Cylinder



Appendix C1

An overview of the measured values at the two water meters in Munguli with calculations on average consumption and standard deviation for the water meter placed by the storage tanks.

Tank (A)

Date	Reading 1	Time	Reading 2	Time	Amount	Comment
1. period						
03.02.18	8,7649	07:15:00	21,5955	12:30:00	12,8306	Correct
04.02.18	21,5865	07:40:00	30,6456	17:07:00	9,0591	Correct (calculation error in book)
05.02.18	30,6556	07:00:00	35,022	11:06:00	4,3664	Correct (wrongly read in book)
				Total	26,26	
				Consumption/person/day (L)	58,35	*3 days and 150 people*

Comment first period: seems like they read after the pump has been switched on, as evening and morning values don't harmonize.

Date	Reading 1	Time	Reading 2	Time	Amount	Comment
2. period						
06.02.18				*No readings*		
07.02.18	40,27	18:32	57,1778	16:45:00	16,9078	Correct (wrong time)
08.02.18	57,1778	07:25	71,3241	16:50	14,1463	Correct
09.02.18	71,3241	11:00	77,0809	14:20	5,7568	Correct
10.02.18	77,9342	08:30	88,4572	12:20	10,523	Started after pump start?
11.02.18	88,4572	07:45	98,4449	16:30	9,9877	Corrrect (reading error to 12th?)
12.02.18	98,5549	07:00	98,5549	16:10	0	
				Total	57,32	
				Consumption/person/day (L)	63,69	*6 days and 150 people*
3. period						
15.02.18	136,2326					Own reading of meter, because the teacher wasn't present
				Total	37,79	
				Consumption/person/day (L)	71,98	*3,5 days and 150 people*
4. period						
13.02.18	106,5356	07:30	116,6456	16:20	10,11	An amount missing since the 12th, reading is too late
14.02.18	110,7139	07:10	118,9423	16:20	8,2284	Isn't possible that the morning value is smaller than the evening value
15.02.18	118,9423	07:05	137,3336	14:10	18,3913	Seems like there have been problems with the measuring,
16.02.18	137,3336	07:05	147,4228	15:10	10,0892	several mistakes and smaller values the following day
17.02.18	147,4228	07:45	153,5684	14:00	6,1456	
19.02.18	153,5684	07:30	161,1713	13:15	7,6029	
				Total (from 12th)	62,62	
				Consumption/person/day (L)	59,63	*7 days and 150 people*
5. period						
20.02.18	161,1713	07:40	165,3496	-	4,1783	Changed the values from the book to something that makes sense
21.02.18	165,3496	07:20	182,9315	14:00	17,5819	Changed the values from the book to something that makes sense
23.02.18	182,9315	08:15	195,795	14:00	12,8635	
25.02.18	195,795	07:30	210,0688	14:00	14,2738	Corrected value
				Total	48,90	
				Consumption/person/day (L)	54,33	*6 days and 150 people*
6. period						
28.02.18	210,0688	07:44	223,9753	13:10	13,9065	First is a small error, the last is corrected to a more sensible value
02.03.18	227,9924	07:31	235,8911	11:46	7,8987	Started reading after pump start?
04.03.18	235,8911	11:10	245,4548	14:45	9,5637	
				Total	21,48	
				Consumption/person/day (L)	28,64	*5 days and 150 people*
				Total	245,45	Total in the whole period I was there
				Consumption/person/day(L)	56,43	Averge in the period I was there

Formula for standard deviation S

$$S = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}}$$

Period	x	x-x	(x-x)^2
1	58,35	2,24	5,03
2	63,69	7,59	57,57
3	71,98	15,87	251,97
4	59,63	3,53	12,47
5	54,33	-1,77	3,14
6	28,64	-27,46	754,26
	Sum of (x-x)^2	1084,45	
	Average of x (x)	56,10	
	Standard deviation	13,44	

An overview of the measured values at the two water meters in Munguli with calculations on average consumption and standard deviation for the water meter placed by the pump outlet.

Pump (B)

Date	Reading 1	Time	Reading 2	Time	Amount	Comment
1. period						
03.02.18	14,0552	07:22:00	27,6829	12:08:00	13,6277	Correct
04.02.18	27,6526	08:00:00	38,888	16:50:00	11,2354	Less than the morning before, reading error?
05.02.18	39,9045	07:25:00	44,1839	10:35:00	4,2794	Started after pump start or error?
				Total	29,14	
				Usage/person/day (L)	64,76	*3 days and 150 people*

Also differences between evening day x and morning day x +1, which indicates either errors or reading after pump has started.

Date	Reading 1	Time	Reading 2	Time	Amount	Comment
2. period						
07.02.18	51,8437	09:20	70,6888	16:37	18,8451	
08.02.18	70,9843	08:40	95,8432	16:15	24,8589	Seems like all the morning and the evening numbers differ in a way that doesn't make sense with a reading mistake. The pump has perhaps already started in the morning?
09.02.18	96,5043	11:20	105,7809	14:00	9,2766	
10.02.18	106,9342	08:45	117,1758	12:05	10,2416	
11.02.18	118,7353	11:20	129,2701	16:05	10,5348	
12.02.18	130,1796	08:00	130,1796	15:50	0	
				Total	73,76	
				Consumption/person/day (L)	81,95	*6 days and 150 people*
3. period						
15.02.18	170,9307					Own reading of meter, because the teacher wasn't present
				Total	41,66	
				Consumption/person/day (L)	79,35	*3,5 days and 150 people*
4. period						
13.02.18	138,8864	08:00	143,1877	15:45	4,3013	
14.02.18	143,2346	08:05	151,1696	16:00	7,935	
15.02.18	152,5504	08:20	171,0318	14:00	18,4814	
16.02.18	172,0563	11:44	181,1475	15:50	9,0912	
17.02.18	183,0318	10:30	188,0307	13:40	4,9989	Here there are mistakes on the cubic, which leads to great mistakes
18.02.18	190,1254	08:06	202,9568	13:00	12,8314	
				Total (from 12th)	72,78	
				Consumption/person/day (L)	69,31	*7 days and 150 people*
5. period						
20.02.18	202,9941	08:15	205,9837	14:20	2,9896	Changed values
21.02.18	205,9253	08:00	221,9941	13:45	16,0688	Changed. Less than the evening before!
23.02.18	222,9283	08:30	233,8963	13:10	10,968	
25.02.18	230,0734	08:00	255,542	13:40	25,4686	Less than the evening before!
				Total	55,50	
				Consumption/person/day (L)	61,66	*6 days and 150 people*
6. period						
28.02.18	71,962	**?**	227,4925	13:38	**-**	Wrongly read or recorded
02.03.18	272,9453	07:50	280,2178	11:25	7,2725	
04.03.18	281,2243	11:40	292,4914	14:35	11,2671	
				Total	65,00	
				Consumption/person/day (L)	86,67	*5 days and 150 people*

Total	292,49	Total in the whole period I was there
Consumption/person/day(L)	67,24	Averge in the period I was there

Period	x	x-x	(x-x)^2
1	64,76	-9,19	84,45
2	81,95	8,00	64,02
3	79,35	5,40	29,19
4	69,31	-4,64	21,52
5	61,66	-12,29	151,04
6	86,67	12,71	161,66
	Sum of (x-x)^2	511,88	
	Average of (x)	73,95	
	Standard deviation	9,24	

P