Master's thesis

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

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Resilience of rural water supply systems

Case study from the Mbulu and Mkalama districts, Tanzania

Master's thesis in MTBYGG
Supervisor: Sveinung Sægrov
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Kunnskap for en bedre verden

Abstract

This thesis studies rural water supply systems and is based on a case study from the Haydom area in Tanzania. The work has been conducted in collaboration with NTNU, the non-governmental organisation Norwegian Church Aid and their partner organisation in Tanzania, 4CCP. Resilience is used as a theoretical framework. Resilience is understood as the ability of a system to maintain performance and return to its former function after having endured stress or an unwanted incident. Resilience is in this seen to increase the overall sustainability of a system as it makes it more adaptive and robust. Infrastructure asset management has been applied as a framework to more directly address how to improve the resilience of rural water supply systems.

The physical conditions lay the foundation for any water supply situation. In the study area there are significant hydrogeological differences within quite close proximities. The groundwater table is however generally very deep. The water is found to be of good quality, except for elevated fluoride levels. Additionally, pH values below 6,5 pose a challenge to the down-hole components of the hand pumps found in the study area. However, none of the samples taken indicated a pH-value below the threshold, but corrosion in the pipes was reported as a widespread problem. The main challenge for the water situation in the study area is insufficient consumption. On average people consume 12,5 l/pd, which is very low compared to the level recommended by WHO to ensure safe and sanitary conditions (20 l/pd). Long distances and waiting times at the water point means that water collection is a time-consuming process, which disproportionally affects the everyday lives of women and children.

The study has focused on India Mark II Extra-Deep Well hand pumps and solar powered pumps. The solar powered pumps are new and seem to be working well. For the hand pumps the main issues appear to be that their capacity is exceeded, both in terms of depth and users. Preventive maintenance is lacking and downtime of pumps when they break is longer than necessary. Improved management of the pumps can therefore increase the resilience and extend their lifetime. Water supply in rural areas in Tanzania is carried out by community owned water supply organisations (COWSOs). To increase the functioning of a COWSO it is found to be particularly important to ensure that they are legally registered and have a bank account, to develop a budget and a financial plan, that they produce reports and take minutes of meeting, as well as collaborating closely with the district engineer, anti-corruption committees and external actors. A sustainable water supply system is also reliant on sufficient funding. This is done through the collection of tariffs and establishing a tariff which provides the required service at a manageable risk is vital. In this study, 107 willingness to pay (WTP) surveys have been carried out. The analysis found a correlation between WTP and income and COWSO capacity. Furthermore, it showed a negative correlation between increasing WTP and current service and time spent fetching water. However, no correlation was found between gender and WTP, and for the location of the villages the data was inconclusive.

To manage infrastructure and improve the resilience of rural water supply systems, continuous observation and measurements should be undertaken. More knowledge about the physical systems and relevant measurements is required to translate observations and raw data into concrete strategies and actions. The overall knowledge base – measurements, competence and practical understanding – can be used more efficiently to reduce the failure frequency, adapt to changing conditions, establish stronger organisations and a system that is sufficiently and robustly financed.

Sammendrag

Denne oppgaven omhandler rurale vannforsyningssystemer og er basert på en casestudie fra Haydom-området i Tanzania. Prosjektet har blitt gjennomført i samarbeid med NTNU, bistandsorganisasjonen Kirkens Nødhjelp og deres partnerorganisasjon i Tanzania, 4CCP. Det teoretiske rammeverket benyttet er resiliens. Resiliens er forstått som et systems evne til å opprettholde sin ytelse og å gå tilbake til sin tidligere funksjon etter å ha vært utsatt for stress eller en uønsket hendelse. I denne konteksten ansees økt resiliens for å øke systemets bærekraft, ved å forbedre systemets adaptivitet og robusthet. IAM (infrastrukturforvaltning) har blitt brukt som et rammeverk for å videre undersøke hvordan man kan forbedre resiliensen til rurale vannforsyningssystemer.

De fysiske forholdene utgjør grunnlaget for vannforsyningssituasjonen. I studieområdet er det betydelige hydrogeologiske forskjeller innenfor relativt små områder. Generelt sett ligger grunnvannsnivået imidlertid svært dypt. Vannet er ansett for å være av god kvalitet, bortsett fra forhøyede fluoridnivåer. I tillegg utgjør pH-verdier under 6,5 en utfordring for rørkomponentene til håndpumper brukt i studieområdet. Det ble imidlertid ikke tatt prøver som indikerte en pH-verdi under terskelen, men korrosjon i rørene ble rapportert som et utbredt problem. Hovedutfordringen for vannsituasjonen i studieområdet er det lave vannforbruket. I gjennomsnitt bruker folk 12,5 l/pd, noe som er svært lavt i forhold til det nivået som WHO anbefaler for å sikre trygge og hygieniske forhold (20 l/pd). Lange avstander og ventetider innebærer at å hente vann er en svært tidkrevende prosess, hvilket har store implikasjoner på i hovedsak kvinner og barns hverdag.

Studiet har fokusert på India Mark II Extra-Deep håndpumper samt soldrevne pumper. De soldrevne pumpene er nye og ser ut til å fungere godt. For håndpumper synes de største problemene å være at de blir brukt over kapasiteten, både med tanke på pumpedybde og antall brukere. Det mangler forebyggende vedlikehold og nedetiden på pumpene ved reparasjon er lengre enn nødvendig. Forbedret forvalting av pumpene kan derfor øke resiliensen og forlenge levetiden. Vannforsyning på landsbygda i Tanzania utføres av lokale vannkomiteer (COWSOer). For å øke en COWSOs funksjon er det spesielt viktig å sikre at de er juridisk registrert og har en bankkonto, å utvikle et budsjett og en økonomisk plan, at de produserer rapporter og fører protokoll fra møter samt har gode samarbeidsrelasjoner med distriktsingeniøren, anti-korrupsjonskomiteer og eksterne aktører. Et bærekraftig vannforsyningssystem er avhengig av tilstrekkelig finansiering. Dette gjøres gjennom innsamling av tariffer og etablering av en tariff som dekker ønsket tjeneste med en akseptabel risiko er essensielt. I dette studiet har 107 betalingsvillighet (WTP) undersøkelser blitt gjennomført. Undersøkelsene viser korrelasjon mellom WTP og inntekt og COWSO kapasitet. Videre viser de også negativ korrelasjon mellom økende WTP og eksisterende tjeneste og tidsforbruk ved vannhenting. Det ble imidlertid ikke funnet noen sammenheng mellom kjønn og WTP, og for lokasjon av landsbyene var dataen ikke signifikant.

For å forvalte infrastrukturen og forbedre resiliensen i rurale vannforsyningssystemer bør nivået av kontinuerlige overvåkning og målinger økes. Mer kunnskap om både de fysiske systemene og relevante overvåkningsdata er påkrevd for å kunne omsette observasjoner og rådata til konkrete handlinger og tiltak. Det er avdekket et potensial for at det samlede kunnskapsgrunnlaget – målinger, kompetanse og praktisk forståelse – kan brukes mer effektivt til å redusere feilfrekvensen, tilpasse seg endrende forhold, etablere sterkere organisasjoner og et system som er tilstrekkelig og robust finansiert.

Preface

This Master's thesis and its research have been conducted at the Department of Hydraulic and Environmental Engineering at the Norwegian University of Science and Technology (NTNU) in Trondheim, in the spring of 2019. It equals 30 ECTS and is the end of the five-year programme in Civil and Environmental Engineering, with a course specialization in Water and Wastewater Engineering. The research has been carried out in cooperation with Norwegian Church Aid (NCA) and their partner organisation in Tanzania, 4 Corners Cultural Program (4CCP).

First and foremost, we want to thank our supervisor Sveinung Sægrov who has made this whole project possible. He has believed in and guided us from the beginning and his enthusiasm and knowledge has been of great help and inspiration. Manfred Arlt with NCA has co-supervised this thesis and has provided invaluable insights and close follow-up during the entire process. We are very grateful that we have been given the opportunity to benefit from his competence and experience. Zachayo Makobero who works with NCA Tanzania has also been important in the process and has provided us with detailed and useful data. Nelson Faustini, the senior programme officer at 4CCP, has also had a pivotal role in the making of this thesis as the research conducted would not have been possible without him. We would also like to send our most sincere thanks to the rest of the staff we worked with at 4CCP who translated, travelled with us and made our stay in Tanzania not only a research project, but also an experience where we made friends that we will forever appreciate. Though they were all part of an unforgettable experience we would like to send a particular thanks to Wilmina Joseph, Hilaria Habiye, Huruma Olomi, Joram Sumawe and Reginald Tango. All the other people we met while in Haydom, whether they were local residents or visiting from abroad, also provided plenty of insights from different fields, a more thorough understanding of the local situation – and joyful times.

Furthermore, Rebecca Martinsen who wrote a related thesis last year has been incredibly generous in sharing her material and preparing us for our stay in Tanzania, which made the whole processes much easier. Additionally, we would like to thank Kristian Trægde who was not only a good friend in Haydom but has also provided useful input on issues related to water quality. Our families and friends who have supported us not only in the production of the thesis, but throughout the entire studies, have also been crucial for its completion. Finally, we would also like to thank each other for being adaptive and generous with each other in what have at times been a stressful and challenging process. It is not necessarily an easy feat to share a room for over nine weeks and then write together while based in two different countries, but we feel very lucky that we have been given the opportunity to work together and learn from each other.

Trondheim, 11th of June 2019

Ingvild Misund ……………………………………………..   Sigrid Møller ……………………………………………..

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List of Abbreviations

4CCP	Four Corners Cultural Program
COWSO	Community Owned Water Supply Organisation
EiT	Experts in Teams (Eksperter i Team)
F	Fluoride
GDP	Gross Domestic Product
GNI	Gross National Income
HDI	Human Development Index
HDPE	High Density Polyethylene
HLH	Haydom Lutheran Hospital
IAM	Infrastructure Asset Management
IRC	International Research Centre
JMP	Joint Monitoring Program
LCCA	Life Cycle Cost Analysis
l/pd	Litres per person per day
mg/l	Milligram per liter
NAWAPO	National Water Policy
NCA	Norwegian Church Aid
NGO	Non-Governmental Organization
NOK	Norwegian Krone (1 TZS = 0.0036 NOK, as of 02.06.2018)
NTNU	Norwegian University of Science and Technology (Norges teknisk-naturvitenskapelige universitet)
O&M	Operation and Maintenance
PETS	Public Expenditure Tracking System
PPP	Purchasing Power Parity
PVC	Polyvinylchloride
PV	Photovoltaic
RWS	Rural Water Systems
RWSN	Rural Water Supply Network
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
TSH	Tanzanian Shilling (1 TZS = 0.00043 USD, as of 06.06.2018)
TCP	Telethon Campaign Programme
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children’s Fund
USD	United States Dollar (1 USD = 2,300 TZS, as of 06.06.2018)
UWS	Urban Water Systems
VEO	Village Executive Officer
VLOM	Village Level Operation and Maintenance
WASH	Water Sanitation and Hygiene
WHO	World Health Organization
WTP	Willingness to Pay

1 Introduction

This thesis investigates the resilience of rural water supply (RWS) in Tanzania. To analyse this, infrastructure asset management (IAM) is applied as a framework. The thesis emphasises reasons for pump failures and their prolonged downtime, the functioning of community owned water supply organisations (COWSOs) and willingness to pay (WTP). This chapter addresses the motivation for this work, presents the research questions, briefly discusses the associated topics, explores the importance of water and its role in achieving sustainable development and provides a plan for the report.

1.1 Motivation

It is estimated that at any given time more than one-third of the hand pumps in Sub-Saharan Africa (SSA) are not working (Oxford University Innovation, n.a.). Lack of access to an improved water sources drastically impacts the quality of life for millions of people. The main motivation for writing this thesis was to investigate how to increase the resilience of RWS systems by improving IAM, so that the water supply is more reliable and sustainable. Hopefully this thesis can be used for direct improvement, which is highly motivating. Furthermore, this work has been done in collaboration with Norwegian Church Aid (NCA) and their local partner organisation 4 Corners Cultural Programme (4CCP). NCA are now in the final year of a five-year water, sanitation and hygiene (WASH) programme in Tanzania initiated by the WASH Telethon Campaign Programme (TCP).

The thesis emphasises both the crucial role of water in development and everyday life, and the pivotal position of infrastructure in this process. It has also been a stated goal to elaborate on the excellent work done by Rebecca Martinsen in her Master's Thesis from 2018, which was also written in collaboration with NCA and 4CCP. Additionally, this Master's thesis directly builds on a project thesis produced in the autumn of 2018 which was a literature study concerned with the resilience of RWS in Tanzania. It functioned as preparation for the fieldwork that has been conducted for this Master's thesis. Furthermore, we both have experience with and a keen interest in development work, and particularly the role of water in this process. It has therefore been a valuable experience to investigate how technical and non-technical components interact and how both are needed to achieve resilient and sustainable systems.

1.2 Research questions

The purpose of this thesis is to identify which factors affect resilience and how the resilience in a RWS system can be improved. The project thesis leading up to this Master's thesis dealt with a variety of topics, and though they were all partly related and had merit it was considered beneficial to focus on five main topics that impact and reinforce each other. They are:

- How do the nature based conditions (geology, hydrogeology and climate) affect the possibility of groundwater abstraction?
- How can the current water situation be characterised, both in terms of quality and quantity of water?
- What factors are important for choosing appropriate pump technology, why is the failure frequency for India Mark II Extra-Deep Well so high and what can be done to remediate it?
- How can community owned water supply organisations increase their function and contribute to improved management of water supply?
- What are the factors that affect willingness to pay for water and what are appropriate tariffs, both for current and improved services?

The nature based conditions for water supply is the foundation for the groundwater system and will also impact the resilience. The ground conditions are thought to impact both how much water the aquifer can sustainably supply and certain quality parameters. Furthermore, climate change is predicted to impact the local hydrogeology and though it does not have a significant or immediate impact on deep groundwater, changing precipitation patterns and prolonged droughts has been hypothesised to further challenge already vulnerable livelihoods.

The water situation in the study area was considered to be in quite a dire situation with people lacking access to sufficient amounts of water and spending unnecessary amounts of time collecting water. In addition to having a negative impact on the health and well-being of the users, limited access to clean and safe water disproportionately affects women and children – particularly in terms of time spent collecting water. The quantity was therefore considered to be too low from a consumer perspective, but it was not initially clear whether this was due to natural, financial and/or organisational restrictions. From a quality perspective the major concerns associated with the use of groundwater were fluoride levels and the pH, as reflected by the literature. The fact that groundwater is considered to have at least one hygienic barrier as the water percolates through soil and deeper layers makes quality concerns less of a pressing issue.

The chapter addressing the reasons for pump failure places an emphasis on the India Mark II Extra-Deep Well, which is a hand pump designed for being use to a depth of 80 metres (RWSN, n.a.). A hypothesis was that the frequent pump failures in the region were related to the pump being used in a way that exceedes its capacity. It was also thought that pump failures were exacerbated as a result insufficient to non-existent operation and maintenance (O&M). Another known issue for the pump is that a low pH value (less than 6,5) can lead to corrosion of the metal pipes in the rising main. Furthermore, as this pump operates with an open source it can be produced and assembled in different places, which means that the quality might be varying. There was also a stated goal to attempt to gather information on pump failure and systematise it, as this appeared to be lacking.

The functioning of COWSOs addresses the organisational mode applied for water supply in rural Tanzania and therefore also the importance of 'soft factors' in water provision. 4CCP and NCA emphasise community mobilisation in their work and argue that this is necessary for sustainable systems. Well-functioning COWSOs are a vital part of ensuring a resilient water supply system and becomes a crucial actor in implementing IAM. It was hypothesised that they were good at fairly distributing water and resolving water related conflicts because the committee members themselves are customers. However, it was thought that they were lacking in capabilities related to long-term planning and technical improvement.

WTP is concerned with what water consumers consider to be an acceptable cost for a given service. For WTP it was hypothesised that women would be willing to pay more as they had more to gain from improved water services. Furthermore, it was thought that people would at least be willing to spend 3-5% of the household's average yearly income on water and that people with a poor current service would be willing to spend more on improvements in their water supply, at least in relative terms. A foundational hypothesis was that the closer the tap is to one's home the more the costumer would be willing to pay. It was also initially thought that it is preferable to pay an annual fee, compared to a per bucket fee.

The functioning of COWSOs and the amount of money collected through tariffs will have a direct impact on the physical infrastructure installed, which is why this is considered as core aspects of a water supply system. We argue that the components mentioned, as well as the physical conditions which constitute the foundation, directly impact the resilience of a system. Together they represents vital parts of successful asset management.

1.3 Associated topics

Though we have argued that the main topics presented as the research questions are vital topics that to a large extent cover the most essential parts needed for resilient water supply systems, there are however many other aspects that would have been worth going in to if the time and resources were available.

First of all, looking at sanitation more specifically would have been beneficial as this has a major impact on the lives of millions of people. Water is often tied to sanitation, both through their physical relation but also as a concept. WASH is an area of development that focuses on this, and partly tries to capture synergies between the two different fields. It would therefore have been interesting to further study the school programmes for WASH carried out by 4CCP. These programmes emphasise the importance of hand washing, decent toilettes, safe hygiene practices and also addresses education around puberty, menstruation and sexual health. This is important work that has a direct impact on health and quality of life.

Initially it was planned to conduct WTP analysis for so-called 'veggie gardens' as it would be very interesting to compare the results of domestic consumption and water for income generating activities. Information related to 'veggie gardens' would also be useful for NCA. However, there are currently few 'veggie gardens' in the Haydom area and the two that were visited were not operational in the wet season as they then rely on precipitation and the users grow very little due to low prices.

Additionally, as all the boreholes were already drilled, pump testing did not become a part of the fieldwork. Though some reports are available, this does not fully provide the same information that could have been achieved by being there during the process. There were plans to collaborate with another university and purchase a hand pump and conduct pump tests in a laboratory, which would have been interesting and potentially very important work, but unfortunately the time was limited so this will hopefully be done in future projects.

The above does not provide and exhaustive list over relevant or interesting topics, but it was considered important to narrow the thesis down so that some in-depth analysis and a thorough understanding could be accomplished. We therefore hope that the collaboration between NTNU and NCA and 4CCP, or similar organisations, will continue in the future and that more of these important questions can be investigated.

1.4 Access to safe water sources

Water is an essential part of human life and health. It permeates virtually all aspects of everyday life in some shape or form. It is needed for direct consumption, ecosystems, agriculture, energy production, the making of products, and carries a spiritual and aesthetic purposes for billions of people (UN DESA, 2015a). Though the importance of access to sufficient amounts of clean water is clearly understood and recognised, this remains a widespread and serious issue to this day. Globally there is enough fresh water available, but this vital resource is unequally distributed both in time and space (Jihyunjenlee, 2012). Currently water scarcity affects over 40% of the global population, but this percentage is expected to increase in the future (UN, n.a.). As of 2015, 844 million people, or just under 30% of the world's population, did not have access to a safely managed drinking water solution (WHO and UNICEF, 2017).

Using a safely managed source is according to WHO and UNICEF's Joint Monitor Program (JMP) to drink water from "an improved source which is located on premises, available when needed and free from faecal and priority chemical contamination" (JMP, 2017). This is however not the case for the majority of people in a rural setting in a low-income countries, and through projects such as the TCP it is realistic and often only considered possible to achieve a basic drinking water supply situation. This entails that one is "drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing" (ibid), see Figure 1.1.

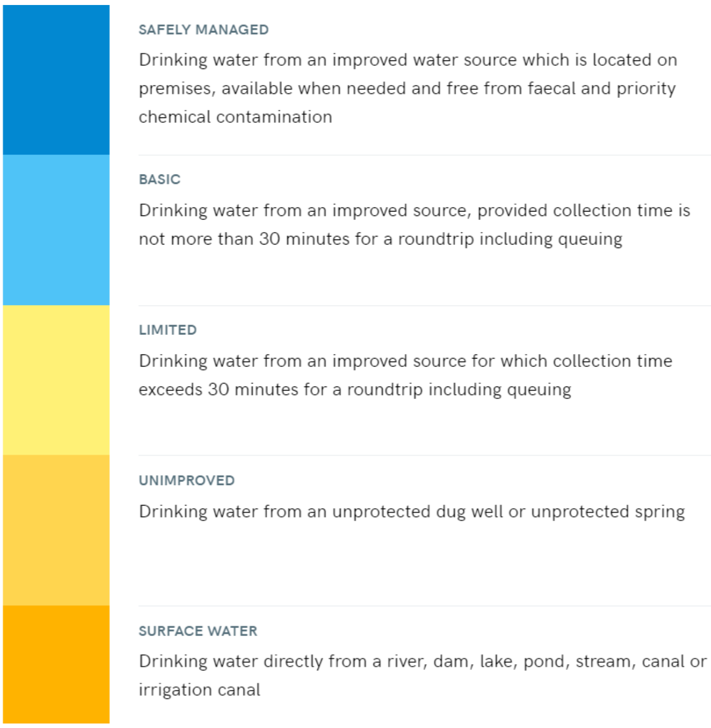


Figure 1.1: The Drinking Water Ladder as developed by JMP (JMP, 2017).

Figure 1.2 shows how access to an improved drinking water source remains a great challenge particularly in SSA (WHO and UNICEF, 2017). Tanzania is found to have between 50-75% coverage, but this is for the country as a whole (ibid). The national policy sets out that 85% of people in rural areas should have access to basic drinking water services by 2020 (URT, 2016). However, current numbers from the Mbulu region are approximately 42%, according to an interview with the district engineer of Mbulu.

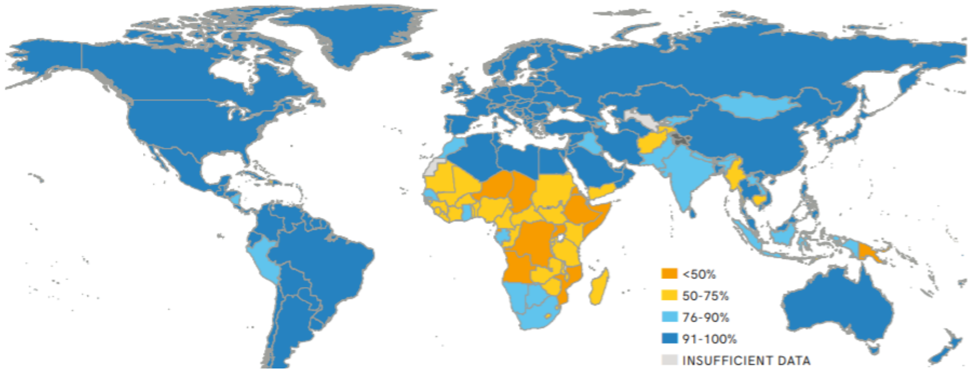


Figure 1.2: Proportion of people using at least improved drinking water services, 2015 (WHO and UNICEF, 2017).

According to WHO guidelines a person needs at the very minimum 15 litres per day (l/pd) to drink, prepare food and ensure required sanitation and hygiene (WHO, n.a.a). This does however apply to emergency situations, and this very minimal amount should not apply for long periods of time. 20 l/pd is therefore set as the minimum amount of water needed to ensure sustainable livelihoods (ibid). This amount does however only apply to purely domestic use and not what are often other vital activities such as agriculture or livestock-keeping.

It is not just the amount of water that is important, but also its quality and proximity. The major impacts of inadequate water supply appear to be the prevalence of fairly easily preventable diseases such as diarrhoea and missed economic opportunities due to the time spent collecting water. Globally, almost 1000 children die on a daily basis due to water and sanitation related diseases (UN, n.a.). In rural northern Tanzania the time spent collecting water is heavily dependent on the season and in the dry season numerous hours may be spent just to reach a non-safe water point, where one has to queue up to several hours before returning home. This is often done several times per day and represents a full-time job – if not more in terms of hours spent. Water therefore intersects almost all aspects of life and has both direct and indirect impacts on the well-being of people.

1.5 Water, sustainability and the SDGs

A safe and secure water supply is important for sustainable livelihoods. Sustainable development is a term often attributed to the 1987 Brundtland report which defined it as meeting the needs of today "without compromising the ability of future generations to meet their own needs" (UN, 1987, p.15). Sustainability is commonly seen to rely on three pillars; the economic, social and environmental. Seeing water as a crucial part of sustainable development is an overarching theme for this thesis and we argue that it is beneficial to expand the term sustainability beyond the traditional three pillars to also include assets and governance, as done by the more recent TRUST project, as seen in Figure 1.3 (Venkatesh et al., 2017).

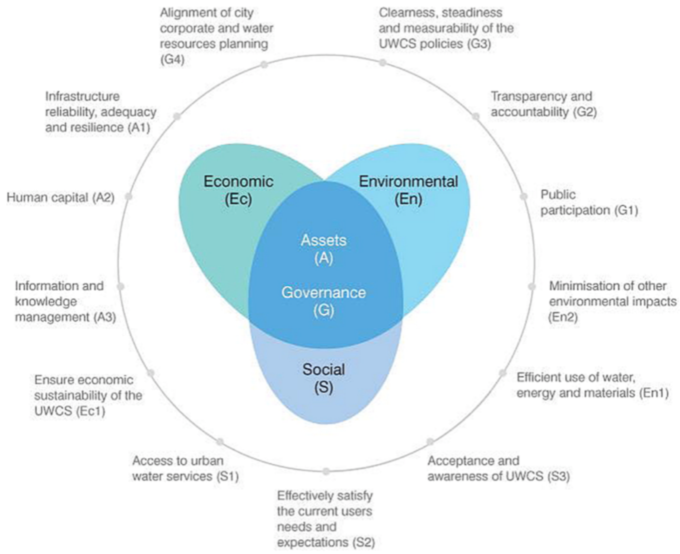


Figure 1.3: TRUST project framework for sustainability assesment of urban water services (Venkatesh et al., 2017).

The importance of safe water provision and the proper management of water sources is expressed in the Sustainable Development Goals (SDGs). The SDGs are a list of 17 ambitious targets ratified by all the members of the UN that are to be reached by 2030, see Figure 1.4.

Figure 1.4:The sustainable development goals (IMF, n.a.).

SDG 6 aims to ensure the availability and sustainable management of water and sanitation for all. By 2030, targets include an achievement of universal and equitable access to safe and affordable water for all, as well as reducing water pollution and increasing water use efficiency across all sectors (UN, n.a.). Reaching this goal holds great value in and of itself, but improved water and sanitation is also an important aspect in achieving the other SDGs. In rural areas of low-income countries, it is arguably the first five goals where water and sanitation have the biggest and most significant impacts.

<u>SDG 1 - No poverty</u>

Water insecurity negatively affects economic growth. Inadequate water supply and sanitation "continues to have the greatest economic consequence of all water-related risks, and it remains the most harmful risk to people" (Sadoff et al., 2015, p.175). Globally, it is estimated that 260 billion USD are lost annually because of inadequate water supply and sanitation, largely due to the time dedicated to collecting water or going to open defecation sites (ibid). SSA experiences the largest negative impacts of inadequate water supply and sanitation as measured as a proportion of GDP. Furthermore, the region also experiences the largest variability in crop production as a result of hydro-climatic variations (ibid). This partly illustrates how agriculture is important for a reduction of poverty.

SDG 2 - Zero hunger

By 2050 the agricultural sector needs to produce 60% more food globally and 100% more in developing countries to meet the needs of a growing population (UNW DPAC, n.a.). Globally, agriculture accounts for about 70% of water withdrawals, but rain-fed agriculture remains the most widespread. This approach is however almost half as effective as optimal agricultural management (ibid). To reduce world hunger, an improvement of water management and expansion of irrigation systems is therefore needed. Still, what has been observed in the rural regions in northern Tanzania, in the making of this report, is that irrigation systems seem to be rare. The soil appears to be very fertile, but again local people are heavily dependent on the seasons and precipitation falling in a sufficient and predictable manner. Rainwater collection during the wet season and drip-irrigation is therefore likely to increase the agricultural output and may also open up for more varied crops that have a higher nutritional value or income generating properties.

SDG 3 - Good health and well-being

Clean water is essential to lower the global mortality ratio and under-five mortality rates. Globally, diarrheal diseases kill approximately half a million children under five years old annually, but "a significant proportion of diarrhoeal disease can be prevented through safe drinking-water and adequate sanitation and hygiene" (WHO, 2017). At the hospital in Haydom, doctors in the paediatric department reported that diarrhoea remains in the top three reasons for admittance, but if the children arrive early enough it is relatively easy to treat. It is however better to avoid the illness in the first place, which is why safe water sources are so crucial. Furthermore, proper water management also serves a preventive function against epidemics such as malaria. Malaria occurred in an estimated 219 million cases worldwide in 2017 and stagnant surface water is literally a breeding ground for malaria (WHO, 2018). In 2009, Hayeda Secondary School in the Mbulu district experienced a cholera outbreak, due to the use of surface water, which rapidly spread and affected numerous students and ended up taking the lives of two pupils. After NCA installed six rainwater tanks, which provide water to the school, there have been no major issues related water and this partly highlights the important role of water in the attainment of good health and well-being.

SDG 4 - Quality education

The example from Hayeda Secondary School further illustrates how water and sanitation also has a significant impact on the access to and quality of education. In 2009 during the cholera outbreak only 17% of the students passed their exams, but in 2018 the passing rate was 100% and the school was found to be the best in the district. Schools provide an arena to teach about proper practices regarding water and sanitation and may therefore have a positive impact on the wider community. Furthermore, target 4.5 aims to eliminate gender disparities in education and ensure equal access to all levels of education (UN, n.a.). Inadequate sanitation facilities is a major reason for girls to not attend school, particularly after they start menstruating (Lawford et al., 2018).

SDG 5 - Gender equality

On an annual basis it is estimated that 40 billion working hours are lost in SSA due to water collection (Deen, 2018). Women and girls are responsible for water collection in 80% of households without access to water on the premises (UN, n.a.). Collecting water is a demanding task which may exclude them from paid work and education. This can be understood as a form of discrimination, which according to target 5.1 should be ended in all its forms (ibid). Improved access to water may therefore relieve the burden of women in many countries who spend excessive time accessing safe water for their families (Lawford et al., 2015). Lack of access to safe water is at "the heart of the poverty trap, especially for women and children, who suffer in terms of illness, drudgery in collection of water, and lost opportunities because of the time that water collection consumes" (Kaliba et al., 2009, p.119).

Interconnectedness SDG 1 to SDG 6:
It is argued that working towards achieving the goals set out in SDG 6 will also positively impact gender relations and reduce poverty by freeing up time which can be spent in the formal labour market. Furthermore, improved irrigation systems are likely to reduce hunger and malnutrition and also improve the economic conditions. Suffering from malnutrition may reduce one's ability to perform in school, hence an increased agricultural output due to improved irrigation may therefore have an indirect effect on the attained education, which further points to the interconnectedness and the role of water. Access to clean water and sanitation is therefore a crucial component in achieving sustainable development. Creating robust and resilient water supply systems, particularly in rural areas in low-income countries, is thus of the utmost importance.

1.6 Plan for the thesis

This thesis firstly provides a brief description of Tanzania, its socioeconomic characteristics, the ethno-linguistic groups and the study area. Chapter 3 will present the theoretical framework of resilience and illustrate its importance for, and linkages to, sustainability. Furthermore, it will discuss how IAM can be a useful tool in creating and assessing resilient water supply systems. It has been found most beneficial to not include the theoretical background of the specific research topics in the theory chapter. The theory chapter will therefore focus on the overarching theoretical framework. The 4th chapter explains the methods used in this thesis and addresses some of the major limitations encountered in this work. Chapter 5 to 10 constitutes the results and discussion part of the thesis, where each chapter contains theoretical background, results, discussion and a brief conclusion. Chapter 5 is focused on the physical conditions including climate change, the geology and hydrogeology of the northern Manyara and Singida region and its implications for water supply. Chapter 6 analyses the water situation from the perspective of the quality of water, while chapter 7 discusses the quantity of water. The 8th chapter reviews the different pumps in the study area and reasons for pump failures in the India Mark II Extra-Deep Well, and possible amendments are suggested. Chapter 9 explains and analyses the role of COWSOs and tries to identify what factors are needed for well-functioning and sustainable committees. The COWSOs are also classified and analysed according to a rural IAM framework. The 10th chapter presents the findings from the WTP surveys and investigates this in relation to what has been identified as the most relevant parameters. Chapter 11 is the conclusion which will summarise the most important findings, discuss what factors should be addressed to increase the resilience of the water supply system and point to areas where more research is needed. The last chapter identifies areas that should be investigated in future work.

2 Case description

This chapter will briefly present relevant aspects of Tanzania's geography, history and characteristics that are deemed relevant for the study area. Additionally, details about the fieldwork will be explained.

2.1 Tanzania

Tanzania is a large country in the eastern part of SSA with a long and rich history. It is the most populous country in East Africa with approximately 55,5 million people. The population distribution is however extremely uneven with population in the north of the country and along the coast (CIA World Factbook, n.a.).

Tanzania lies just south of the equator and close to the Great Lakes area. The country has a long shoreline in the east and borders Lake Victoria in the upper western parts. It is also part of the Rift Valley and home to Africa's highest mountain, Kilimanjaro. Tanzania is therefore a country with great variations in terms of climate, altitude and terrain. The country receives much sun and has two wet season per year which normally take place from March to May and a shorter one from October to December, but the precipitation received varies a lot within the country (Noel, n.a.). Tanzania borders Kenya and Uganda to the north, Rwanda, Burundi and the Democratic Republic of the Congo to the west and Zambia, Malawi and Mozambique to the south, see Figure 2.1. Tanzania is therefore close to many countries that have experienced war and conflict in recent times and prides itself on being a peaceful and stable nation.

Figure 2.1: Map of Africa, where Tanzania is highlighted with a dark blue colour (JCDecaux, n.a.).

2.2 Tanzania's history

Mainland Tanzania (Tanganyika) was a colony under both German and British rule, while Zanzibar was under Omani rule. After a revolution in Zanzibar, Tanganyika and Zanzibar united in 1964 forming the United Republic of Tanganyika and Zanzibar, which later the same year got renamed to United Republic of Tanzania (Benjaminsen and Hem, 2017). Julius Nyere became the first president of the new republic. He is seen as the 'father of the land' and set out policies and a political vision that were to have a lasting impact on Tanzania (ibid). He was inspired by Marxism and some argue that his vision for an African socialism was an inspiring and refreshing one aiming to reduce poverty and human suffering for both men and women and avoiding increasing inequality (Schneider, 2015). There were improvements in terms education and health, but when Nyere left office in 1985 Tanzania was one of the poorest countries in the world (ibid).

Three decades later Tanzania is still considered to have a low human development index (HDI), scoring 154th out of 189 countries (UNDP, 2018). HDI assesses gross national income (GNI) per capita, life expectancy at birth and education levels. The low score indicates how Tanzania still struggles with poverty, high mortality rates and limited education levels – despite this being something that was meant to be addressed by the socialist policies.

The socialist policies have also arguably had an impact when it comes to water provision as most people got water for free from the government, contributing to a mindset where water was not seen as a commodity that should be paid for. Viewing water as a human right, and not as any other commodity which can be sold in the marketplace to the highest bidder, is not unique or necessarily wrong, but it may make it more challenging to sustain the infrastructural systems needed to provide water. It is also the view of some that water is a gift from God and it is therefore not necessarily the job or cost of people to find it and handle it in a safe and sustainable way.

Another issue, which is not by no means reserved for the water sector, is corruption. The new President John Magufuli, who has been in power since 2015, has placed an emphasis on tackling corruption. He initiated visible efforts just days after his inauguration when he made an unannounced visit to the Ministry of Finance and redirected funds meant for Independence Day celebrations into anti-cholera operations (Paget, 2017). As reported by media outlets "it became apparent that he was genuinely waging war on corruption in the Tanzanian state" (ibid). The World Bank (2018) reported that in 2017, 72% of Tanzanians said that corruption has decreased somewhat or a lot, while this number was 13% in 2014. These are important and much needed measures both in the direct effects they have, but also in terms of the signal it sends and the potential ripple effects. President Magufuli has however also been accused of waging a war on democracy itself, particularly by overseeing the suspension and closure of media outlets (Paget, 2017). This can obviously make it harder for external and internal organisations to work within the country, which is considered a negative development that may have long lasting effects – also when it comes to the improvement of water systems.

2.3 Socioeconomic characteristics

Though Tanzania has had improvements in HDI scores since the turn of the millennium, this has somewhat slowed down in recent years (World Bank, 2019). As of 2015, Tanzania was classified as belonging to the group of the 48 least developed countries and as a low-income country (UN DESA, 2015b).

Tanzania's gross domestic product (GDP) was 52,09 billion USD in 2017, equal to 162,5 billion USD with purchasing power parity (PPP) (World Bank, 2019). This places them 75th in the world, but when assessing GDP per capita Tanzania is 193 by a country comparison (CIA World Factbook, n.a.). The country has however had a relatively high economic growth, where the annual average since 2000 has been between 6-7% (ibid). This is above the average for the region and represents one of the highest growth rates in Africa (Benjaminsen and Hem, 2017). The recent growth is largely attributed to Tanzania's vast natural resources and the tourism industry (ibid). The economic growth has led to a reduction in poverty as the national poverty rate declined from 34,4% in 2007 to 26,8% in 2016 (World Bank, 2019). These percentages are in relative terms and not absolute figures and the number of poor people has stagnated due to population growth (ibid). It should also be mentioned that high growth rates may also indicate a low starting point. Though the improvements are positive and should not be undermined, high growth rates do not necessarily indicate a strong economy.

The inclusivity of economic growth should also be addressed. The tourism industry for example contributes to 25% of GDP but only employs two percent of the population (Benjaminsen and Hem, 2017). The mining industry can also be very profitable, but it is likely to benefit few people. A way to denote income inequality is the Gini coefficient. This is a "measure of the deviation of the distribution of income among individuals or households within a country from a perfectly equal distribution" (UNDP, n.a.). A value of 0 represents absolute equality while a value of 100 represents absolute inequality. Tanzania's Gini coefficient is as of now estimated to be 37,8 (ibid). It is higher than many famously equal Scandinavian countries but also lower than many high-income countries and other countries in the SSA, particularly those with plenty of natural resources. This may be due to the fact that Tanzania's economy still mainly relies on agriculture. Agriculture constitutes just less than one-quarter of GDP, 85% of income from exports, and employs around 70% of the workforce (Benjaminsen and Hem, 2017).

In accordance with agriculture being an important sector, the majority of people in Tanzania live in a rural environment, currently between 65-70% of the population (CIA World Factbook, n.a.). The rate of urbanization is estimated to be just over 5% per year over the period from 2015-2020 which will impact the urban to rural ratio (ibid). However, the population growth for the country as a whole is just under 3% and birth rates are normally higher for poor families in rural areas. The average fertility rate is 4,8 children per woman and average life expectancy is 63,1 years (ibid).

The median age is 17,9 years which means that Tanzania has a very young population (ibid). The large proportion of young people in the population is reflected in Figure 2.2 showing the population pyramid for Tanzania, contrasted by Figure 2.3 presenting the population pyramid for the world. The triangular shape of the population pyramid of Tanzania indicates a younger and more rapid growing population than the world average. It is a typical pyramid for a developing country with high fertility rates and low life expectancies. Such a structure may pose challenges due to limited availability of employment and opportunities for young people. Efforts to lower fertility rates has somewhat stagnated in recent years, though this is something that is focused on by organisations such as NCA. As indicated in Figure 2.2 the male to female ratio is fairly equal in Tanzania (ibid).

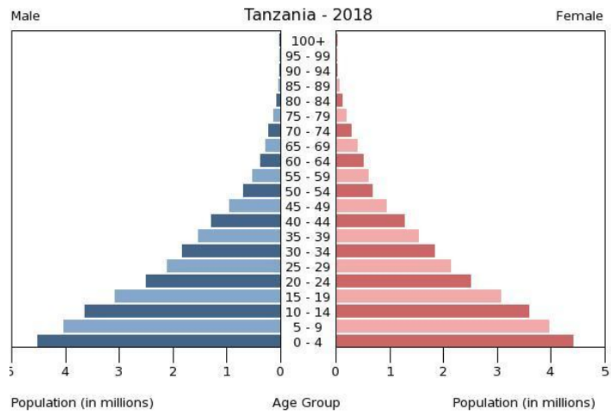


Figure 2.2: Population pyramid for Tanzania (CIA world Factbook, n.a.).

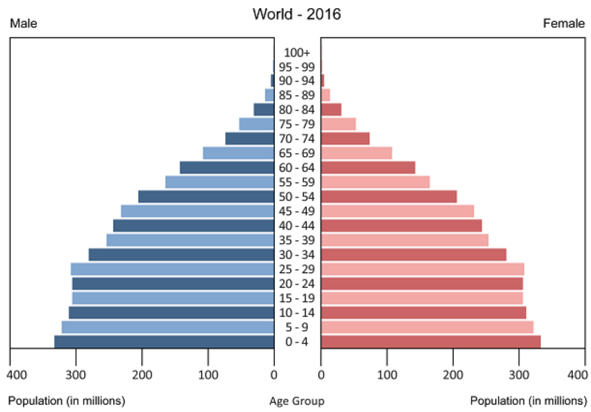


Figure 2.3: Population pyramid for the whole world (CIA world Factbook, n.a.).

Tanzania is a country where economic growth has not translated into improved rural water services as they have remained virtually static over the last 25 years (Lockwood et al., 2017, p.3). This is partly reflected in how the top causes of death according to the Centers for Disease Control and Prevention are diarrheal diseases, neonatal disorders, HIV/Aids, tuberculosis, malaria and so-called neglected tropical diseases (CDC, 2018). Other sources however find that malaria is the leading killer of children under 5, while HIV is the main source of adult mortality (CIA World Factbook, n.a.).

Tanzania is also an incredibly diverse country with more than 130 ethno-linguistic groups or tribes and over 100 different spoken languages, whereas only Kiswahili and English are the official languages (CIA World Factbook, n.a.). The heterogeneous composition may lead to different cultures in regards to practices and knowledge related to water and sanitation.

Despite many of the challenges discussed, Tanzania is considered a safe and peaceful country. It is one of the least developed countries in the world, but has experienced recent growth, though this is not particularly inclusive. Water services are therefore still insufficient and with a young and growing population this is an issue that is likely to be exacerbated in the future.

2.4 Study area

The heterogeneity of Tanzania is to a large extent reflected in the town of Haydom, indicated by the red pin, see Figure 2.4, where the fieldwork for this thesis took place.

Figure 2.4: Location of Haydom indicated by a red pin in the northern part of Tanzania (Google Maps, n.a.).

In Haydom four main different ethnic groups live together side by side. According to 4CCP Cultural Centre the Hadzabe, who speak a Khoisan language, traditionally depend on hunting and gathering – which is also the case for many Hadzabe today. The Datoga are pastoralist Nilotic people who traditionally keep cattle, sheep and goats. The Iraqw are a Cushtic speaking ethnic group in the Great Lakes area and they are seen to be the descendants of Neolithic Afro-Asiatic peoples who practiced plant and animal husbandry. The Bantu people are speakers of Bantu languages, compromising several hundred indigenous ethnic groups in SSA due to several expansions and migrations. In Tanzania the Bantu people have been associated with cultivation and living in small, organised villages.

The combination of settled, nomadic and semi-nomadic peoples in one area can often lead to conflict, particularly over opposing interests in relation to land and water issues. Furthermore, seeing as many different languages are spoken and different religions and beliefs may be practiced, this can further complicate relations. This has however not been the case in Haydom where these four groups peacefully live side by side, and Kiswahili being a shared and official language. To celebrate the coexistence and individual culture of the four different groups the cultural programme – 4CCP – was initiated. As of 2015, their work has also involved activities related to water supply in collaboration with NCA as part of the TCP.

2.5 Fieldwork

The fieldwork conducted for this thesis has been done in collaboration with both 4CCP and NCA. The collaboration with NCA has mainly taken place in beforehand and also afterwards with Manfred Arlt, NCA's Global Wash Advisor, as a co-supervisor. 4CCP provided the programme for our stay, suggested which villages to visit and were responsible for arranging all meetings, translation and all associated logistics.

The fieldwork took place from the 20th of January to the 10th of March 2019 in the Mbulu and Mkalama districts, which are respectively in the Manyara and Singida region, east and west of Haydom, where the main villages visited can be seen in Figure 2.5. The fieldwork included interviews with stakeholders, surveys and measurements. The itinerary for the stay was updated throughout and 4CCP were very accommodating in adapting to what was deemed most useful for the thesis. See the programme for the fieldwork in Appendix 1.

Figure 2.5: Main villages visited for fieldwork.

The programme was very well thought out and provided solid amounts of data and information. Still, many of the places visited are in a rural area, often with limited infrastructural access and a significant amount of time was therefore spent travelling. This however provided a good opportunity to see much of the local area and talk to the people we worked with from 4CCP and gain further insight. Collaborating with the two organisations has been a very rewarding process as it combined real-life experiences and competence with a more theoretical and academic approach.

As mentioned, the different groups in the Haydom area have traditionally focused on different income generating or life-sustaining activities. In the Mbulu and Mkalama region most people now seem to be involved in both subsistence farming and some cash crop cultivation, often alongside keeping of livestock. Different lifestyles and cultures can present a challenge when it comes to shared water systems. For example, it was reported in some villages that certain groups did not fully appreciate the importance of access to clean water, nor safe water practices, and were therefore less willing to participate in community mobilisation.

An increasing amount of people are involved in activities either related to tourism, particularly safaris, or to the Haydom Lutheran Hospital (HLH). HLH was set up by a Norwegian missionary in 1955 and quite rapidly Haydom town grew around it. The hospital does crucial and much needed work, however, it also appears that the strong and prolonged presence of external actors, such as missionaries, students and visitors, has also had negative effects on local people and mentalities. We were introduced to the idea of 'donor syndrome' in certain villages where community mobilisation proved particularly difficult. It was argued that people were so used to receiving hand-outs, that a generation had become virtually pacified and strongly reliant on external help. In the long-term, external support can therefore have detrimental effects on several sectors within a local society – including water provision. This illustrates how the best intentions may have unintended negative consequences, and it is imperative to consider the future implications and sustainability of actions and programmes at all levels of development work.

3 Theory

As in the project thesis, resilience will be used as a theoretical framework in this Master's thesis. This chapter is therefore based on much of the same literature, though some amendments and improvements have been made. Resilience will be discussed in relation to sustainability, water infrastructure and development. Additionally, IAM and its role in achieving resilience in RWS systems will be explored.

3.1 Definition resilience and sustainability

The term resilience has been used to denote material properties and to address complex and adaptive systems within natural sciences. This is clear from dictionary definitions where resilience is either "the capacity to recover quickly from difficulties; toughness" or "the ability of a substance or object to spring back into shape; elasticity" (Oxford Dictionary, n.a.). More recently, resilience has also been used within social sciences such as psychology, finance and national security (Walker and Cooper, 2018). The concept has also been applied together with sustainability when studying ecological systems, to assess the "speed of return to equilibrium following perturbation" or to describe the "size of a disturbance needed to dislodge a system from its stability domain" (Perrings, 2006, p.17). In 1973 Holling wrote an important paper analysing the stability and resilience of ecological systems, seeing resilience as the "persistence of relationships within a system and […] a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist" (p.17). He considered resilience as the level of disturbance a system could withstand without changing its core structures and processes, as well as the time required after a disturbance to return to a stable state (ibid, p.14). Resilience has in recent years become quite a popular term within several disciplines and its usage has increased substantially. Though the almost exponential growth of the term resilience is largely due to it being a useful concept, it has also been criticised for being another 'buzzword', somewhat similar to the concept and term sustainability.

Sustainability has over the past three decades become a guiding principle and goal for development. Though there is no direct consensus on the precise definition of sustainability, it is, as addressed in the introduction, "widely agreed that any conception of sustainability must account for the interconnections of environmental, economic, and social factors [...] and be attentive to the long-term needs of future generations" (Milman and Short, 2008, p.758). Resilience, on the other hand, focuses on the response of systems to both persistent stress and extreme disturbances, though its application and precise definition is also discussed (Marchese et al., 2018). The relationship between sustainability and resilience is however even less agreed upon in the literature. Marchese et al. conducted a review of the literature on the topic and found that three main frameworks dominated the literature:

1. Resilience as a component of sustainability
2. Sustainability as a component of resilience
3. Resilience and sustainability as separate objectives
   (ibid, p.1275)

These three approaches are not compatible, if not directly contradictory. The researchers however found that "implementations of these frameworks were found to have common goals of providing benefits to people and the environment under normal and extreme operating conditions" (ibid). Seeing as there is some ambiguity both in terms of the definitions themselves and particularly how they relate to each other, it is important that those who use them clarify their approach or stance. Here sustainability is understood to apply to functioning systems and their continued functioning in the long-term future, whereas resilience addresses systems that are under stress now or might be so in the more immediate future. In this thesis they are not considered to exist in a hierarchical relationship, but resilience is viewed as a factor which will increase the sustainability of a system.

Milman and Short (2008) also fall into the first category mentioned above. They argue that efforts to define, quantify, and measure sustainability have led to the development of a variety of indicators which have the potential to help organizations and governmental institutions track progress towards or away from sustainability. This can help in transforming the abstract concept of sustainability into an actionable objective. However, they present a critique of sustainability indicators through "their failure to consider resilience: the ability of a system to maintain (or improve) upon its current state over time" and therefore propose a new indicator – the Water Provision Resilience (ibid, p. 758). The indicator considers the "percent of the population with access to safe water and evaluates the ability of an urban water system to maintain or improve the current level and quality of access over the next 50 years" (ibid). This serves as an example of how resilience can be incorporated into indicators of sustainability. Pizzol echoes this and argues that resilience is a "property of systems that is deemed essential for their sustainability" (2015, p. 296). Building on this, it is therefore found that resilience is an important factor in achieving sustainability and particularly useful when addressing water systems.

However, the difference between resilience and sustainability as theoretical frameworks and intellectual approaches is found to be less stark in a rural low-income setting when considering a water supply system. This is due to the 'soft factors' being equally, if not more decisive than 'hard factors' in ensuring that the system functions as expected both today and, in the future, and that it is able to cope with both internal and external stressors.

3.2 Resilience and water infrastructure

In recent years resilience has increasingly been applied to assess how water infrastructure systems perform under stress. However, the majority of this work is focused on urban water supply systems (UWS) in high-income countries. Resilience aims to create flexible and adaptive systems. A highly sophisticated system that performs well under normal conditions is not deemed resilient if the entire system fails to deliver due to a minor error, and it takes a long time for it to become functioning again. Resilience is therefore a function of all the elements in a system, and their connection to each other (Pizzol, 2015). Furthermore, it is argued that it exists is a trade-off between efficiency and resilience, as the majority of natural systems favour resilience, while most human made systems favour efficiency. Thus, by allowing a certain level of sub-optimal performance in terms of efficiency, a system may be better adapted to cope with stressors (ibid).

Butler et al. see resilience as "the degree to which the system minimises level of service failure magnitude and duration over its design life when subject to exceptional conditions" (2014, p. 349). Mugume et al. echo this and argue that for engineering systems resilience is "interpreted differently from ecological resilience and focuses on ensuring continuity and efficiency of system function during and after failure" (2015, p.16). This points to a divergence between engineered systems which are designed for a given purpose and ecological systems that emerge through evolution.

Makropoulos et al. however, find that the difference between the two systems is not as stark, and thus argue that introducing resilience as a concept for engineered systems benefits from a definition similar to that for ecological systems. As a result, they understand resilience "as the degree to which an urban water system continues to perform under progressively increasing disturbance" and suggest "performance as a function of disturbance" as an indicator (2018, p.317). By doing so they illustrate how resilience can be more than just another elusive concept when applied as an operational method.

By proposing a resilience assessment method, they provide an approach to test the resilience of a UWS which takes the form of a 'stress-test' with increasingly stressful scenarios. The factors considered are climate proofing of cities, ageing infrastructure, and uncertainty of both water availability and demand (ibid). Their analysis finds that there exist trade-offs between robustness and resilience, decentralised and centralised systems and efficiency represented as energy costs and resilience. It is "suggested that the methodology could inform strategic planning under large-scale uncertainty and provide evidence-based support for investment decisions concerning future system configurations" (ibid, p. 327). This is however applied to UWS and largely in high-income countries and the methodology is therefore not ideal for water supply in rural areas, particularly in low-income countries.

In this thesis resilience is used to address both infrastructural systems as well as political and societal structures. The most useful definition for this purpose, is seeing:

> *resilience as the ability of a system to maintain performance and to return to its former function after having endured stress or an unwanted incident.*

It should be emphasised that stress does not only apply to external events such as natural disasters. The internal stressors of a system, such as inadequate maintenance which leads to pump failure, should also be included. By including both technical and non-technical systems, and importantly their intersection, a more holistic approach is attained.

3.3 Resilience and development

SDG 9 aims to "build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation" (UN DESA, n.a.). Target 9.1 seeks to "develop quality, reliable, sustainable and resilient infrastructure, […] to support economic development and human well-being, with a focus on affordable and equitable access for all" (ibid). An indicator for this the proportion of the rural population residing within 2 km of a road which is useful in all-seasons (ibid). Seeing as safe water sources also constitutes critical infrastructure a similar metric could be applied. Target 9.A further highlights the importance of striving towards resilient and sustainable infrastructure in “developing countries through enhanced financial, technological and technical support to African countries [..]” (ibid). Infrastructure is crucial for improved living conditions and resilient infrastructure creates more adaptable and sustainable systems. Resilience has also been used to assess the vulnerabilities and available coping mechanisms of communities. It has thereby become a widely used concept within development, particularly when addressing climate change. A World Bank report finds that “building climate resilience is essential to the global goals of ending extreme poverty and promoting shared prosperity” (2013, p.viii). Projects aiming to develop infrastructure which is climate resilient are based on four main principles:

- Robustness – building infrastructure that can withstand prescribed levels of stress and demand in the event of an adverse natural event.
- Redundancy – requiring the inclusion of a measure of in-built sustainability that can withstand repeated adverse events and keep infrastructure functional during an event.
- Resourcefulness (innovation) – developing institutional capacity to mobilize recovery and mitigation resources in the event of a major adverse weather event.
- Rapidity – introducing measures that enhance the capacity to contain losses or prevent further degradation of infrastructure in a timely and efficient manner before, during, and after an adverse natural event.
  (Baxter, 2017)

Non-governmental organisations (NGOs) have also adopted resilience as an approach to development work. Oxfam for example, see resilience as “the ability of women and men to realize their rights and improve their wellbeing despite shocks, stresses and uncertainty” (Jeans et al., 2016, p. 5). Based on this they have developed strategies and approaches to improve resilience and reduce the “impacts [...] on people living in poverty as well as the causes of vulnerability and risks” (ibid). Vulnerability is an important concept which can be defined as “the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impact of hazards” (UNISDR, 2004, p.16). It is a multidimensional concept which it is vital to recognise as communities and individuals suffering from chronic stressors are less capable to deal with an acute shock. An example is how people experiencing poverty are less able to adapt to the effects of a natural disaster. This is due to limited coping mechanisms and livelihoods that already partly eroded. Risks are a combination of probability and consequence, and particularly the consequence is likely to be enhanced for vulnerable communities and people. Furthermore, vulnerability must be addressed on both a macro and a micro level. Within a household, several dynamics are in place and power and gender relations must be investigated, as the same event may affect individuals differently based on for example class or gender.

According to Oxfam there are three critical capacities needed for resilient development. Firstly, the absorptive capacity denotes the ability to undertake intentional protective action which alleviates the effects of known stresses and shocks. Secondly, the adaptive capacity addresses the potential to undertake intentional but incremental adjustments that can create more flexibility in the anticipation of change in the future. Finally, transformative capacity signifies the capability to create intentional changes to reduce or all together stop the drivers of vulnerability, risk and inequality. It is important that risk is not disproportionately and unfairly borne by vulnerable people. This is emphasised to highlight how resilience should not be about constantly being forced to adapt or surviving contexts that are unjust, but rather to ensure inclusive development (Jeans et al., 2016).

This addresses perhaps the most important criticism of resilience as a framework for development. It has been argued that resilience in the development discourse overly encourages entrepreneurial practices and thereby serves as a tool for a neoliberal approach which essentially forces people into 'self-reliance'. "Resilient peoples do not look to states to secure their wellbeing because they have been disciplined into believing in the necessity to secure for themselves" (Reid, 2012, p. 69). There is validity to this critique as resilience as both an idea and approach may transfer too much responsibility to people that are already marginalised and stressed. By doing so it may fail to address the underlying causes and systemic issues creating the challenging conditions in the first place. An example could be how a rural subsistence farmer has to adapt to and absorb the consequences of droughts brought on by climate change, when it is the drivers of climate change that should be addressed. Resilience remains a fairly new term when applied to social sciences like development studies, and thus its meaning and potential policy implications are not yet clearly established. Though it is useful to interrogate a new term and its associated consequences, resilience does not directly imply that the responsibility to absorb and adapt is transferred to those with limited coping strategies. For this purpose, it is argued that resilience may provide a fruitful framework to analyse water supply systems, when applied in the right way.

3.4 Resilience in a rural setting

The main differences between UWS and RWS systems is the lower population density and greater distances in the latter. As a result, in-house solutions are often less viable, especially in countries such as Tanzania which have a lower level of economic development. In this case study the infrastructure itself is less extensive as there are no transport pipes and no associated wet sanitation. However, a resilient water supply system still remains one which is able to perform while undergoing stress and the time needed to return to full functionality. As mentioned, in SSA in general, it is estimated that one-third of pumps are not functioning at any given time, which presents a major challenge. Furthermore, the down-time is prolonged beyond what is to be necessary. A RWS system can improve its resilience by reducing the number of failures and lowering the down-time. Additionally, the system should be flexible and allow for changes in climate, usage and population growth. The technical components needed for a water supply system should be easy to maintain and repair, both with regards to availability of tools and spare parts, but also considering the local competence and skill. The goal of a RWS system is to provide a resource in accordance with what is expected by its customers, with a manageable risk and at an acceptable cost. A resilient system should also be accessible to all types of users including the elderly, the disabled and children. Non-technical aspects are also important for a resilient water supply system and relevant stakeholders must be included, alongside proper governance and long-term plans for both financing and O&M.

3.5 IAM and resilience

To achieve resilient systems IAM provides a useful framework. According to Alegre and Coehlo, IAM for urban water infrastructure is:

> the set of processes that utilities need to have in place in order to ensure that infrastructure performance corresponds to service targets over time, that risks are adequately managed, and that the corresponding costs, in a lifetime cost perspective, are as low as possible.
> (2012, p.50)

They further point out how IAM methods are somewhat different from the management of other assets because the infrastructural system does in theory have an indefinite lifespan. The different components need individual replacement, but this will ideally lead to an incremental renewal of the entire asset system (ibid). Infrastructures are not replaceable as a whole, only piecemeal, and "consequently, in a mature infrastructure, all phases of assets lifetime coexist" (ibid). IAM is now becoming an increasingly important topic in the move towards compliance with performance requirements in water supply and wastewater systems and sustainable management of these systems should respond to the need for:

- Promoting adequate levels of service and strengthening long-term service reliability
- Improving the sustainable use of water and energy
- Managing service risk, taking into account users' needs and risk acceptance
- Extending service life of existing assets instead of building new, when feasible
- Upholding and phasing in climate change adaptations
- Improving investment and operational efficiency in the organization
- Justifying investment priorities in a clear, straightforward and accountable manner (ibid, p. 50)

The US Environmental Protection Agency have a similar approach to the topic and find that:

> Asset management is the practice of managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service level customers desire. Asset management is a framework widely adopted by the water sector as a means to pursue and achieve sustainable infrastructure. Asset management can open communications between drinking water system staff and decision makers, help move systems from crisis management to informed decision making, facilitate more efficient and focused system operations and improve financial management to make the best use of systems' limited resources. An asset management plan serves as a tool to record all of a system's asset management practices and strategies.
> (2014, p.1)

It is clear how this directly ties to resilience and by extension sustainability, but a challenge remains how to translate this to a rural setting. There is little literature related to this and it is therefore an area in need of further studies and work. IAM in a rural setting, particularly in a low-income country, will often have less sophisticated technical systems and less available data.

The International Water and Sanitation Centre (IRC) have developed a briefing note addressing the implementation of IAM for water supply in a rural setting. The briefing note states that IAM, which involves a series of "systematic and coordinated management practices", aids to improve performance while simultaneously reducing the costs and the risk of asset failure (Boulenouar and Schweitzer, 2015, p. 1). Furthermore, IAM can better sustain services and reduce the number of interruptions. However, there are not many good examples of IAM "from the rural water sub-sector of developing countries" (ibid). This is unfortunate as successful IAM, even in simplified forms, can help to lower the risk and increase performance and cost-effectiveness of a system – which is particularly important in environments which struggle with limited resources.

3.6 IAM factors and measurement

The IRC briefing note maps out the five main pillars of asset management:

- asset register
- level of service
- asset failure
- maintenance strategies
- long-term financing
  (Boulenouar and Schweitzer, 2015, p.3)

As illustrated in Figure 3.1, the pillars are connected and will have an impact on each other. Furthermore, the importance of long-term planning and an integration of all stakeholders is highlighted to enhance the management of assets.

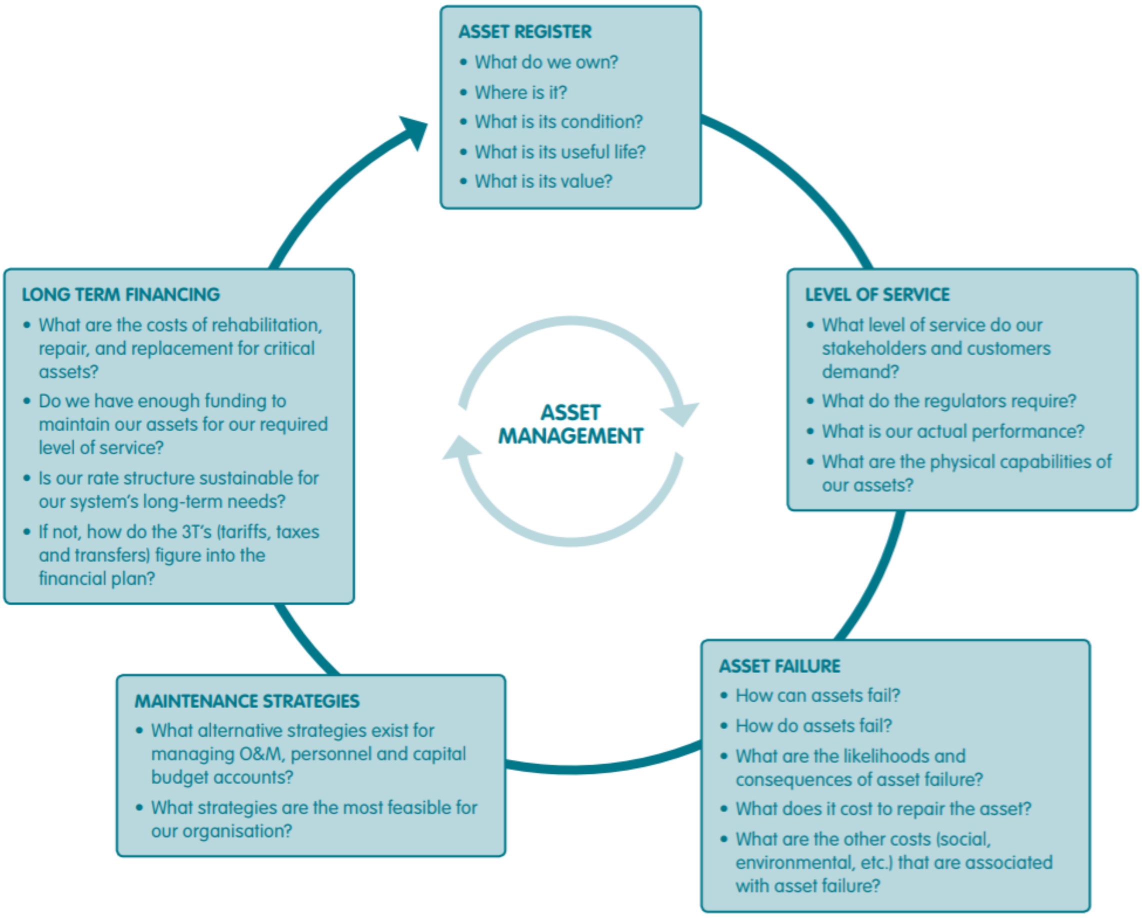


Figure 3.1: The core areas of asset management (Boulenouar and Schweitzer, 2015, p.3).

In the water sector, assets refer to the various physical components of a given system, such as, pumps, pipes, generators, valves and storage tanks (ibid). To manage the assets, so that services are maintained at given levels with the highest "functional life and optimum performance at the lowest possible cost", a set of decisions and processes are needed. Thus, "well planned, resourced and implemented IAM helps avoid the large lump sum replacement and rehabilitation costs associated with premature failure and unplanned breakdowns" (ibid).

Effective IAM can be achieved when an alignment exists in between the operational tasks performed, the tactical goals pursued and the strategic management objectives (ibid). This necessitates a thorough understanding of the lifespan of the various components, as well as the impact of O&M and the system which it operates in. Achieving this relies on the availability of sufficient and reliable data and requires three important pillars of competence, namely: engineering, business management, and information management (ibid).

IAM is usually carried out by the service provider in UWS systems. For RWS systems in developing countries, the responsibility is often found to be divided between several stakeholders and thus more fragmented (ibid). Commonly, water committees are responsible for the maintenance of the water points and the collection of tariffs. Monitoring of the water point's functioning and strategic decisions is however normally conducted by service authorities with jurisdiction. The latter is therefore responsible for making decisions related to rehabilitation, investment, as well as decommissioning of infrastructure (ibid). In rural Tanzania COWSOs are responsible for water supply alongside local authorities and external partners, but it seems that the committees themselves are also responsible for tactical decisions and only collaborate with service authorities when there is an issue. To realise and sustain resilient water supply systems an alignment between the decision levels alongside long-term planning is required.

The emphasis of this thesis is on natural conditions, pump failures, the functioning of COWSOs and WTP. These are all important aspects of a resilient and sustainable water supply system and proper management is needed to achieve this. The initial step is to identify the available resources and the necessary steps needed to improve the system, and how to assess this. Each service authority must find the appropriate level of IAM practices in accordance with available human and financial capacities and the infrastructural profile (ibid). It may not be possible or appropriate to systematically adopt advanced practices of IAM, which are "only effective if there are adequate resources (i.e. financial and human resources) available to support the strategies, knowledge and capacity development, and practices which make up IAM" (ibid, p.7). Service providers and service authorities in the rural water sector often face significant shortfalls in resources and as a result IAM practices are not applied or not effective in achieving the desired objectives. However, even simplified versions of IAM can extend the lifespan of an asset and reduce the costs.

4 Method

The overarching method can be understood to be the use of IAM as theoretical framework to assess the water supply situation in a rural context in Tanzania. The concrete methods or tools used to gather information will be presented here, alongside their purpose, use and challenges. The main limitations encountered in this work are also discussed.

4.1 General methodology

Research is largely divided into two overarching categories; quantitative and qualitative. Quantitative research is based on the use of computational, statistical, and mathematical tools to derive results (SIS, n.a.). It is conclusive in its purpose as it tries to quantify the question at hand and therefore relies on a larger sample size. Qualitative data on the other hand, is generally more explorative, has a wider scope, a smaller sample size and is less conclusive in its results (ibid). Qualitative research is dependent on the collection of verbal, behavioural or observational data which is interpreted in a subjective manner (ibid). It has been a stated goal to combine the use of both qualitative and quantitative data in this thesis as it is believed that this provides the most useful data set and the most truthful assessment of the situation. As explained by Kelle (2006), quantitative and qualitative methods can fulfil different yet complementary purposes within mixed-method designs. Quantitative and qualitative methods cannot substitute each other but help to illuminate different aspects of a phenomena. For example, quantitative methods can describe the actions of large numbers of different actors, whereas qualitative methods provide information about possible reasons for these actions. For RWS this can mean that quantitative methods are focused on collecting data on how much water people consume and what they pay for it, whereas qualitative methods are more concerned with analysing the underlying reasons for this.

The verifiability of qualitative methods is therefore a challenge, which is one of the reasons for why it is common to apply a combination of the methods (Olsson, 2011). Reliability is connected to verifiability and an important aspect to consider when conducting research. If the same measurement can be repeated several times under the same conditions and with the same results, one has good reliability (ibid). To achieve this the parameters used for measurements and the methods must be clear so that there is no doubt as to what to measure and how to do it. In other words, reliability is a measure of whether one's measurements are done in a consistent manner (ibid, p.41). Another associated term is validity, this indicates to which extent the collected data represents what one wishes to measure or analyse. It therefore says something about how well the data illustrates the core of the research questions which are to be answered in the study, or whether one is measuring the right parameters (ibid). It is an advantage to use several parameters that together provide an improved indication of the study object (ibid). These are all factors that should be kept in mind, both when developing the methods used for research and when employing them.

4.2 Methods to gather information

Seeing as this thesis continues the project done by Rebecca Martinsen (2018) in her Master's thesis it is found beneficial to use the same framework for methodology, which was based on Olsson (2011, p.41). He finds that there are seven common methods used to collect information. They are:

- Review of documents
- Use of existing data from systems, reports and similar sources
- Interviews with key stakeholders
- Participating observation
- Direct observation/measurements
- Surveys or questionnaires
- Case studies, which partly are a combination of several of the approaches mentioned above (Own translation from Norwegian)

In this thesis all the seven data collection tools have been used, though some more extensively and some have been emphasised in the work leading up to the thesis itself. The approaches to gather information will be presented and their purpose, advantages and disadvantages will be briefly discussed, but not in the exact same order or wording as suggested by Olsson. In addition to the approaches mentioned above, logging has also been used. Though this does not directly gather information it is a useful tool when conducting field work. Table 4.1 presents an overview of the methods used.

Method	**How**	**Purpose**	**Where**
Literature review	Reading relevant academic articles, reports and associated documents.	Getting an overview of the relevant field(s) and state of the art.	Mainly done in Trondheim, Norway prior to the departure to Tanzania, but also after returning.
Case study	Overarching approach, other methods take place within this context.	A case study has been applied to test the hypotheses and answer the research questions.	The case study took place in the Mbulu and Mkalama region in Tanzania 20.01.19-10.03.19.
Interviews	Single and group interviews with district engineers, local residents, NCA and COWSOs.	Establish in-depth knowledge related to specific topics such as COWSOs, water situation, pump failures, NCA's work and climate changes.	The interviews took place in the Mbulu and Mkalama region in Tanzania 20.01.19-10.03.19.
Participating observation	Travelling with senior people from partner organisations.	Getting information through observation of conduct, dynamics and questions posed.	The observation mainly took place in the Mbulu and Mkalama region in Tanzania 5. -11.02.19.
Measurements	Testing of fluoride levels with Palintest and measurement of pH with strips at water points.	Assess the quality of the groundwater both for human consumption and safety of pumps.	The testing took place in the Mbulu and Mkalama region in Tanzania 20.01.19-10.03.19.
Surveys	Willingness to pay surveys addressing current water situation and WTP for given improvements.	Establish the most wanted improvements and the factors affecting it, as well as sustainability of projects.	The WTP surveys took place in the Mbulu and Mkalama region in Tanzania 20.01.19-10.03.19.
Logging	Daily summary of what was conducted, as well as EpiCollect5 for location of villages.	Reference for events and impressions. EpiCollect5 was done to establish a map of the villages.	Logging took place daily during the stay 20.01.19-10.03.19 and EpiCollect5 was done in the last week.

Table 4.1: Overview of different research method used during the field work in Tanzania describing how, the purpose and where.

4.3 Literature review

It was here found beneficial to view document review and use of existing data from systems, reports and similar sources as a literature review. This was mainly carried out in the project thesis as a preparation for the Master's thesis. The project thesis was based solely on secondary literature and much of that work is therefore combined with the research results from the fieldwork in Tanzania in this project. Olsson recommends that review of documents is done as a preparatory activity, even if other forms of information gathering is also used (2011). The purpose of a literature review is to familiarise oneself with state-of-the-art knowledge, the theoretical approaches to a topic and the most important research related to a given field. A literature study includes four elements:

- Literature search
- Detailed review of selected research papers
- Writing up state-of-the-art
- Putting own research into perspective of state-of-the-art
  (Jørgensen, n.a.)

This thesis relies mainly on scholarly articles and reports from international bodies such as the UN and the World Bank, as well as non-governmental organisations like the IRC. Additionally, documents and reports from the Government of Tanzania have been used in this work. Google Scholar, Web of Science and ScienceDirect have been used to find relevant articles, journals and reports. For this thesis, literature related to sustainability and water supply, resilience and IAM, as well as the functioning of local water organisations, WTP and pump failures have been particularly relevant. Typical search words used have therefore been a combination of: *Tanzania, water, groundwater, hydrogeology, resilience, rural IAM, SDG 6, rural water supply, WTP, India mark II Exxtra-Deep Well* and *COWSO*.

To find useful articles and journals a combination of both systematic searches and chain searches has been applied. A systematic approach searches in databases based on specific words, while a chain search uses the sources in the reference list of the initial source to 'snowball' further.

The review of the selected research papers was based on several criteria:

- The content and its relevance for the thesis
- The year of publication, as it is usually preferred to have recent information
- Where it was published, whether it is a reputable organisation or a journal as it is important to rely on reputable sources
- The author, as the person writing the article or report has a specific background both in terms of geography and time
- Citations, as this is an indication of whether this is a source of information others trust and use in their work
  (Kaya, 2001)

A-state-of-the-art is then formed based on the available literature. In this case this was most relevant for hand pumps, which constitutes the main technical component of the thesis, as well as IAM for a rural setting. The latter is a new and largely unexplored field and the main article relied upon in this work is the briefing note produced by the IRC.

The next step is then to place oneself within the literature and depending on the nature of one's topic this may take on different forms. Seeing as the emphasis of this research is based on primary sources, the main aim has been to write an academic thesis alongside producing a report that is useful and accessible for the partner organisations. Furthermore, it is a goal to address the knowledge gap and expand on the limited, but very important, literature related to how to best manage assets to increase sustainability and resilience in a rural context in low-income countries.

After the fieldwork, it has however become clear that more literature is needed in relation to additional topics. An example of this is the challenges inherent in being researchers in an international setting. Additionally, collaboration with the partner organisations and others has also provided more and alternative works, including articles and reports. This has been particularly important for boreholes and their associated drill core reports, hand pumps and the parameters affecting the functioning of a COWSO. Though a literature study is part of a preparatory stage, and it has very much been so in this process, it is however not limited to the initial phases, as new information and findings come to light and need to be contextualised in relation to the literature.

4.4 Case study

After the preliminary work, which largely relied on secondary literature was conducted, the field work was carried out. In a case study, a study object or a collection of a few study objects are investigated based on several data sources (Olsson, 2011). The purpose is to provide insight and understanding, and a combination of quantitative and qualitative data is often used. It is important to bear in mind that case studies are not meant to be representative and generalised as no two situations or cases will be identical – they will be affected by both time and location (ibid).

According to Yin the need for a case study arises when “an empirical inquiry must examine a contemporary phenomenon in its real-life context” and especially when “the boundaries between phenomenon and context are not clearly evident” (1981, p.98). He illustrates this by pointing out how some research is based on an experiment in a laboratory, and though this is an important part of the scientific method, it is not a useful approach to other types of research. Investigating the factors which can improve the resilience of rural water supply and what is needed for improved management of infrastructural and non-infrastructural assets can arguably only be done through the use of a case study.

A case study can be understood as an overaching method in which other more direct methods such as interviews and surveys take place, as illustrated by Figure 4.1.

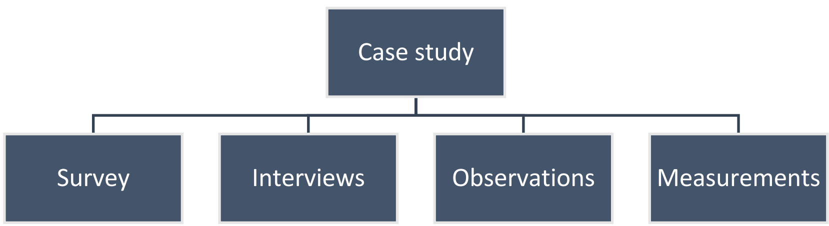


Figure 4.1: The case study method can be seen as an overarching method for survey, interviews, observations and measurements.

The case study at hand is centered around the fieldwork that took place in the area surrounding Haydom, Tanzania between 20.01.19 to 10.03.19. However, the use of documents and existing literature conducted beforehand is also a part of the case study and overall analysis. One could have for example done a case study using the same area and research question based purely on secondary literature – much like what was done in the project thesis. This does however contain several restrictions and is not likely to be as useful, but a case study is not limited to the fieldwork conducted.

The logging can also be seen to be part of the case study. Its purpose is twofold as it is used both to store information on the undertaken activities in an orderly manner and monitoring the progress of the project, as well as providing a tool for processing impressions and challenges experienced. A log can be very useful when one returns home and the memory of the experience and the order of events starts to fade somewhat when writing the thesis. However, as Punch point out many "methodological and ethical accounts of fieldwork become sanitised and smoothed over particularly because they tend to be written several months after the fieldwork has taken place" (2012, p.86). She therefore argues that what she calls a 'field diary' can be essential as the work written as a result of the fieldwork can often lose its immediacy and emotional impact, and this often represents an important aspect of the project (ibid). Being engaged in a case study that mainly takes the form of fieldwork will be impacted by, and also impact the researcher(s) – this should therefore to a certain extent be included in the final product.

4.5 Interviews with key stakeholders

A more direct method of gathering information that was used, were interviews with key stakeholders. Several interviews were conducted while in Tanzania. They can mainly be divided into two main groups: individual interviews and group interviews. The questions were prepared before leaving Norway based on the project thesis and the proposed research questions. The questions were discussed with Manfred Arlt (NCA) and Sveinung Sægrov (NTNU), and later with 4CCP staff in Tanzania, but respondents were to our knowledge not informed about the nature of the interviews beforehand. Seeing as we were two people conducting interviews together, one was in charge of asking the questions while the other took notes. When conducting group interviews in the villages it was deemed slightly problematic to bring our laptops with us, hence handwritten notes were taken and later transcribed. A recording device was also used for several interviews, after explicitly asking for consent. See Appendix 2-6 for the interview questions.

<u>Individual interviews:</u>
The individual interviews were aimed mainly to gather specific information on a given topic. Three different district engineers were interviewed; the one in Mkalama, the one for rural parts of Mbulu and the district engineer for Mbulu town. The questions posed were technical and focused on the overarching challenges they identified. One interview was held with two local water technicians in Haydom and the focus was on the reasons for pump failure for the hand pumps and their experiences and recommendations for improved O&M.

Furthermore, a dentist and an orthopedician at HLH were interviewed, mainly in relation to fluoride levels in the water. A paediatrician was also interviewed regarding water-related diseases such as cholera, typhoid, malaria, and any potential changes in health following the development of improved sources.

Additionally, an official interview with Manfred Arlt (NCA) about the WASH-programme, stated goals, future work and major challenges, was conducted. A similar interview was also carried out with Gwen Berge, the country director for NCA Tanzania, though this was more focused on NCA's work in Tanzania in general and the main challenges beyond the WASH sector. One individual interview was also done in relation to climate change with Yona Assecheck, an older politician from a village close to Haydom, though the questions for this interview was prepared while in Tanzania.

Group interviews:
The data for the functioning of COWSOs was collected through group interviews where a list of questions, mainly regarding the current water situation, the COWSO's function, challenges and future plans, as well routines for operation and maintenance, were posed (see Appendix 2). Eleven in-depth interviews were conducted, in addition to nine more informal meetings and conversations with COWSO members when visiting villages as part of NCA's monitoring of TCP.

The COWSO interviews were designed to not be a survey, but to open up for a conversation and allow flexibility for a specific situation. The questions were updated once during the stay, partly because it became apparent that it was an advantage to have comparable data and it was therefore sought to answer all the same questions in all the villages. The COWSO members were often present alongside other villagers and also, in many cases, the village leaders and the local Public Expenditure Tracking System (PETS) committee. The PETS committee is an anti-corruption committee, normally established alongside the COWSO. In almost all the interviews men talked the most and it was normal for two or three individuals to answer the majority of the questions. The number of people present varied from just six people to over thirty, which obviously impacted the dynamic within the group and the interview itself. Several of the COWSOs that were interviewed had not yet received a pump, as this would happen in the final stages of the TCP which is being finalised this year. In some cases, it was not quite clear whether a hand pump or a solar powered pump was to be installed.

Questions for focus development groups (FDGs) were also planned and prepared, which were scheduled to be smaller groups based on age or gender. The questions for the FDGs were intended to initiate a dialogue and be even more explorative. The questions were divided into two parts – one to map out the current situation and its challenges, and one to explore ideas for the future and possible improvements. Because villagers also participated in the COWSO meetings the FDG questions often became somewhat superfluous and repetitive, and were therefore not used extensively. In total four FDG sessions were conducted after a COWSO interview, but this was then mainly focused on the 'brainstorming' part of the questions. This did however present a nice opportunity to have a more intimate conversation. It should perhaps have been used more extensively as it allowed members of the community who were not very outspoken in the larger group setting to share their opinions and experiences – often particularly relevant for women.

4.6 Participating observation

Participating observation was also used as a method to gather information and perhaps most importantly to attain a better understanding of the situation and what was to us unknown dynamics. According to Olsson, participating observation can be challenging because the roles may be mixed together, particularly if conducted in one own's workplace (2011, p.42). This was not of great concern to us as we were always outsiders, but we were at times less directly active in our research. From the 05.02.19-11.02.19 Manfred Arlt (Global WASH Advisor NCA) and Zachayo Makobero (WASH TCP Officer NCA Tanzania) came to Haydom as part of the monitoring work done by NCA for the TCP. We got to travel around with them alongside Nelson Faustini (Senior Programme Officer 4CCP) to several of the villages involved in the WASH programme. This was a very rewarding and interesting experience. It was useful to see what type of questions were emphasised by those with extensive experience from the WASH field and how NCA and 4CCP actively tries to engage and mobilise the local communities – a balancing act of creating incentives and providing motivation, but also setting forward clear demands and requirements. Additionally, when we travelled to conduct interviews and surveys with our translators and guides, we learned a lot about local life, customs and ways of interacting, as well as information regarding the work done by 4CCP in the villages. We also discussed experiences with each other and other people at the HLH throughout and sought to ask many questions instead of assuming that we understood the 'hows and whys' of a situation. Though much of this was not part of a direct process of gathering relevant information and quantifiable in terms of analysis it provided an important source of insight and understanding.

4.7 Direct observation/measurements

Direct observations and measurements were also carried out. Direct measurements are a source of quantitative data, but as discussed above the results will be affected by both the reliability and validity. The direct measurements constituted both pH testing and fluoride testing. This was done to assess the quality of the water, both in relation to its safety for human consumption and possible damaging effects it could have on the pump system.

During the fieldwork 11 pH tests were conducted using pH paper manufactured by MColorpHast, see Figure 4.2. To use this test, one dips the indicator paper in the water sample until the reactive part of the paper is saturated. The strip is then compared by the colour change with the set colours for specific pH-values. This is a quick and simple solution, suited for tests in field. The major drawback with this type test is that one can only measure pH in approximate and whole numbers, in other words one cannot obtain decimal values, though it is possible to identify a sample as lying between two values.

Figure 4.2: pH testing in field showing a pH value of approximately 7.

During the fieldwork nine fluoride tests were conducted using Paline tests, which is a photometer reagent test. This kit was brought to us by Manfred Arlt and it was therefore not available for the first couple of weeks. To check the fluoride level, one dissolves two different types of tablets into a measuring tube, which creates a colour-changing solution. The next step is to compare the colour of the solution to a colour wheel where the different shades of red and/or orange represent different concentrations. The colour change is observed through two holes, where a control tube is in one of the holes and the sample is in the other, to adjust for any turbidity. What typical samples look like can be seen in Figure 4.3. If the concentration is too high for the colour wheel (it measures a maximum of 1.5 mg/l for a standard solution), one can dilute the sample and again use the two tablets to compare in the colour wheel. Initially, we lacked distilled water to properly dilute some of the samples that were above the threshold given by the WHO (1,5 mg/l), and therefore did not have the exact measurement for four of the nine samples. This is therefore something that could have been better prepared and planned but presents an opportunity for future work.

Figure 4.3: Samples from two different locations, where the saturation of red indicates the concentration of fluoride in the water sample.

4.8 Surveys

Finally, surveys represented a large part of the work conducted and were used for collecting data for WTP analysis. Figure 4.4 shows a classification framework for methods to measure WTP. One method to collect data on WTP for improved water is using stated preferences. The other method is using revealed preferences, which looks more into averting end preventive behaviours. For revealed preferences, few studies have been done on WTP in the developing world, hence, there is lack of historical information. Compared to stated preferences, revealed preferences do not give estimates of total WTP as the method does not take into consideration subcomponents like health benefits etc. (Van Houtven et al., 2017).

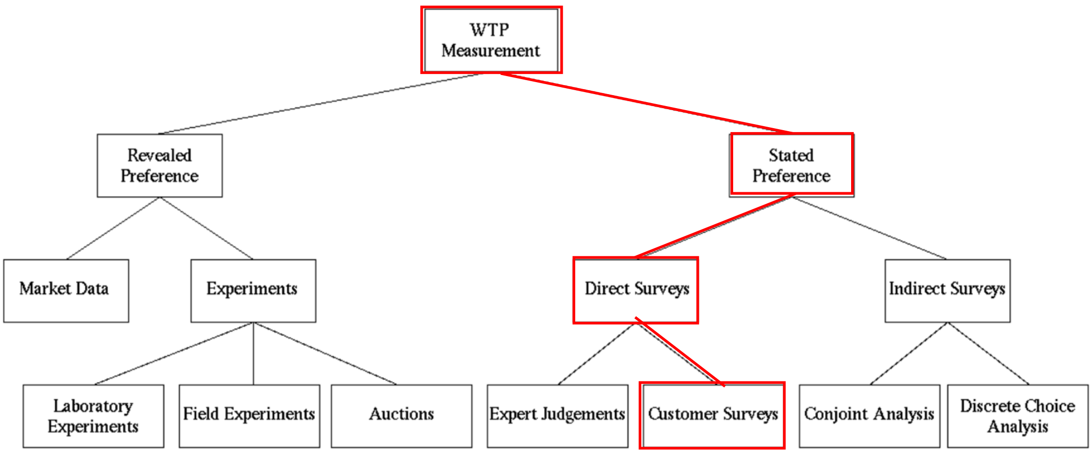


Figure 4.4: Classification framework to measure WTP (Breidert et al., 2006). The red line indicates the chosen method.

In this thesis the chosen method for WTP data collection was a direct customer survey. In direct surveys the respondents, in this case customers, are asked to state their WTP for some product/service (Breidert et al., 2006). The advantage of using a direct survey in a field setting is that the respondents are aware of participating. When estimating WTP, it is important to include a diverse group of respondents in terms of gender, age, occupation and socioeconomic level to get the most valid estimates. Though this may also be a source of high variation it remains an imperative principle.

An important aspect when conducting a customer survey to map the WTP is how the questions are formulated. Stoetzel did a study where the idea was that there is a maximum and a minimum price customer are willing to pay, that can be elicited by directly asking the customer, which is referred to as a direct approach (1954, cited in Breidert et al., 2006). Another method often used is a sliding scale, where the researcher increases the price incrementally until the customer says stop. Originally the plan was to use a sliding scale approach, but due to having issues with translation while conducting the survey and time limitations, the direct approach was chosen. Instead of asking for the maximum and minimum price, the respondents were asked what they would 'like' to pay and what they would 'accept' to pay for their current service. Having to directly ask the respondents about their WTP for different improved services is considered to be less reliable (Balderjahn, 2003, cited in Breidert et al., 2006). This is because the respondent might be affected by the interviewer. However, direct surveys are cost and time effective and give individual level estimations. On the other hand, they are poor for validity of estimations and do not necessarily reflect real behaviour (Breidert et al., 2006). Regardless of the limitations of a direct survey, it remains a useful methodology and presented the only viable approach for this study.

A direct customer WTP survey was conducted for 107 individuals and the questionnaire can be seen in Appendix 7. The survey investigated WTP for five different scenarios, see chapter 10 (p. 95).The survey also sought to collect information regarding the current water situation including the amount consumed by the household, the source of water, who was responsible for collecting water, how long they spent, how much water was collected each trip and how long did they have to wait at the water point. Furthermore, data on the respondent's age, gender, income and the number of people in the household was also gathered for analytical purposes – though the survey was anonymous.

Three main limitations with the method used for the WTP survey were encountered. The first limitation was that the respondents were not directly anonymous. As they were interviewed face to face, they might have responded according to what they thought was expected or wanted. The reason, however, for doing face to face surveys was due to some illiteracy and the importance of the respondents properly understanding the questions. The second limitation was the use of a translator, which was sometimes limiting due to varying English knowledge among the translators. Translation errors might therefore have occurred. For example, WTP levels above 1000 TSH per bucket are excluded as it most likely is a translation error, where the respondent has perceived the question as what they are willing to pay for a repair or a one-time investment. The last limitation is that 44% of the respondents were in the 40-50 years age-group, which is not entirely representative. A better distribution in terms of age would therefore have been an advantage.

4.9 Limitations

A challenge and limitation with this type of work has been a lack of data. There appears to be less available data on for example climate and hydrogeology, at least in standardised forms. We have also come across incorrect data, particularly related to boreholes and ground conditions. This is in the best case not usable and in the worst case misleading and detrimental to an analysis.

Another challenge which was experienced was translation and the associated language barrier. It is always challenging to have information translated because of nuances lost and that it by definition requires extensive knowledge of several languages. The very act of translation is according to one scholar "both political and highly subjective", and goes beyond semantic issues, to include questions of hegemony and exclusion (Müller, 2007, p.206). The team at 4CCP did a good job at translating, but we could perhaps have been better at attempting to clarify when something did not make sense. Translation may lead to misunderstandings, which is something that should be accounted for. When issues related to the technical components of a pump were being discussed for example, translating proved challenging seeing as this involved terms that are very specific and not widely known. In addition to the language itself a cultural translation is also needed in many cases. Sometimes specific dynamics and reasoning for actions can be difficult to understand, particularly when one encounters cultural differences. Translation also takes a lot of time, which slowed down some of the work. It also makes the process of interviewing someone less flexible and spontaneous.

Another challenge, or at least something to be aware of, is the sum of identities we carry with us as researchers and how this may impact the process. Being young, female, Caucasian, engaged in academic education and even being from Norway in an area with such a strong Norwegian presence, are all factors that affect the dynamic when we conducted an interview or a survey.

As Sultana points out, when a researcher from the Global North conducts research in the Global South one must be even more aware of issues such as literacy, access, and a sense of equality (Sultana, 2007). She argues that when one conducts fieldwork in an international setting one must be "attentive to histories of colonialism, development, globalization and local realities, to avoid exploitative research or perpetuation of relations of domination and control" (ibid, p.374). It is therefore very important that ethical concerns are an integrated part of the entire process of the research. This applies to "conceptualization to dissemination, and that researchers are especially mindful of negotiated ethics in the field" (ibid). Though this was something we tried to be vary of and mitigate to the extent possible, it was at times perhaps detectable. For example, in one survey, a woman finished her answers by asking us if she had responded correctly to the questions posed – illustrating how it was important for her to give the answers she thought were expected, rather than her opinions and experiences.

Another more general issue was that of having a representative population. As mentioned earlier there was quite an even distribution of women and men both in the surveys and interviews, though in the group interviews the women tended to be very quiet. Additionlly, seeing as the groups that were interviewed were mainly COWSO members and active members of the community who showed up to the meetings arranged by 4CCP, we therefore believe that we did not necessarily get into contact with more marginalised groups.

Furthermore, measuring errors are always a potential limitation and as mentioned the fluoride tests were not optimal in terms of the total number of samples and the detail level. Seeing as the test is based on a colour reactive solution which is compared to standardised colours for concentrations, it is based largely on a subjective assessment, thus open to human interpretation and potential errors. We do however believe that the tests conducted give an indication of the situation. The same is somewhat true for the testing of the pH value, but once again the exact level was not as relevant as the only requirement was a pH-value between 6,5-9.

Another obvious limitation is the limited sample size both in terms of the number of villages visited and how many people were present. If one is to draw general conclusions this might be insufficient. Seeing as this is a case study there are scaling issues, as it is impossible to identify one universal finding. It is therefore not clear to what extent the findings and conclusions drawn from this limited research carried out in a specific area of northern Tanzania is transferable to the rest of the country and similar rural settings in SSA in general. This should however not be read as a way of downplaying our work and findings, but rather as a call for and encouragement to conduct further research.

5 Physical conditions – results and discussion

This chapter discusses the physical conditions that influence the possibilities to abstract groundwater of sufficient quantity and quality and will address the research question:

> *How do the nature-based conditions (geology, hydrogeology and climate) affect the possibility of groundwater abstraction?*

The first half will discuss the hydrogeology, groundwater recharge, local geology and groundwater table. The second half will address the effects of climate change. Each section will present the background, results and discussion, before an overall conclusion assessing the implications for resilience

5.1 Hydrogeology

5.1.1 Background – hydrogeology and ground conditions

As hydrogeology is the combination of hydrology and geology, it is defined as "the study of the occurrence, movement and chemistry of groundwater in its geological environment" (Nonner and Nonner, 2002). Geology, hydrology and hydrogeology is essential to study and analyse when planning and implementing a system for groundwater abstraction. They are important factors affecting the quality and the quantity of the groundwater, in addition to its availability and depth to the groundwater table. Knowledge about the hydrogeology of an area is needed when planning the pump system and getting up to date information during the lifespan of the system will form a basis for decision making needed to manage the source in a more sustainable way. Information about the ground conditions lay the foundation for effective IAM and increased resilience.

Water occurs in two principal zones beneath the land surface, the unsaturated and saturated zone, as seen in Figure 5.1 (USGS, n.a.). In the unsaturated zone both air and water occur within the pores and fractures, while in the saturated zone all pores and fractures are filled with water. Abstraction from a borehole should always occur within the saturated zone to assure sufficient quantity and reduce the chance of the well drying out. Another reason for abstracting in the saturated zone is that the capillary forces in the unsaturated zone are relatively strong, making it harder to pump out a considerable amount of water (ibid).

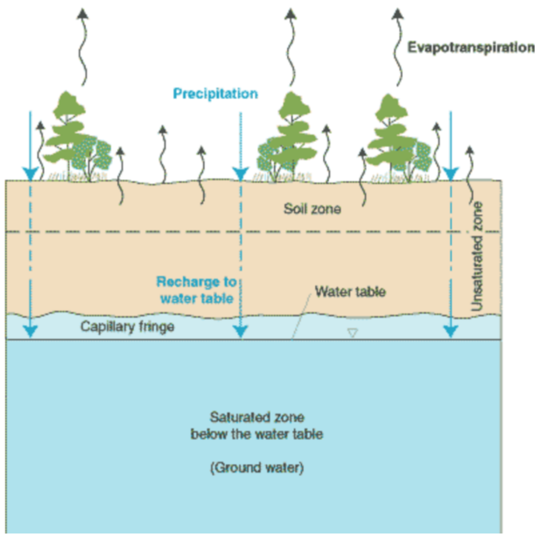


Figure 5.1 Build-up of the zones below the land surface (USGS, n.a.).

An aquifer is a geological composition which is porous and permeable (Raghav, n.a.). In order to define a geological feature as an aquifer it must store and transmit groundwater, as well as having a sufficient yield for wells and springs. The four main types of aquifers that exist are unconfined, perched, confined and leaky aquifers. Figure 5.2 shows the difference between a confined and an unconfined aquifer, in addition to a perched aquifer.

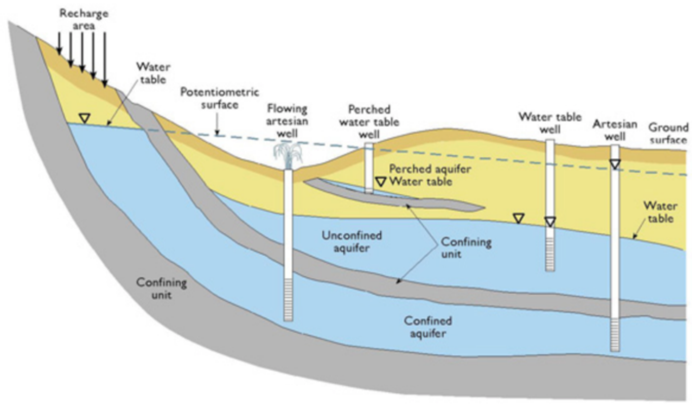


Figure 5.2: Confined, unconfined and perched aquifer (Topper et al., 2003).

An unconfined aquifer is not overlain by any type of confining layer (impermeable layer), but it has a confined layer at its bottom (ibid). The upper layer of the aquifer is the groundwater table, which means that the groundwater within the aquifer is in contact with the atmosphere. Fluctuations of the groundwater table occurs according to changes in groundwater storage, hence groundwater from such an aquifer can be sensitive to climate changes. Perched aquifers are a special case of unconfined aquifers, where an impermeable layer (or relatively impermeable layer) forms a lens, so that it creates an aquifer of limited extent, above the general groundwater table (ibid). If a well abstracts water from a perched aquifer, water is only available in small quantities for a relatively limited period of time. The limited extent and the vulnerability to climatic changes, makes perched aquifers a less resilient and sustainable source.

A confined aquifer is better protected against climate change and pollutions such as pathogens and human waste. This is due to it having confining layers both over and under the aquifer. Because of this, there is often high pressure within the aquifer. Water from such a well might therefore arise to the surface without pumping, if the piezometric surface is at the same level or above the surface level, as can be seen as flowing artesian well in Figure 5.2. Lastly, leaky aquifers are aquifers that are underlain and overlain by a semi-pervious layer which allows for vertical leakages if a head difference exist (ibid). However, this is a rare type of aquifer.

As the two most likely types of aquifers that abstraction occurs from in rural Tanzania are either confined or unconfined, the focus will be on these two types of aquifers. The most resilient aquifer to pump from in terms of pollutants and vulnerability to climate changes, is a confined aquifer. However, it usually requires a deeper well than an unconfined one. This can cause an increased pressure on the pump, which may result in pump failures. Knowing the type of aquifer one is abstracting from, is important for its proper management.

The main source of groundwater recharge is precipitation, in any form, that does not evaporate or runoff directly into a stream, river, lake or pond (Topper et al., 2003). Precipitation that percolates into the ground, may eventually reach the groundwater table. Different types of boundary conditions will affect the recharge properties of the aquifer (Parkin, 2018). The main categories of boundary conditions are head boundary, flow boundary and no-flow boundary, which can be seen in Table 5.1.

Boundary	Types
Head boundary (perched and unconfined aquifers)	- Hydraulic connection between surface water features and aquifer - Surface topography
Flow boundary (all aquifer types)	- Recharge area - Multiple abstraction wells - Hydraulic conductivity
No-flow boundary / hydraulic boundary (all aquifer types)	- Base of aquifer, if impermeable - Adjacent bedrock, if impermeable, also known as fault - Divide of elevation (gradient of a point is moving in opposite directions) - Specific yield / storage capacity

Table 5.1 Boundary conditions and associated examples (Parkin, 2018).

Abstraction from a confined aquifer will not be affected by head boundaries due to the overlying aquitard, while for unconfined ones they play an essential role. That is because they reflect the water table, which will affect the pumping depth when abstracting from an unconfined aquifer. Flow boundaries describe the movement of water within and in and out of the aquifer (ibid). A recharge area denotes the area which receives water entering the aquifer, leading to groundwater recharge. It might be located far away from where an abstraction borehole is installed, which highlights the challenge and importance of mapping. Proper management of the aquifer requires a balance between recharge and abstraction, hence, abstraction rates from all boreholes abstracting from one aquifer is essential to map. Hydraulic conductivity refers to the relationship between the hydraulic gradient and the specific discharge, providing information about how the aquifer transmits water (ibid). This depends on properties of the porous medium and the soil type. All of the flow boundaries are relevant for all types of aquifers. No-flow boundaries are also known as hydraulic boundaries, occurring when the head gradient is zero (ibid). Variations to the depth of the aquifer are not necessarily reflected by the surface topography, especially for a confined aquifer. Storage capacity is described as specific yield for unconfined aquifers and storativity for confined ones (ibid). Specific yield refers to the quantity of water which can be removed freely per unit saturated volume of an unconfined aquifer per unit drop in water level (ibid). For a confined aquifer storativity is used, which is a function of saturated thickness and specific storage. It is defined as the quantity of water removed from a unit area of the confined aquifer per unit drop in hydraulic head (ibid). Information about either storativity or specific yield is useful to achieve improved management.

All boundaries require detailed mapping of the geological properties of the soil and basement rock to achieve an overview of the complex processes involved. To do this one must conduct geological surveys of large areas, which is a time-consuming process. Mapping the groundwater recharge in industrialised countries can typically be done with models of core samples, surface features and terrain models. This is a labour-intensive approach relying on the collection and handling of large amounts of data, where hydrogeologists need to use a number of different modelling tools such as Geographic Information Systems. This may pose too big of a challenge for a developing country such as Tanzania, especially in rural areas where resources are limited. Some data can however be collected in a simpler manner, such as conducting pump testing in field to find the recharge rate. This is something NCA and 4CCP require from their constructors drilling new boreholes. As there must be a balance between the abstraction rate and recharge rate, to avoid the well drying out, this is crucial information needed for the sustainability of the borehole. Knowing the recharge rate can help to avoid putting too much pressure on the aquifer, hence, also making the water supply more resilient. Another way of monitoring the sustainability of the borehole, is to frequently measure the groundwater level over time. If it drops significantly, one must implement remediating actions (ibid). Increased information about the boundary conditions makes it easier to manage the aquifer in a sustainable way as it provides a better basis for decision making.

Interfering wells is a concept where abstraction wells interfere due to them being closely spaced, resulting in an increased drawdown (Dunn, 2018), as illustrated in Figure 5.3. All abstraction wells produce drawdown during abstraction, and its width and depth depends on both geology and abstraction rate. If the drawdown of one well crosses with the drawdown of another well, the total drawdown will increase. In the case illustrated in Figure 5.3, the pump in the middle well must be lowered in order to adapt to the effects of the interfering wells.

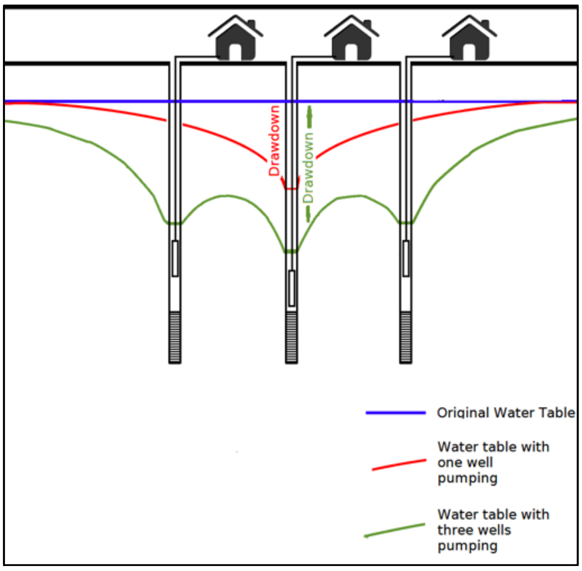


Figure 5.3 Drawdown with interfering wells (Dunn, 2018).

The amplitude of interference depends on the following factors, which increase the interference:

- Reduced spacing
- Increased abstraction rate
- Reduced permeability
  (Dunn, 2018)

Interfering wells do not only affect the total amount of water abstracted from the aquifer, they also impact the flow directions. However, interference of wells is a greater concern in urban, than in rural areas. As there are a limited number of wells in the study area and they are spaced far away from each other, currently interfering wells is not a pressing concern. Nevertheless, if one of the COWSOs want to expand their system by installing a new pump, the constructors need to have the concept of interfering wells in the back of their mind.

5.1.2 Results - local geology and groundwater table

The geological properties of an aquifer affect the sustainable abstraction rate as it directly influences the recharge rate. It is easier to both predict the volume of and abstract water from an aquifer consisting of porous media, such as limestone and sandstone, compared to an aquifer where water is within joints and fractures (Parkin, 2018). This is due to the fact that water can be captured within pockets in the aquifer, which impedes the movement of water. Furthermore, joints and fractures makes it even harder to quantify the specific yield/storativity of the aquifer as the water is not evenly distributed over the whole aquifer. Hence, abstracting from such aquifers is often less sustainable, as it is more difficult to manage the source properly. On the other hand, abstracting from deep confined aquifers contains advantages in terms of less pollution. Because the water has to pass through a lot of sediment and rocks, the water will be filtered, thus less polluted in terms of pathogens and other substances. Compared to surface water, it is most likely safer to consume, though it does depend on how the mineralogy of the sediments and rocks have affected the groundwater.

Mbulu and Mkalama lies within two geological formations, known as the Central Plateau and the so called Gregorian Rift Valley. These two formations have relatively different geology, and especially within the Gregorian Rift Valley there are large variations within a small geographic area (BGS, 2000). Areas with an altitude level between 1000-1500 m.asl in Tanzania, are situated within the geological region called the Central Plateau, which is composed of ancient crystalline basement rocks (ibid). Predominantly the Central Plateau is composed of faulted and fractured metamorphic rocks with some granites.

Within the study area, the Geological Survey of Tanzania (2019) has identified three main types of geology, which can be seen in Figure 5.4. The first type is sandy, gravely and silty sediments, which are predominantly alluvial and eluvial sediments. Alluvial means that the sediments are not cemented together, while eluvial means that they are in a more cemented formation. An increased fraction of sand and gravel will increase the permeability, while silt may form a consolidating layer. The next type of geology consists of granatoids, migmatite, mafic and ultramafics and meta-sediments (ibid). Granatoids are a coarse-grained igneous rock, while the rest of the sediments/rocks are non-porous rocks that are hard to fracture. The final type of rock commonly found are relatively small greenstone areas which are durable, but highly porous rocks (ibid). Overlying this heterogenous basement are diverse, metamorphosed sedimentary and extrusive volcanic rocks and weathering products of varying thickness (Key, 1992).

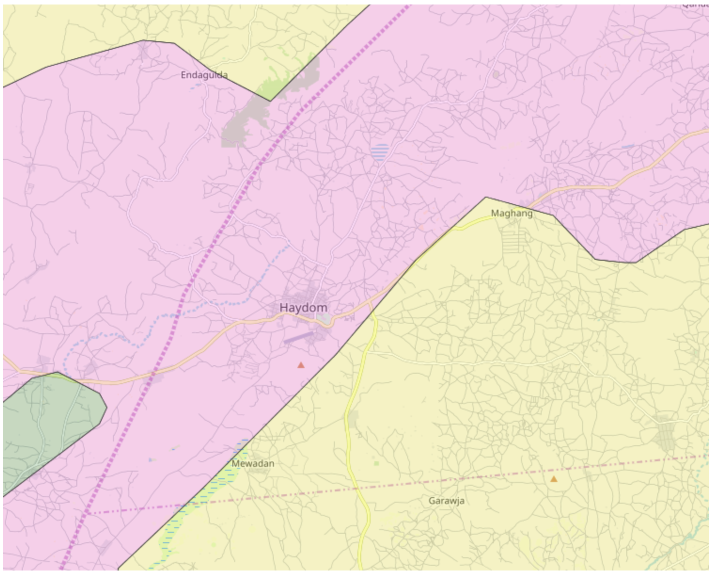


Figure 5.4 The basement rock in the study area. The pink colour symbolises the migmatite-granitoid-meta sediment complex, yellow is eluvial and alluvial sediments while green is the greenstone (Geological Survey of Tanzania, 2019).

Porosity and fracturing of the overlying rocks will affect the recharge of the aquifers. For both the greenstone and the eluvial and alluvial sediments water will be within the pores of the aquifer, while for the granatoide the amount of water available for abstraction has to be in fractures and joints.

The East African Rift System is a classic example of a continental rift system (BGS, 2000). The rift extends from Ethiopia southwards where it divides into the Eastern and the Western branch. The part of the study area that lies within the Rift Valley is a part of the Eastern branch, also recognised as the Gregory Rift (ibid). Volcanic and intrusive rocks, mainly with basaltic composition and some sodic alkaline rocks and ingenious carbonites, dominates the rift zone. This means that they are not porous and there are few fractures (ibid). Consequently, one needs to be lucky to find an aquifer that provides sufficient amounts of water for abstraction.

Figure 5.5 shows four lithographies from the study area where the two to the right are from the Rift Valley, while the other two are from the Central Plateau. One can observe differences between the two zones, but more significantly one can see that there are big local differences. The second borehole was dry during testing, which is due to the granite not being fractured. For the rest of the boreholes the abstraction occurs in confined fractured aquifers. Abstraction from joints and fractures might provide limited quantities, which explains why some of the boreholes experience low yields, while others have a high yield. Having an overview of the aquifer's recharge rate is essential to establish how much can be abstracted, hence what is sustainable as the well can dry out if it is over-abstracted (see textbox 5.1).

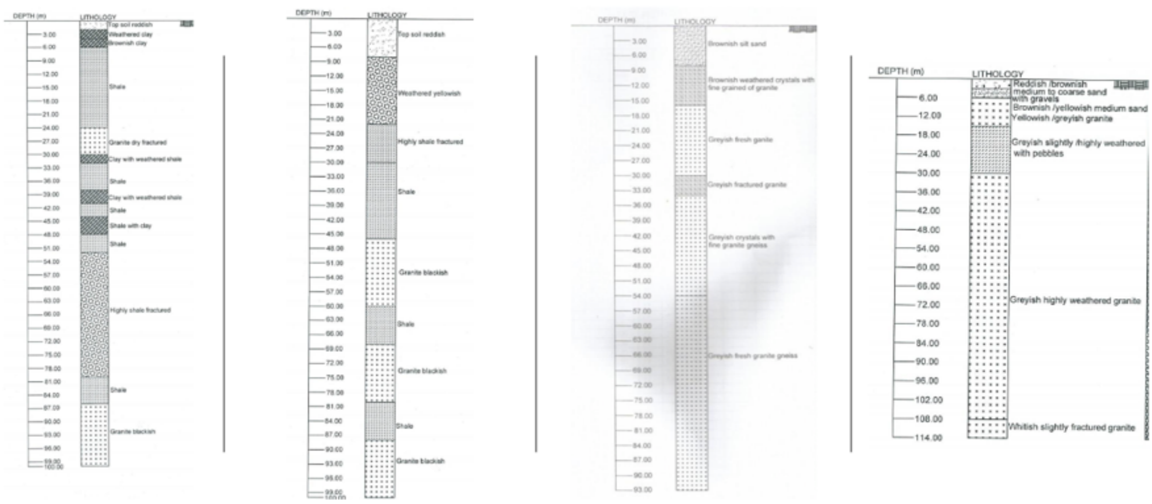


Figure 5.5 Lithography's from four different boreholes in the study area (provided by 4CCP).

TEXTBOX 5.1

Hayeda village has an India Mark II Extra-Deep Well, which was visited during the fieldwork in Tanzania. The village serves about four times the population compared to what the pump is designed for. Even though the consumption per person is low in the village, the amount of water abstracted was well over the yield of the borehole due to the high population. This results in the well regularly drying out, which in turns means that the aquifer is in risk of drying out completely. An effect of this was that the inhabitants had to wait in between pumping, in order to allow the water level to increase above pumping depth. This borehole is abstracting from fractures and joints in the basement rock, so the volume of water within the aquifer is therefore hard to map. If the recharge rate is as slow as it appears, in combination with other factors such as land use changes (e.g. deforestation) and climate change (changes in precipitation patterns and increase evapotranspiration), the well can dry out in the long run.

The groundwater table fluctuates both with season and from year to year as it is affected by climatic variations, precipitation and vegetation (Encyclopædia Britannica, 2016). The groundwater table might also be affected by withdrawals if one abstracts too much water from a well, or it might rise if one recharges the aquifer artificially. Hence, the groundwater table can increase or decrease by both natural factors and human influence. When installing an abstraction well the depth to the groundwater table must be determined, as it is an important design factor.

In the study area, the groundwater table is generally at a deep level, ranging from 40-250 meter below the ground (Kashaigili, 2010). Figure 5.6 shows a graph of the pumping depth for all 34 boreholes that 4CCP together with NCA have installed/rehabilitated in the study area. As one can see the pumping depth is deep, as indicated by the literature, with an average pumping depth is of 102 m. For the already existing hand pumps that 4CCP and NCA have been involved with, the average depth is 94m, where the deepest one is pumping from 162m. As the India Mark II Extra-Deep Well is designed for a pumping depth of maximum 80m, this is concerning and presents a major factor negatively affecting the residence and sustainability of the system. Pumping from such a great depth will cause a lot of internal pressure, which again may cause damage to vulnerable components within the cylinder and the rising main. Ultimately this will affect lifetime, O&M costs and eventually the resilience as the downtime might be increased, compared to if they were using a motorized pump designed for deeper abstraction levels.

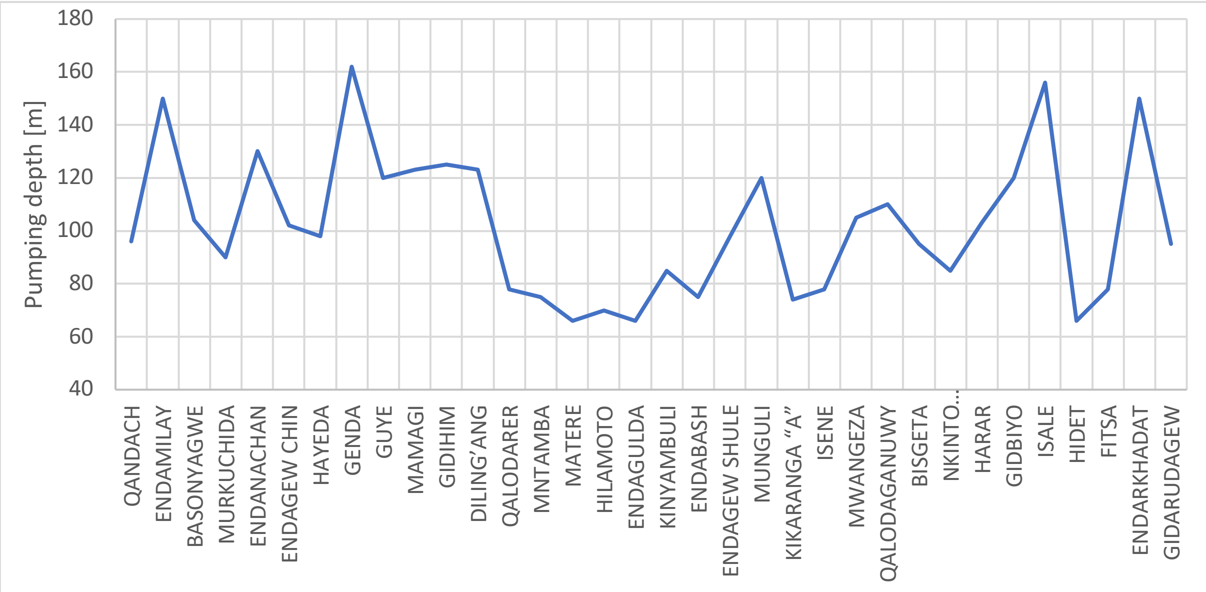


Figure 5.6 Pumping depth of the NCA/4CCP boreholes in the study area.

5.1.3 Discussion – data and monitoring

Changes in quality and quantity of the groundwater is a slow process as it is an almost inaccessible resource well concealed below the surface. Still, monitoring can indicate the aquifer's response to contaminant load and abstraction, which can improve its management. In an ideal world, one would be able to access information about water level, quality, abstraction rate, river flow gauging (if abstraction occurs from an unconfined aquifer), satellite land-use surveys and meteorological data (Tuinhof et al., 2006). Combining those data with baseline information such as pump tests, water well records, population growth, irrigation data and geological maps, will provide information which can be used for sustainable source management (ibid).

It is expensive and time-consuming to properly manage groundwater, hence, there must be a balance between the information access and the effort put into accessing it. Tuinhof et al. (2006) proposed that the key requirements to the system should be that the data is collected and stored properly for future use, induced by a specific objective and not just for the sake of collecting. For all situations, and especially for a rural low-income setting, one should design the monitoring system based on the possibilities of handling and analysing the data. It can be beneficial for improved IAM as an increasing database provides increased knowledge, thus creating a better basis for making decisions and developing strategies.

Monitoring is divided into two categories – direct and indirect monitoring (ibid). Direct monitoring is more expensive and difficult to sustain as it is done by meters, though this technology is quite rapidly becoming cheaper and more accessible. Indirect monitoring is less accurate, as it is done by collecting indicative data, for example looking at operating hours in relation to the pumping rate (ibid). One can further use remote sensing with satellite or airborne sensors or do estimations comparing demographic changes with water use per capita (ibid).

A direct monitoring system which for instance measures the depth to the groundwater table a couple of times per year, e.g. every June and October, would create a more resilient system. If one lacks information about the physical conditions it is hard, if not impossible, to properly manage the source. Therefore, the service provider should keep documents reflecting the ground conditions and the aquifer. This data should continuously be updated as more information is gathered on the conditions through monitoring.

5.2 Climate and climate change

5.2.1 Background – climate

The climate in the region varies a lot between four different seasons. From January to February there is a short dry season, followed by a long rainy season from March to May. This long wet season is dominated by high humidity, temperatures between 30-35 degrees Celcius and heavy downpours in the afternoon (Noel, n.a.). A long dry season where there is hardly any rain and the temperature is relatively low dominates the time between June to October. Lastly, from November to December there is a short wet season with lighter precipitation and higher temperatures compared to the long wet season.

5.2.2 Results – climate and climate change

The Central Plateau receives little rain, but is not completely dried up, also known as a semi-arid climate, commonly referred to as a savanna (BGS, 2000). Hydrology affects the groundwater recharge as the difference between precipitation and evapotranspiration, may result in recharge. For the Central Plateau the precipitation is approximately 550 mm/year. As can be seen from Figure 5.7, it is notably some of the lowest in Tanzania (ibid). A study done by Noel (n.a.) projected that due to climate change the average annual temperature on the Central Plateau will increase by approximately 4 degrees Celsius by 2075. This is above the global 1,5 degrees Celcius target found to have devastating effects, according to the IPCC (2018). Noel’s study also found that climate change will lead to a 5-15% decrease in annual rainfall, within the same time frame.

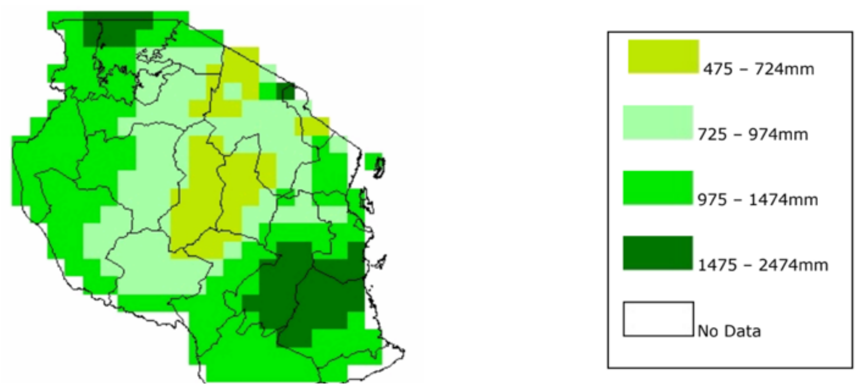


Figure 5.7 Distribution of precipitation in Tanzania (Noel, n.a.).

Kishaigili wrote a report in 2010 that referred to multiple studies done on climate change predictions. While the temperature increase was relatively similar for all the studies, there were large deviations in water flow projections and rainfall patterns. Nevertheless, Kishaigili stated that Tanzania as a whole has to plan and implement adaptation strategies for different future climate change scenarios. In the strategies it is recommended to include and consider ENSO (irregular periodic variations in winds and sea surface temperatures), land use change and population growth. If they address such aspects, the systems and the inhabitants could become more climate resilient.

Between 1991 and 2007, access to improved sources increased from 35-42% for the rural population of Tanzania (Noel, n.a.). These numbers are quite similar to what the district engineer of Mbulu reported during an interview, where he stated that in his district 41,8% of the rural population have access to an improved source. The main reason for the increase in access was due to groundwater extraction. However, for the rural population in 2009, 31,5% relied on surface water features (ibid). These ecosystem sources are unreliable as they are largely influenced by seasonal variability and climate change, not to mention the obvious quality issues. Furthermore, it was found that 50% of the all the improved sources were non-functional and that 25% had failed after only two years of operation (ibid). While several studies agree that one-third of the hand pumps in SSA are out of function at any given time, the number is thus even higher in Tanzania than in the SSA region. Another study by Jiménez and Pérez-Foguet (2011) conducted from 2006-2009 found that 50% of the investigated sources had quality and/or seasonal problems. Furthermore, they found that hand pumps had the worst track record in terms of sustainability.

When considering the impact of climate change it is however important to differentiate between weather and climate. The difference between weather and climate is time. Weather is the conditions of the atmosphere over a short period of time, while climates is how the atmosphere 'behaves' over a longer period of time, typically set to thirty years (NASA, 2005). During the fieldwork an interview was conducted with Yona Assecheck, a 74 years old politician and small-scale farmer, see textbox 5.2. He explained how the precipitation patterns have changed over the last decades. In his words, it previously used to

TEXTBOX 5.2

Due to climate change the summer of 2018 was extremely dry. Yona Assecheck, an old Datooga farmer, had 200 cattle which reflects his fortune. Due to the extremely dry season there was almost no water for the cattle to drink and there was very little food for the cows to eat. This resulted in 160 of the 200 cows passing away, as they were too thin to sell. This illustrates how vulnerable livelihoods are directly impacted by changes in the climate.

rain until the ground was saturated, but now the precipitation is very irregular and insufficient. Also, he had found that the precipitation now can be characterized as more intense and with heavier showers, compared to before. Lastly, his opinion was that the long wet season is reduced from November-May to now span from December-April. Additionally, he found that the temperature had gotten much higher, especially in the bottom parts of the Rift Valley. The temperature change and the change in precipitation has resulted in reduced amounts of water in the village's closest river. He explained that in the past they had to dig 5-6 feet deep traditional wells in the river bed during the dry season to access water. Now they have to dig 12-16 feet if they are to find any water. This is not necessarily due solely to changes in the climate but can also be impacted by local human activity, but higher temperatures and more irregular rain does not positively contribute.

In interviews done with villagers during the fieldwork they were asked about climate change. It might have been translation error, but it seemed like almost none of the villagers had heard about climate change. This was however also confirmed by Yona Assecheck, who only had learned about this due to his political career. When the villagers were asked if they had experienced a rise in temperature or changes in precipitation patterns, several respondents reported that this was something that was experienced. Based on interviews, it seemed like the consequences of climate change are more damaging in the Rift Valley, than on the Central Plateau.

5.2.3 Discussion – climate and climate change

Surface water cannot deliver sufficient quantities of water for domestic, agricultural and livestock purposes for the rural population in the study area. As climate changes is thought to result in a decrease in precipitation, alongside an increase in temperature, a higher relative evapotranspiration will be experienced in the future. This poses a great challenge for the people in the area. Increasing evapotranspiration results in decreasing groundwater recharge, as less water will percolate into the ground. Furthermore, it will also reduce the quantity of surface water, potentially leading to higher contaminant concentration in the remaining water. Climate change might partially explain why the groundwater level in the study area is so deep, hence also to some degree explain why the shallow wells are drying out. Other reasons for this can be over-abstraction, land use change and demographic changes.

In Noel´s (n.a.) opinion, further development of groundwater wells and implementation of rainwater harvesting structures, will improve the water supply system in rural areas of Tanzania, as they are more resilient water supply options. Key aquifers are in Noel's study anticipated to dry up, leading to deeper wells having to replace shallow wells, or the latter must be updated to abstract from deeper levels. Even though it is expensive to drill such wells, this presents the only available option for obtaining climate resilient systems (ibid). Furthermore, it is recommended to educate farmers and livestock holders about climate change and inform them of measures they can implement in order to adapt to the changes. Climate change is a fact and an ongoing process in the study area. Thus, implementing strategies to adapt to the changes is crucial when doing IAM intended to increase the resilience.

As most of the people living in the study area are dependent on livestock-keeping or farming, climate change poses a major challenge to their livelihoods. The reduction in precipitation can cause crops to fail and animals to die due to lack of water and food. When visiting Endagulda village in the Rift Valley it was perceived as a very dry area. The villagers in Endagulda explained during an interview, that the last four summers the crops had failed due to drought. This can be enormously damaging, even life threatening, to people depending solely on farming to survive. When extreme weather conditions continue to occur, it leads to an erosion of already vulnerable livelihoods. Improving and creating more flexible water management systems, that adapt to climate change, is needed for achieving SDG 2 (Zero hunger) and indirectly SDG 1 (No proverty) in rural agrarian societies.

5.3 Physical conditions - conclusion

The nature-based conditions create the foundations for a potentially resilient and sustainable system. Nature-based conditions are hard to alter so they must be managed in the best possible way. For example, the type of aquifer and its associated geology will have an impact on the water supply situation. Abstraction from fractures and joints can give a vulnerable supply of water as the quantity may be varying. Furthermore, climate change is something that should be accounted and prepared for when designing systems so that they will continue to function under changing conditions in the future. Systems and communities should develop their absorptive, adaptive and transformational capacity. Sufficient data is crucial for optimal management of water sources, but this is unfortunately often lacking in the area. This is particularly challenging seeing as there are large geological variations within the study area. Further mapping and collection of data is therefore important to properly manage water sources now and in the future, especially when considering population growth and future climate scenarios.

6 Water quality parameters – results and discussion

Following sub-chapters will discuss the quality of water, especially groundwater, to address part of the research question:

> *How can the current water situation be characterised, both in terms of quality and quantity of water?*

The chapter is structured with general background information first, then results and discussion on fluoride, followed by brief presentation of results and discussion related to salinity and pH. Lastly, a general conclusion assessing the quality on the water in the study area is presented.

6.1 Contamination of water

6.1.1 Groundwater pollution

As surface water is transported through the soil, the geology and its chemical composition will affect the content and quality of the water. Compared to surface water, groundwater has a far higher mineral content and it is less likely to contain pathogens (NGU, 2017). Accordingly, groundwater is usually considered a good option for drinking water supply for smaller towns, villages and isolated settlements (ibid). Groundwater however presents some challenges in relation to quality that should be addressed. It can become naturally contaminated as it passes by and is stored within its aquifer. Furthermore, it is very difficult to clean up aquifers contaminated by human activities (Earle, 2015).

When the groundwater percolates, it is in contact with the surrounding rocks or sediments. An aquifer consists of materials that are relatively inert (almost no biological or chemical activity) or made up of materials that dissolve very slowly into the water (ibid). The groundwater will however accumulate more dissolved material over time. Some rocks and sediments contain minerals that potentially can contaminate the water with elements that make it unsuitable for human or agricultural use.

Groundwater can also be contaminated by pollution from the surface, and there are several types of anthropogenic sources of contamination (ibid). Figure 6.1 shows how pollution from the land surface enters the aquifer and build up within it. The vulnerability to anthropogenic contamination depends on the depth to the groundwater table, permeability of the aquifer, slope of the surface and amount of precipitation (ibid). Generally, confined aquifers tend to be less prone to contamination, compared to unconfined ones. An increasing depth to groundwater table, steeper slopes and dry areas are also less vulnerable to pollutants. Examples of anthropogenic sources of contamination, relevant in the study area are:

- Chemicals and animal waste related to agriculture
- Landfills
- Leaking fuel storage tanks
- Septic systems

  (ibid)

Contaminants in the groundwater can be removed by manipulating the groundwater flow through extraction or injection of water at certain locations.

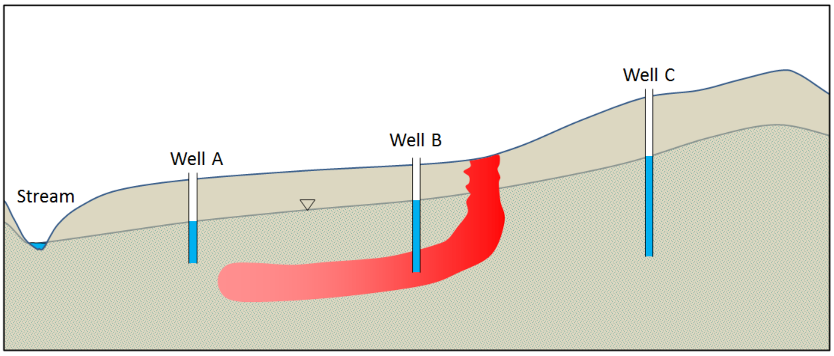


Figure 6.1: Spreading of a groundwater contaminant plume in red (Earle, 2015).

Several different quality parameters and associated thresholds have been put forward for water by various organizations. The Environmental Protection Agency in Ireland (2001) have over 100 different parameters, excluding pathogens. There are also different thresholds for what is accepted for human consumption and for environmental protection. Quality of groundwater is largely affected by the geology, if one does not consider the storage and transportation method. For the Rift Valley, main features are high alkalinity, sodium and fluoride concentrations (BGS, 2000). The water is also relatively soft and, in some places, quite saline. For the Central Plateau the main quality parameters concerns are "high alkalinity and relatively high sodium concentrations and with slightly acidic to highly alkaline pH values (6,1-9,1)" (ibid, p.2). Additionally, the water may have a high concentration of total dissolved solids. Furthermore, it has been measured extremely high levels of fluoride in Mbulu. On a more positive note there are no evidence of nitrate, iodide or arsenic in the groundwater.

6.1.2 Safety of water

For a water stressed country such as Tanzania it is even more imperative to protect and ensure the safety of productive water sources. In developing countries, unlike developed countries, contamination may occur at collection, transportation and while storing the water at home, thus potentially causing a major health risk for millions of households (Knight et al., 1992). A study done in Malaysia in 1992 showed that there was an increased risk of diarrhoea if water is not stored properly (ibid). Pots, buckets and other containers with wide openings used for collection and storage are easily contaminated by faeces, flies, cockroaches and rodents (Tumwine, 2005). In 2017, 3 of the 11 most common causes of mortality in Tanzania were water related (IHME, 2018). They were malaria, diarrheal diseases and malnutrition. Additionally, pneumonia is a common cause of mortality, which might occur due to legionella in the drinking water (ibid). Both stagnant surface water and open buckets attracts malaria mosquitos and other insects. The at-home risk can relatively easily be reduced, if one rather uses a can that can be properly closed instead of an open bucket to store the water. The can must however be cleaned regularly.

A study done in Zambia tested the effect of using household bleach to disinfect the water, as well as education on causes and prevention of diarrhoea (Quick et al., 2002). The study showed that it was difficult to convince people to use at-home bleach due to the unfamiliar taste. Additionally, bleach does not help with turbidity or chlorine resistant organisms such as Cyclospora cayetanensis and Cryptosporidium parvum (ibid). However, the study showed that the risk of diarrheal diseases was 48% lower for individuals using bleach than for the control group. WHO recommends boiling, chlorination and coagulation-flocculation to reduce the risk of diarrheal diseases (Tumwine, 2005). Boiling does however consume a lot of energy, as it requires 1 kg wood per litre water boiled. Other alternatives are adding drops of iodine into the water, using water purification tablets or solar disinfection by putting a transparent bottle of water in the sun for 2 hours (Water Wise, n.a.). One important aspect to take into consideration if using the the solar disinfection alternative is that the water needs to have low turbidity.

Research indicates that rainwater is safer to consume than water from an unimproved source (Ahmed et al., 2010). It is however highly recommended that the water should be treated in some way, at least boiled if it is to be used for direct consumption. Furthermore, it is important to clean the rainwater harvesting tank, the pipes and the roof collecting water regularly as bird faeces and other organic material can lead to pathogens polluting the water. Typical pathogens leading to forms of diarrheal diseases from rainwater harvesting are Salmonella, Campylobacter, Legionella, Giardia and Cryptosporidium (ibid).

6.2 Fluoride

6.2.1 Background – fluoride and fluorosis

Fluoride is used in dentistry to strengthen the enamel, which is the outer layer of the teeth, to prevent cavities (Frank, 2018). It is therefore important to be exposed to a certain level of fluoride, which is why some public water suppliers, for example in the United States, add a small amount of it into the drinking water, a process called fluoridation. However, a too high fluoride concentration in the drinking water can result in dental problems, and long-term exposure can lead to potentially severe skeletal damages, due to it being a cumulative toxin (ibid).

Fluorine is the most electronegative element in the periodic table, making it the most reactive, meaning that it has the highest oxidizing capacity (Johansen, 2013). This is also the reason for why it forms strong bonds in compounds. Due to its high reactivity, fluorine cannot be found free in nature (ibid). For the fluorine to achieve a stable state, it exists as a halogen known as fluoride (F^-). In this state it can form compounds, which is why fluoride can be found naturally in human teeth and bones. Fluoride can also be found in groundwater and because of its high oxidizing capacity, it readily takes the place of hydroxide (OH^-) ions. According to Johansen, "fluorine forms minerals with properties that, with the right environment, cause dramatic fluorine content in water" (ibid, p.5). Fluoride is mainly found in the minerals fluorite, fluorapatite and cryolite, see Table 6.1 (Jha et al., 2011).

Mineral	Chemistry	Characteristics
Fluorite	CaF_2	Found worldwide, colourful and associated with quartz, calcite, barite and dolomite
Fluorapatite	$Ca_5(PO_4)_3F$	Phosphate containing mineral. The fluorine is discarded
Cryolite	Na_3AlF_6	The least common of the three

Table 6.1: Minerals containing fluorine, which can release fluoride into the water (Jha et al., 2011).

A study done by Gerasimovsky and Savinova cited in Nanyaro et al. (1984), indicated that fluorapatite is the only fluorine-bearing mineral in the alkali rocks in the Rift Valley. There are multiple chemical factors that increase the ability of fluoride to dissolve in water. The first factor is that aluminium can form strong complexes with fluoride, and thereby reduce the level of free fluoride in the solution of water with lower pH values (Skjelkvale 1994, cited in Jha et al., 2011). An increased alkalinity will result in aluminium forming complexes with the OH^- groups, thus increasing the solved fluoride concentration. However, calcium (Ca) and magnesium (Mg) have the ability to inhibit solution of fluoride, but a study done in the Rift Valley show low concentrations of Ca and Mg, so this is not particularly relevant in the study area (Jha et al., 2011).

In addition to the F-containing minerals, another explanation of fluorine in groundwater is gas and steam ascending from magma chambers to the surface (Nanyaro et al., 1984). The gas and steam may dissolve in the groundwater, hence increasing the F^- concentration in the water. This might also be a reason for why there are large variations of F^- concentration in the areas in and around the Rift Valley (ibid). Some F^- might be trapped in pockets increasing the concentration in certain locations, especially as the groundwater in this area exists in fractures in the rock.

Dental fluorosis occurs when one consumes a too high level of fluoride while the teeth are still forming under the gums (Frank, 2018). It results in an increased porosity of the enamel, due to a decrease of calcium content in the teeth. The first symptom is white spots on the teeth, especially the front teeth (incisors) and the grinding surface of the first molar. Severe cases of dental fluorosis are visible as brown lines on the teeth, where the crystal structure of the tooth has collapsed. This may be perceived as 'dirty' or 'rotten' teeth, but it is not due to lack of dental hygiene. Even though dental fluorosis mainly causes cosmetic issues, it can in severe cases also lead to an increased risk of cavities due to a higher porosity of the teeth, making it more difficult to do proper dental care.

Skeletal fluorosis is similar to dental fluorosis and is a serious condition also resulting from a chronic ingestion of large amounts of fluoride over many years, particularly during periods of bone modelling and/or remodelling (Zohoori and Duckworth, 2017). The cumulative toxin can alter the creation and resorption of bone tissue (ibid). Fluorosis results in bones getting weaker and early symptoms are stiffness and joint pains. Impaired muscles and thickened bones in the central skeleton due to periosteal sleeves of abnormally structured osseous tissue (osteophytosis), mineralization of tendons and muscle attachments, and bridging between the edges or the vertebral bodies are symptoms in severe cases (ibid). Additionally, deformities for the weight-bearing bones are characteristically evident in severe cases.

Some studies done on fluoridated water have suggested a variety of other health problems. Examples of these are; low IQ scores in children, bone cancer, arthritis and kidney disease. However, there are also studies which have found no correlation between these health problems and an elevated level of fluoride (ibid). Table 6.2 shows levels of fluoride and their effects on the body.

Fluoride concentration (mg/L)	Effects
<0,5	Increased caries
3-6	Risk of moderate adverse effects, like severe dental fluorosis
6-10	Severe adverse effects such as skeletal fluorosis
>10	Increased risk of crippling skeletal fluorosis

Table 6.2: Effects of different levels of fluoride in drinking water (Jha et al., 2011).

6.2.2 Results – fluoride testing in Mbulu and Mkalama

In Mbulu the fluoride concentration is measured to be up to 99 mg/L, which is actually the highest measurement done in the world (BGS, 2000). This is concerning as the WHO has recommended an upper limit value of 1,5 mg/L (WHO, 2004). The maximum limit of fluoride sat by the Government of Tanzania is however 8 mg/L (Ghiglieri et al., 2010). During an interview with the district engineer in Mbulu fluoride was problematised. The district engineer reported that if the fluoride concentration is measured above the stated Tanzanian threshold, the well would be abandoned.

Some of the test results, as seen in Table 6.3, show only that the fluoride level exceeds 1,5 mg/L. The reason for this is the lack of distilled water during the first period of testing. However, for 7 of the 9 tests, the fluoride level exceeded the WHO threshold. Nevertheless, none of the samples which were measured with distilled water exceeded the threshold stated by the Tanzanian government.

Village	Fluoride mg/l
Haydom public supply	>1,5
Basouto	0,2
Getanyamba	1,4
Endanachan	>1,5
Endamilai	>1,5
Munguli	>1,5
Hospital (source)	1,6
Hospital (storage tank)	2,8
Getanyamba	1,6

Table 6.3: Fluoride tests conducted during field work for nine different locations. Some of the results only show that the concentration exceeds 1,5 mg/l.

Even though there were no measurements which indicated an extremely high level of fluoride, dental fluorosis is visible in the study area.Table 6.4 shows an overview of classification of dental fluorosis and Figure 6.2 to Figure 6.4 shows examples of patients visiting the dental clinic at HLH.

Classification	Typical symptoms
Normal	Translucent, smooth enamel with a glossy appearance.
Questionable	Seen in endemic areas, borderline between normal and very mild
Very mild	Small opaque, paper-white areas scattered irregularly over the labial and buccal surface of teeth.
Moderate	Entire tooth surface involved, minute pitting often present on labial and buccal surfaces, brown surface, brown stains, frequently disfiguring
Moderately severe	Entire tooth surface involved, marked pitting with intense brown stain
Severe	Widespread, deep brown or black areas, corrosion type of mottled enamel

Table 6.4: Classification of dental and skeletal fluorosis (Johansen, 2018).

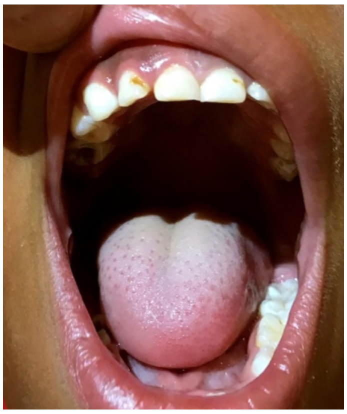


Figure 6.2: Moderate case of dental fluorosis at a 6 years old patient with milk tooth. Can be seen as brown spots on incisors and white surface on the first molar.

Figure 6.3: Moderate case of dental fluorosis at a 12 years old patient. The fluorosis can be seen as a lot of white spots on the chewing surface of the first molar.

Figure 6.4: Severe case of dental fluorosis at a 14 years old patient. The fluorosis can be seen as brown lines on the incisors.

In rural Tanzania not much work regarding fluorosis is done at the dental clinics. An interview was conducted in May with the Norwegian dentist Kristian Trægde, who has a lot of experience from the dental clinic at HLH. They have recently started doing some treatment of patients with severe dental fluorosis. In severe cases possible treatments include applying a facet or a crown on the damaged tooth made of porcelain, or putting regular composite filling on the damaged parts of the tooth in less severe cases. The type of treatment depends on available materials and the severity of the fluorosis, but a goal will always be to preserve as much of the natural tooth as possible. At the dental clinic in HLH they however only do composite fillings. The lifetime of a filling, facet or crown depends on the use, size and dental hygiene. For a composite filling the maximum lifetime is 10-15 years. Still, the solutions to mitigate the results of dental fluorosis are thought to be a very costly solution and therefore not as viable for most people in the study area.

During an interview with the orthopaedic surgeon at HLH, skeletal fluorosis was discussed. The surgeon had not observed skeletal fluorosis while he had been working at the hospital but said that during his practice in Arusha, he had seen several cases of skeletal fluorosis.

6.2.3 Discussion – fluoride

Not enough tests were conducted to identify whether there is a correlation between location and elevated levels of fluoride in the drinking water. However, from looking at maps and the measurements, there is clearly an elevated level of fluoride, exceeding the WHO recommended 1,5 mg/L, along the edge of the Rift Valley. The measurements done further away from the Rift Valley had lower values. What is perhaps more interesting are the results from the hospital’s water supply system. Two tests were taken from the groundwater supply to the hospital, one at the storage tank facilities and one at the source intake. There was a higher level of fluoride in the storage tank than in the source intake. This might be explained by the fact that the intake of the pump is deeper than where the sample was collected. In other words, fluoride might have settled, resulting in the top level of the intake containing less fluoride than the bottom layer where the pump intake is. As fluoride in drinking water can be removed by sedimentation, this is a potential explanation.

For COWSOs struggling with a high level of fluoride, one approach to reduce the fluoride concentration could therefore be to install big tanks where the fluoride can settle before tapping and consuming the water. This is naturally only a possibility for solar powered pumps or other types of motorised pumps with storage tanks. However, these tanks must be cleaned regularly, and they need to be closed tanks in order to avoid problems with insects carrying waterborne diseases and other pathogens and organic material contaminating the water. For future work it might be interesting to look at how big these tanks should be, and how many are needed to accommodate for proper sedimentation. This may lead to a more sustainable supply as more boreholes can be used instead of abandoned, but the system must be designed in an efficient and resilient manner. It is also potentially cheaper to install sedimentation tanks rather than drilling a new borehole. An additional benefit is obviously also that the tank can provide a more resilient system in terms of backup solutions if there is a pump failure.

The reason for increasing the fluoride threshold in Tanzania is thought to be concerns that a lower limit would lead to further water stress as fewer sources are considered usable (Ghiglieri et al., 2010). However, looking at Table 6.2 (p.50) and the potential consequences of consuming water with such a high concentration is not good. One should aim to have a concentration at least under 3 mg/l to avoid major negative health effects. The nine samples taken were all below the 3 mg/l limit, so for the study area a lower threshold would not pose a challenge.

6.3 Salinity and pH - results and discussion

During COWSO interviews, respondents were asked about the quality of their groundwater. Some reported a slight salty taste. This is concerning as a too high salt intake is dangerous. On the other hand, a paper written by Alhameid and Al-Naeem (2013) pointed out that high salinity of groundwater may reduce the problems of corrosion as the salt forms a protective layer on metal components. Hence, from a pump management point of view, there is no correlation between high salinity and pump failure. A salty flavour can however be removed by boiling the water.

Technical data for India Mark II Pumps indicates that some pump system components corrode if the pH is less than 6.5 (SKAT and RWSN, 2007). There is however new research suggesting that if the pH is less than 7, the pump system should be made with stainless steel. The pH results can be seen in Table 6.5, showing that one of the places tested had a pH lower than 6.5. It is however important to note is that this result is from surface water, not groundwater. This is due to the village not having their pump construction installed yet. The actual pump failures related to corrosion will be discussed in chapter 8.2 (Results – pump failure, p. 70).

Village	pH
Haydom	7
Basouto	8
Endagew Chini	8
Endanachan	8
Endagulda	6
Hilamoto	7
Endamilai	7
Munguli	7
Hospital (source)	8
Hospital (tank)	7
Getanyamba	7

Table 6.5: pH measurements done at boreholes in different villages.

6.4 Water quality parameters - conclusion

From a quality perspective, the groundwater used in the study area represents a safe source, except for potentially elevated fluoride levels. The Tanzanian fluoride threshold should be reconsidered as it can allow for the use of wells with potentially damaging levels of fluoride. Further work focusing on how to mitigate this, for example by using sedimentation, is therefore recommended. Though the groundwater is seen to be free from organic contamination and pollution, the way it is transported and stored is important to ensure its safety. Water from rainwater harvesting is also an important source, however, it needs to be treated before consumption. The salinity and pH of the groundwater was through interviews, testing and the literature not found to present as big of a challenge as first hypothesised in terms of pump failures. However, recent research has indicated that the 6,5 pH-level might be too low to avoid corrosion in the India Mark II hand pump. Further work should therefore be carried out to assess how the water quality affects the failure rate of pumps, and thereby the resilience of the water supply systems.

7 Water situation and quantity of water

This chapter will discuss the current and future water supply situation in terms of quantity of water, to answer the latter part of the research question:

> *How can the current water situation be characterised, both in terms of quality and quantity of water?*

More specifically, the subchapters will address sources and impacts of water, the water supply situation, the distance to source and future water supply in the study area. For water quantity and distance to source, the results and discussions are presented alongside each other, followed by a discussion on the future water supply situation.

7.1 Background – sources and impacts of water

There are several different types of water sources that are being used within the study area. Improved sources include hand pumps (see Figure 7.1), solar powered pumps (see Figure 7.2), electrical grid pumps and diesel generator pumps. They all abstract groundwater, some from a shallow level but majority from a deep level. People living far away from a groundwater pump either use different forms of surface water or rainwater harvesting, alongside some people also using it alongside groundwater.

Figure 7.1: India Mark Extra-Deep Well.

Figure 7.2: Solar powered pump with storage tanks.

Relying on surface water is inadvisable as the source is greatly affected by seasonal variability and climate change, in addition to the obvious quality concerns. Rainwater harvesting (see Figure 7.3) is also affected by seasonal variabilities, but as long as the tank and roof are cleaned properly, and the tank is closed, it is a viable option for water supply/storage. Both rainwater harvesting and sources of surface water are easily accessed during the wet season, but during the dry season they will both dry out due to a lack of recharge.

Figure 7.3: Rainwater harvesting tank at a school in Mbulu.

Even though there are hand pumps and solar powered pumps that can pump from a deep level, the work load for the customers vary. The deeper the well, the heavier it is for the people to pump up water. This might result in women, children and elderly people struggling to pump. Furthermore, it may reduce how many litres people consume per day. Seeing as it takes longer to manually pump water than to turn a tap, hand pumps are found to increase the queues at the water points. Lastly, the advantage with a motorised pump versus a hand pump is that the motorised pumps in the study area have storage tanks which may be used as backup solutions if the pump fail.

UNICEF posted a press release in 2016 which stated that women and girls in Africa spend a 'whooping' 200 million hours every year on fetching water. They also highlighted how water collection unjustly affects women. In Malawi for example, women spend 54 minutes every day, while men only spend on average 6 minutes per day on water collection (ibid). The enormous number of hours spent on fetching water results in a great economic loss. If people, especially women, could use their time on formal labour instead of fetching water, families and societies' life could be changed drastically. When women work, they are found to invest up to 90% of their income back into their families and local communities, compared with men who only invest approximately 30-40% (IFC, 2013). This further highlights how water plays an important role in realising SDG 1 (No poverty) and SDG 5 (Gender equality), as discussed in chapter 1.4 (Access to safe water sources, p.4). Additionally, if the number of hours spent on fetching water is reduced and women have more time for income generating activities, the households may be able to pay more for safe water so that the tariffs cover O&M and repair costs, in addition to potential expansions of the water supply. This may become a virtuous cycle, crucial for long-term development. However, in a country with high rural population growth and limited work opportunities a direct causality between less time spent on water collection and economic growth cannot be guaranteed.

7.2 Results and discussion – water situation

7.2.1 Water supply

During an interview with the district engineer for rural Mbulu, it was reported that only 42% of the inhabitants in the area had access to an improved source. The goal set by the government is that 85% of the rural population should have access to safe water by July 2020 (URT, 2016). Lack of funding was identified as the main reason for why they are still far away from reaching the goal, and most likely will fall short of it.

The one-to-one surveys conducted with 107 respondents showed that the median number of litres per person per day (l/pd) used in the study area is 12,5 l, which is worryingly low. Figure 7.4 shows a hierarchy of water requirements developed by WHO (2011). WHO states that in emergency situations the minimum requirements is 15 l/pd, but for permanent living situations at least 20 l/pd is needed. The amount of water people use in the study area is less than the minimum, both for permanent and emergency situations. Increasing the water consumption is important for improved health, but as Tanzania already is a water stressed country and the population is growing rapidly, this might be difficult. The database, which can be seen in Appendix 8, contains information about the yield and number of people at all NCA and 4CCP boreholes. The average l/pd the pumps can serve (both hand pumps and solar pumps) if one assumes it operates for 12 hours per day is 33 l/pd. This is within acceptable limits, but is a theoretical and not attainable amount seeing as solar powered pumps usually abstract efficiently for nine hours per day and hand pumps are sub-optimal in terms of fully utilising the yield. What is more concerning is that 14 of the 34 boreholes serve less than 20 l/pd. Low yield, in combination with a high population poses stress on the pump, resulting in both a low consumption and deterioration of the physical infrastructure. It is thought that the low consumption in the study area is due to a combination of physical, financial and organisational limitations.

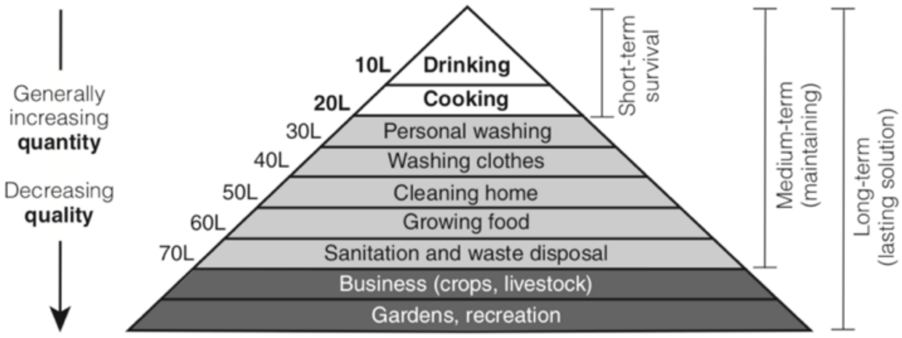


Figure 7.4: Hierarchy of water requirements after Maslow's hierarchy of needs (WHO, 2011).

During interviews with local villagers, respondents were asked about the effects of getting an improved source in their village. The respondents said that the positive effects were or were expected to be:

- Safe and clean water
- Reduction of distance (for most people), and thereby saving time
- Students can attend school
- Reduction in waterborne diseases
- Can use water for 'veggie gardens', hence it can result in economic growth
- Safe for children to collect, thus everyone can contribute to fetch water

The effects mentioned by the respondents were in alignment with what was described in chapter 1.4 (Access to safe water sources, p.4) and chapter 1.5 (Water, sustainability and the SDGs, p.5). The replies to the question about positive effects of improved water access describes well how SDG 6 concerning safe and clean water directly affects:

- SDG 2 - Zero hunger
- SDG 3 - Good health and wellbeing
- SDG 4 - Good quality education

Furthermore, it indirectly affects:

- SDG 1 - No poverty
- SDG 5 - Gender equality

When they were asked about potential negative effects of the water projects, almost no one responded that had experienced this. The only negative effect was that some people had to travel further than what they used to do when fetching from a nearby water feature. Additionally, there was one respondent who said that (s)he had contributed money for the pump, but that the pump was placed too far from his/her house, so that (s)he could not use the pump. Hence, (s)he felt misled into contributing to something that (s)he would not benefit from. Distance related problems can however be solved by expanding the network having multiple taps if the pump is a motorised one.

When asking about who is in charge of collecting water, the most predominant answer was mother and child(ren), see Figure 7.5. In 26,2% of the cases the mother alone was collecting water and in 18,7% of the cases child(ren) alone were responsible for water collection. Additionally, the mother partakes in fetching water in 62,6% of the cases and child(ren) are involved in collecting water in 57,9% of the cases. The fact that children have to help collect water is not ideal, as they should focus their time and efforts toward their education. Globally, girls rather than boys are the ones responsible for gathering water and help out with other chores in the house (Huie, 2016). This may result in them dropping out of school because the chores back home are too time consuming, or they go to school, but they are too tired to focus properly. A study in Tanzania showed that there was a 12% increase in school attendance when water was available within 15 minutes compared to more than half an hour away (ibid).

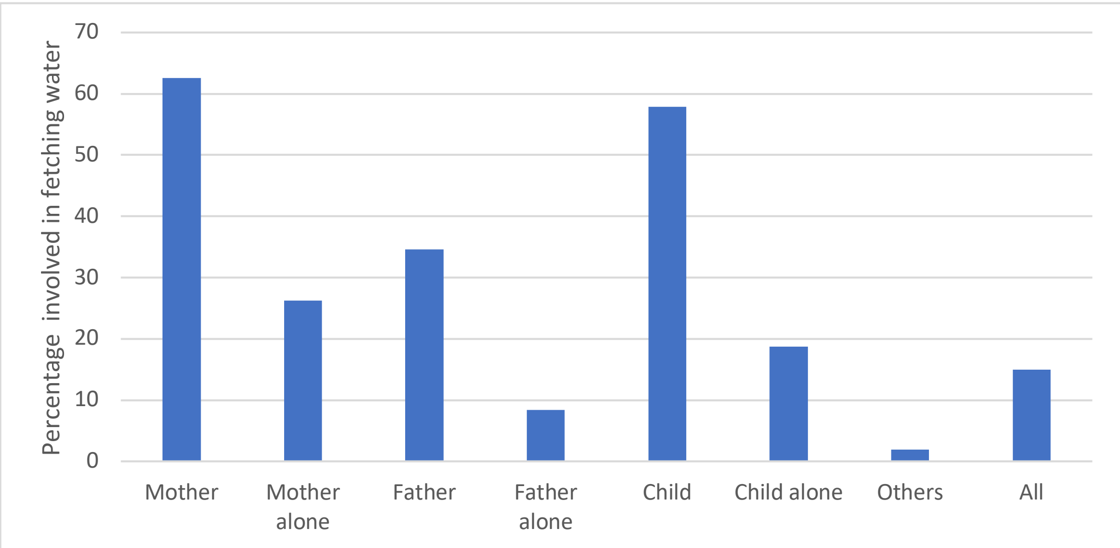


Figure 7.5: Who in the house are in charge of collecting water given in percentage.

During the interviews some challenges related to water supply were also highlighted. The respondents without an improved source said that there is a big seasonal variability in the availability of water. During the dry season, there might not be any water at all, which results in the villagers having to dig deep traditional wells in the dried out river beds or paying overpriced sums for surface water from private wells. Additionally, the poor quality of the surface water was discussed and linked to illnesses by the respondents. For the people using hand pumps the main challenges were reported to be long distances, overuse and long queues. Observations also identified lack of maintenance and backup solutions in case of pump failures, in addition to high failure rates, as a major challenge for hand pumps. When pump failures occur, the downtime is often long due to lacking funds and because of the time needed to acquire spare parts.

For some of the villages with motorised pumps, an insufficient yield in the borehole compared to the number of people served was mentioned as a problem The yield was barely enough to cover drinking water needs. For others with motorised pumps, the dry season could also be challenging as too many people relied on the pump, resulting in a lack of water. Lastly, several respondents highlighted the long distances. For the motorised pumps the technicians and district engineers that were interviewed, said that they do not have sufficient knowledge and experience when it comes to repairing solar powered pumps in particular, seeing as they are relatively new to the region. Lastly, for all types of pumps, the functionality of the COWSO highly affected the water supply in the villages, which is not surprising seeing as they are responsible for RWS. This will be analysed to a greater extent in chapter 9 (COWSO, p.76). Several of the challenges mentioned, highlighted the importance of analysing COWSOs, WTP and pump failures, as this affects the resilience and are important parts of IAM.

7.2.2 Distance to source

The surveys done in the study area, showed that on average each household spends 4,3 hours per day on fetching water. The median number was however 2,8 hours per day for the households. As an analysis approach using average, compared to median, is to a greater extent affected by extreme values. The average and median together show that some households use an extreme number of hours per day fetching water. Median income for a household is 550.000 TSH per year. If one assumes that they work 10 hours for 365 days per year their payment per hour is approximately 150 TSH or 0,07 USD. Hence, if a household only spent 30 minutes and not 2,8 hours per day, an average household could increase their yearly income by 126.500 TSH per year or 55 USD per year, which is equivalent to a 23% increase in income. There is no doubt that this could drastically change a lot of families' lives. On the other hand, as a result of the rapid population growth and large percentage of unemployment in the area, it might not be the case for all people as less time spent on water collection cannot necessarily be translated into higher earnings.

WHO (2011) show how distance affects the water consumption (see Figure 7.6). It is clear how a walking time that exceeds a couple of minutes drastically decreases the water consumption. An increase in return trip travel time from 2 to 5 minutes reduces the water consumption from 50 to just over 15 l/pd. After 5 minutes the curve flattens out and stays at a level slightly above 15 l/pd, the amount required by WHO for emergency situations. However, when the roundtrip time exceeds 30 minutes the consumption further drops before reaching a level just under 10 l/pd. This is far less than the amount required for sustainable livelihoods. The graph highlights how important it is to have a source close to home in order to keep consumption at a high enough level for safe and sanitary conditions.

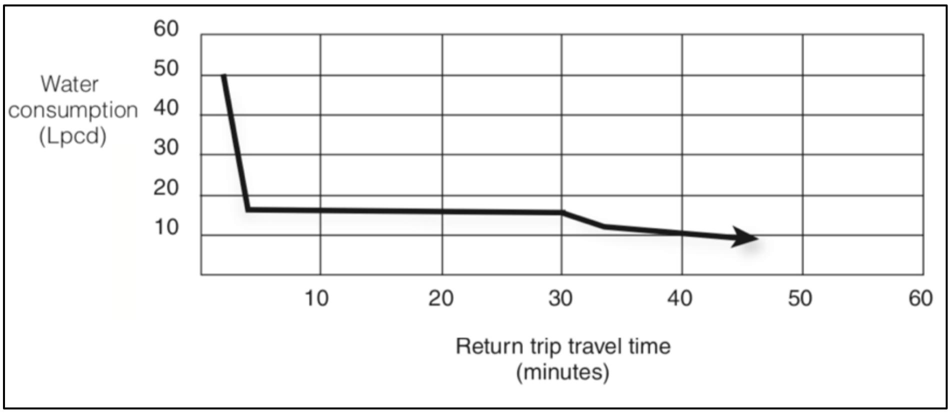


Figure 7.6: Consumption of water versus return trip travel time (WHO, 2011).

Among the 107 respondents, there were only 15 households or 12,7% of the respondents who used less than 30 minutes every day on collecting water, assuming that the respondents walk at a pace of 4 km/hour. As explained in chapter 1.4 (Access to safe water sources, p.4), drinking water from an improved source where the collection time is less than 30 minutes round trip included queuing, is considered basic access to water according to the JMP drinking water ladder. The surveys indicated that 61% of the respondents have access to safe water, but it also became clear that a lot of the improved sources remain far away from individual households. When asking the respondents about one-way distance to their water source it varied from 100m to 10 km, where the mean distance was 2,3 km. For the majority of households this long distance therefore implies that a lot of time will be spent walking, hence very few of the respondents fulfil the 30-minute basic service requirement.

In addition to registering distance to their source, the respondents were also asked about waiting time at the water point. Table 7.1 shows the waiting time in minutes, for both the wet and dry season. The season greatly affects the waiting time, in fact, the waiting time is more than 5 times longer in the dry season than in the wet season. Time of day will also affect the waiting time but having to queue in 40 degrees heat for more than 1 hour in the dry season is not healthy. Evaluating how one can queue in a more efficient way, organising what time of day people can fetch water or potential for regulation of the number of buckets people are allowed to collect, particularly during the dry season, would be a useful topic for further research.

WAITING TIME	DRY (MINUTES)	WET (MINUTES)
Min	0	0,0
Max	480	90
Mean	105,2	19,9
Median	60	10

Table 7.1: Waiting time for wet and dry season, given in minutes.

7.3 Discussion – future water supply

Having sufficient quantities of good quality water is crucial for human prosperity. The value of a water supply system exceeds the direct economic cost associated with specific components. From an IAM perspective, the other costs associated with asset failure, meaning the social, environmental and economic, have ripple effects on virtually all aspects of life. It is therefore essential for the community to have a resilient system.

Climate change and rapid population growth in rural Tanzania is concerning when it comes to water supply, as the consumption per person will decrease due to an increasing demand, in combination with reduction in quantity. Granter (n.a.) has suggested 19 ways to solve the freshwater crisis globally. They are listed below, and the ones considered the most important in rural Tanzania are highlighted with bold font:

- **Educate to change consumption and lifestyle**
- **Invent new water conservation techniques**
- Recycle wastewater
- **Improve irrigation and agricultural practices**
- **Appropriately price water**
- Develop energy efficient desalination plants
- **Improve water catchment and harvesting**
- **Look to community-based governance and partnerships – community mobilisation**
- Develop and enact better policies and regulations
- Holistically manage ecosystems
- **Improve distribution infrastructure**
- Shrink corporate water footprints
- Build international frameworks and institutional cooperation
- **Address pollution**
- **Public common resources/equitable access**
- R&D / Innovation
- **Water projects in developing countries / transfer of technology**
- **Climate change mitigation**
- **Population growth control**

On a consumer level it is necessary to do community mobilisation to make the inhabitants understand the importance of improved sources of water. During the mobilisation it is essential to communicate the positive effects of consuming safe and clean water and taking care of the environment, as well as the importance of paying for the service in order to make it more sustainable and resilient. Furthermore, it is beneficial to educate people on the use of contraception and family planning, like NCA and HLH are currently doing, so that one might be able to control the population growth somewhat. Looking into agricultural practices and the possibilities of having 'veggie gardens' which can have an economic output is important on a village and consumer level. It is also necessary to appropriately price water on a village level and work towards expansion and improvement of existing networks, as well as construction of new structures. On a regional/national level it is important that the decision-makers dare to think in new ways, use new technology and cooperate with village level representatives and external actors such as NGOs and other countries. Policies and action plans addressing and trying to mitigate and adapt to climate change is crucial on all levels. For external organisations such as NGOs, research facilities and universities it is important to do research and development, innovate new solutions, share knowledge and invest in new projects in developing countries. When developing new technology, it is important that this is accessible and cost-effective enough, so that it can be operated and maintained at a village level. Figure 7.7 shows a suggestion of how the stakeholders should interact to attempt to solve the water crisis in a rural setting.

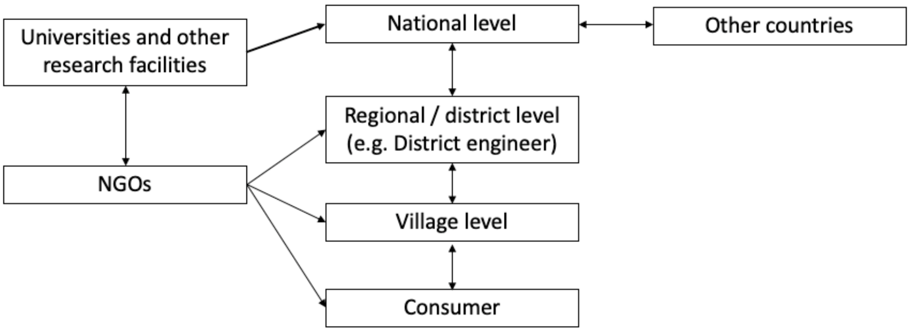


Figure 7.7: How different stakeholders have to work together in order to achieve a more resilient water supply system and solve the water crisis.

7.4 Water situation and quantity of water - conclusion

The water supply situation in the study area is unfortunately concerning, both in terms of the amount of water consumed and the associated time spent collecting water. As indicated in the literature, the burden of water collection disproportionally affects women. However, it was also surprising to see how many children were involved in collecting water. Expanding water points closer to people's house and reducing the waiting time so that a roundtrip to an improved water source takes less than 30 minutes, would fulfil the requirements for basic coverage, according to the JMP drinking water ladder. This is likely to both increase the water consumption and possibly release an economic potential. In order to increase the quantity of water more boreholes are needed but efforts to reduce population growth should also be pursued. Furthermore, stakeholders should cooperate in a more efficient manner and more money should be devoted to the water sector, because of its positive synergies and pivotal role both in people's lives and for development

8 Pumps and pump failures

This chapter will present the different types of pumps used for water supply in rural Tanzania and discuss some of their advantages and disadvantages. Then follows a more detailed investigation into the reasons for pump failures in the India Mark II Extra-Deep hand pump, addressing both the components that break and the assumed reasons for this, aiming to answer the research question:

> *What factors are important for choosing appropriate pump technology, why is the failure frequency for India Mark II Extra-Deep Well so high and what can be done to remediate it?*

Reducing pump failures and the associated downtime is crucial to increase the resilience of the water supply system and provide a more reliable service. This is dependent on choosing appropriate technology, while meeting the design criteria.

8.1 Background – pump types and technology

8.1.1 Appropriate technology and VLOM

Three main pump categories that are prevalent in rural Tanzania. The first is a variety of hand pumps, second solar powered pumps and third diesel generator pumps. NCA and 4CCP have in the TCP installed either hand pumps or solar powered pumps depending on criteria such as the number of people connected, pumping depth and the yield of the borehole. There are however several diesel generator pumps in the area which are installed with the aid of other actors such as the World Bank and Mandal Municipality in Norway.

According to Dunn (1978), as quoted in Short and Thompson (2003), the purpose of development is to improve the quality of life, maximise the use of renewable resources and create workplaces where people now live. To achieve this, regardless of system type used, it is important to install what has been identified as "appropriate technology" (Short and Thompson, 2003). To fulfill this the following criteria should be met:

- Employ local skills
- Employ local material resources
- Employ local financial resources
- Be compatible with local culture and practices, and
- Satisfy local wishes and needs
  (ibid, p.2).

Failure to address the criteria listed above may result in unsustainable and, in many cases, failed systems and projects. The authors argue that "social, economic, health and gender concerns are all directly relevant and yet are often neglected in the design and application of a pumping system" (ibid, p.2). They also highlight how failure to make the community feel and take ownership of the pumping system can result in lack of even the most basic maintenance. This again highlights the importance of NCA and 4CCP emphasising community mobilization prior to pump installation. Additionally, the fact that the inhabitants in the villages contribute with a set percentage of the installation cost, will likely make them feel greater ownership. Short and Thompson further argue that failure to implement appropriate technology "may result in active measures to prevent the technology being used, operating successfully and being shared", as there might be institutional issues and attempts at forms of bribery when implementing new technology in developing countries (ibid, p.4). This is due to the fact that new technology may upset existing societal and financial structures and thereby challenge the interests of certain actors.

Another important aspect to consider when installing pump technology is the level to which it can be operated and maintained locally. The concept of Village Level Operation and Maintenance Management (VLOM), was developed in the 1980s as a technological concept relating specifically to hand pumps for rural water supply (Colin, 1999). For a pump to satisfy this definition it would have to be:

- easily maintained by a village caretaker
- requiring minimal skills and a few tools
- manufactured in-country, primarily to ensure the availability of spare parts
- robust and reliable under field conditions
- cost effective

(Arlosoroff, 1987 quoted in ibid, p.4)

This is similar to several of the criteria suggested in what constitutes appropriate technology, which indicates how there is an understanding that the installed infrastructure must continue to function also in the future.

At first, VLOM was a design concept and related to communal, not household, hand pumps. It was thought that communal hand pumps could meet most rural water supply needs of the developing world if problems with the existing designs could be overcome (ibid). VLOM as a concept gained acceptance and became a widespread concept in the rural water sector after it was first proposed. However, it is argued that it has been only partially successful as an approach as it has been hard to realise in the field, especially in Africa. Therefore, VLOM technology is now increasingly seen as only one amongst many components needed for the sustainable provision of village water supplies, but it remains an important step towards increased sustainability (ibid). However, basing a water supply system on technology which repeatedly fails to achieve its motives and with maintenance requirements that are not realistically executed in a rural setting is an unjust task and responsibility for a COWSO and the village. Based on this, one could argue that VLOM should have a higher priority when it comes to choosing what type of infrastructure to install.

Another important aspect is the instalment- and lifetime costs associated with different types of pumps. Generally, one can say that hand pumps have a low investment cost, compared to motorised pumps, even though the drilling costs of the borehole are fairly similar. The cost of drilling a borehole in the study area is 14 000 USD. A good quality hand pump costs between 2500-3000 USD, but this type of pump will often have fairly high maintenance and repair costs due to wear and tear on the many moveable parts. Solar powered pumps have an installation cost of approximately 16 000 USD, but the energy they run on is for free. Diesel generator pumps have a significantly lower installation cost, but they have high running costs as diesel is expensive. Electrical grid pumps are expensive to connect but have relatively low running costs compared to diesel. However, the system may be unpredictable as the electrical grid in many developing countries frequently experiences issues. One major advantage with the motorised pumps is that they do not break as often as the hand pumps, because people do not directly handle the pump and there are fewer movable parts. Table 8.1 shows the economic lifespan for some common hand pumps in SSA, as well as estimations for solar powered pumps and diesel generator pumps. Motorised pumps cannot directly be compared with hand pumps because they consist of several larger components such as panels, an inverter, a generator and a submersible pump with different lifespans. It should be noted that there are different types of solar- and diesel-powered pumps, which will have different lifespans highly dependent on the quality, thereby also the price. The lifespan is something that should be taken into consideration when choosing a pump, but the lifespans listed in the table do however largely depend on whether or not the technical design criteria of the pump are met. If one pumps from a greater depth than what the pump originally is designed for, and/or if it serves too many people, the economic lifetime, in particular, will be reduced.

PUMP TYPE	**ECONOMIC LIFESPAN (YEARS)**	**WORKING LIFESPAN (YEARS)**
NIRA AF 85 (shallow well)	12-15	25-30
AdriDev (deep well)	9-12	18-25
India Mark II (deep well)	8-10	15-20
Solar (PV) pumps	10-15	15-20
Diesel generator pumps	10-15	15-20

Table 8.1: Pump type and lifespan for hand pumps (Sarkinnen 1994, referred to in Parry-Jones et al. 2001) and estimations for solar powered pumps and diesel generator pumps.

8.1.2 Design criteria

In addition to the suggested requirements related to choosing appropriate technology from an operational point of view, as well as the installation and O&M costs, it is also important to take the actual technical criteria of a pump into consideration. The Borehole Water Association (2017) has made a list of the most important factors to consider when choosing a pump. The first factor to consider is for what application the pump will serve. Domestic use will have different requirements than for example gardening irrigation, filling of a tank or mine dewatering. The next thing to evaluate is the desired flow rate and pressure. Even though there are varying yields for the different boreholes in the study area, one must still consider the purpose of the pump to find the right flow rate and pressure. As the article poses, a gardening irrigation pump requires high pressure and low flow, while filling up a tank requires low flow and low pressure. Both these two different types of purposes are relevant for NCA as they both use storage tanks for their motorised pumps, and they want to implement 'veggie garden' projects which is a small-scale irrigation system. For motorised pumps, the pumping distance in terms of depth to borehole, horizontal distance and ground elevation must also be taken into consideration (ibid). For all types of pumps, an important aspect is also the recharge rate of the borehole. As water is abstracted from the aquifer, a cone of depression will be formed leading to a drop in the groundwater level, as explained in chapter 5.1.1 (Background – hydrogeology and ground conditions, p.35), and the groundwater level will increase when abstraction stops due to recharge. The diameter of the borehole will decide the size of the pump which can be installed. Hence, a cost balancing act must be conducted, as a small pump requires more impellers than larger pumps, but a larger pump requires a larger borehole which is more expensive (ibid). This is a more important aspect for motorised pump using submersible pumps, than for hand pumps. The pipe diameter is another design factor as a small pipe diameter leads to more friction, hence requiring more pressure and then also more kilowatts to account for friction loss (ibid). The last factor listed in the article is the total dynamic head, which addresses the above ground elevation, pipe diameter, pipe length, standing water level and drawdown level (ibid). It needs to be calculated by either a pump installer or a contractor in order to make a final selection of which pump to install.

Bearing in mind the technical properties and the practical aspects discussed, there are several different types of pumps that may or may not be the appropriate one for a given situation. The pump types can first be divided into two main categories:

- hand pumps – using man power to move groundwater from the depth to the surface
- motorised pumps – using some type of external power to move the groundwater

The motorised pumps can then be divided into for example solar powered pumps, diesel generator pumps, electrical grid pumps and hybrid systems which combine different sources of power. However, as described in the previous sub-chapter, the only types of motorised pumps that was seen during the fieldwork was solar powered and diesel generator pumps. Thus, they will be the only variations addressed in this thesis. Nevertheless, different types of pumps have different applications, prices, design criterias and provide varying amounts of water. Table 8.2 shows an overview of the three main types of pumps discussed in this thesis (as well as an additional type of hand pump), with the number of people served, the pump depth, advantages and disadvantages.

The India Mark II (Extra-Deep) hand pump is by far the most common one in the study area, but also on a general basis in SSA. As can be seen from Table 8.2, the hand pumps can serve up to 300 people. A database received from 4CCP (see Appendix 8) contains information about how many people each of the boreholes serve. Based on the 11 hand pumps that 4CCP are/have been involved with, the average pump serves 1295 people. This does not only result in low consumption per person and long queues, but also drastically exceeds the pump capacity, which will reduce its lifespan. For solar powered pumping systems, the pump is designed based on the depth to the groundwater table, the yield and the number of people it is meant to serve. However, the capacity of a solar powered pump is usually 1500 people in the study area, but as seen in Table 8.2 they may serve up to 3000 people. Diesel generator pumps can serve even more people, up to 5000, but they rely on expensive and non-environmentally friendly fossil fuels. Diesel generator and hand pumps can theoretically operate around the clock, but hand pumps will obviously produce significantly less water. There are, based on interviews with technicians and COWSO members, limited local experience and competence when it comes to repair and maintenance for motorised pumps. Additionally, none of the pumps used in the TCP are VLOM. This is due to the low regional groundwater table and the obvious advantages of having a motorised pump. Afridev is an open-source hand pump with an open-top design, which makes it a VLOM pump, but this does only pump to a depth of 45 m (Water Aid, 2013). Due to this it is not found in the study area, and thus not discussed in detail.

Type of pump	Maximum number of people served	Maximum pumping depth	Advantages	Disadvantages
Hand pump: India Mark II Extra-Deep	300	80m	Inexpensive instalment. Well-known technology, spare parts and competence is widely available. Can be operated at any time at no cost.	Serves a limited number of people. Extensive maintenance and repairs are often required. Requires physical effort. Varying quality due to open source. Not VLOM.
Hand pump: Afridev / India Mark III	300	45 / 50m	Inexpensive instalment. Open top and VLOM. Can be operated at any time at no cost.	Serves a limited number of people. Some physical effort needed. Limited pumping depth.
Solar pumps	3000	200 - 250m	Energy supply is free and little maintenance is required. Can serve a large number of people. Accessible to all members of the community. Environmentally friendly. Can potentially be connected to the electrical grid.	Can only operate at a high efficiency for nine hours per day. Repairs are costly when they do happen. Limited experience and competence available for repairs. Not VLOM in terms of repairs.
Diesel generator pumps	5000	Very deep, depending on pump and the associated price	Can operate at any time and in principle around the clock, depending on the pump. Can potentially be connected to the electrical grid. Fairly well-known technology. Accessible to all members of the community.	Diesel is expensive and people often have to travel far to purchase it. Not environmentally friendly. Challenging and costly repairs. Not VLOM in terms of repairs.

Table 8.2: Types of hand pumps and their design parameters in terms of maximum pumping depth and number of people served. Sources: (SKAT and RWSN, 2007) (Bonnier, 1995) (RWSN,n.a.) and Bauman et al. (2010).

8.1.3 Hand pumps- India Mark II

Though not a VLOM design, the India Mark II pump is the hand pump used in NCA's projects in the Haydom area. It is a robust conventional lever action hand pump designed for heavy-duty use (SKAT and RWSN, 2007). The down-hole components consist of a brass-lined cast iron cylinder with a footvalve and a plunger of brass. The plunger has a double nitrile rubber cup seal, the rising main is a galvanised iron pipe with a diameter of 32 mm, and the pump rods are of galvanised steel with threaded connectors (ibid). The standard India Mark II pump serves up to 300 people with a maximum recommended lift of 50 m. One major drawback with this pump is that it is not corrosion resistant, which means that it is not suitable to use in areas with a pH-value of less than 6.5 (ibid). The pump is also challenging to repair seeing as it does not have an open-top, such as other hand pumps like the AfriDev, which is considered a classical VLOM hand pump. An open-top means that one does not have to extract the entire rising main when doing repairs, which requires either a specialised crane or a dozen people or so. The India Mark III, which was developed in 1991 has similar configurations as the India Mark II. It is only the down-hole components that were changed in order to improve the village level maintenance (RWSN, n.a.). The most important improvement is the open top cylinder, which makes it possible to remove the plunger and also the foot valve without lifting the cylinder and the entire rising main (ibid). The India Mark III is however not used in the study area, most likely due to its limited pumping depth. The most used hand pump found in rural Mbulu and Mkalama is the India Mark II Extra-Deep Well, which is able to pump from a depth of up to 80 m. It is therefore better suited for areas with a deeper groundwater table. An issue however with the Extra-Deep Well is that it requires some physical power to pump up the water, but when the natural conditions cannot be changed it provides the only viable option for a hand pump.

The India Mark II hand pumps are open source (ibid). Though this is an admirable principle it means that they can be produced and assembled in various locations. Therefore, they may also be of varying quality, which can affect the water supply situation. Another challenge posed with hand pumps is the lack of ability to store water at the water point, meaning that if the pump fails there is no buffer. To access water people will then have to use unsafe surface water sources while the pump is being repaired. This again highlights the importance of creating resilient systems which continue to partially fulfill their function and to quickly return to their original state. Furthermore, the effort and time spent pumping water can be demanding and makes the pump less available to all members of the community.

8.1.4 Solar powered pumps

Solar photovoltaic (PV) powered water pumps do not require physical efforts to pump water as they rely on solar energy. PV pumps can provide a larger quantity of water from a greater depth compared to conventional hand pumps. They can typically serve a population of about 3000 people and have a maximum depth of up to 200 - 250 m.

Solar powered pumps are successfully used in regions where there is abundant sunlight and have generally proven to be a reliable and cost-effective solution in areas where:

- There is widely spread water resources
- No electricity grid is near
- The fuel and maintenance costs are considerable
  (Mudzingwa et al., 2016, p. 4)

Ramos and Ramos (2009) argue that many countries have available wells and boreholes along with good sun exposure, which makes PV water pumping a favourable option. Their study found that the investment cost of the system could easily be covered by charging 1,2 USD/m^3 (not accounted for inflation), which is a fairly reasonable price for a cubic meter of water (ibid). In the study area, however, the price per cubic meter of water is 1,1 USD with today’s currency if assuming a price of 50 TSH per 20L bucket. This means that the investment cost is not quite covered under these assumptions, according to the findings from Ramos and Ramos. PVP systems carry a high capital cost and might therefore not be available to those who need water the most, unless the government, external actors and NGOs become involved in covering the investment costs. This may provide a well-functioning solution seeing as the cost of O&M are low for solar powered systems. Extending the national grid to small and isolated villages would probably surpass the cost of implementing a solar system, even if the cost of solar energy has not yet become cost effective compared to electricity from the electrical grid (ibid). Implementation of PV pumps is therefore a worthwhile venture for many governments and organisations such as NCA.

A solar powered system is based on a motorised pump which "has low chances of human interaction during operation and less moving parts which correspond to low frequency of maintenance", due to less wear and tear (Mudzingwa et al., 2016, p. 6). Though solar powered systems have a high investment cost the O&M of a PV system is often less than that of hand pumps. The most important tasks for the community in terms of maintenance is to clean the solar panels and keep the water points sanitised, but the latter applies to all types of pump systems (ibid). It is important to remove dust from the panels, as this will significantly reduce the efficiency of the system. The PVP systems visited in Tanzania were fairly new, but they all seemed to be kept in a good condition. However, a challenge is that there is limited competence and availability of spare parts for repairs in the local area. Though daily maintenance is fairly simple, repairing solar powered pumps requires skilled technicians. The technicians employed by 4CCP reported in an interview that they wanted to learn more about solar powered systems, a sentiment that was echoed by the district engineer in Mbulu. Furthermore, when PVP systems fail the repair process is not only challenging, it is also very costly. This means that the COWSOs must collect a sufficient tariff to cover future repairs.

Baumann et al. find that PVP systems in SSA are a cost-effective solution up to 50 m depths and 800 m^4/day (m^3 *m per day), and often presents a solid, long-lasting and environmentally friendly approach to water provision (2010). However, theft and vandalism is by the authors considered to pose a potential problem for solar powered pumps as the panels are quite valuable. For example, NCA have in Sudan experienced that children throw rocks at the panels because they like the sound, though this was not reported to be an issue in Tanzania. All the PVP systems visited in the Haydom area were fenced and had a locked gate, as well as a night guard. Still, theft and vandalism was not considered a major issue by the local communities when interviewed.

PV systems, including both the solar panels and the pump itself, can have a long life-span of up to approximately 25 years, but seeing as the investment costs are high it is crucial to choose a reputable and well-established pump producer (ibid). According to a conversation with Manfred Arlt (NCA Global WASH advisor) on the 28th of May 2019, the pumps used in their projects normally last for 10 to 15 years, and it is often the inverter that breaks first, after approximately 10 years. Though PV systems are mostly reliable, the panels are sensitive to weather conditions and would for example be destroyed by hail or become ineffective if covered by dust and sand. When the panels are connected in series, damage to one panel will affect the whole system. This of course makes the system less resilient. A mitigating effort to increase the resilience in case of failure, is the construction of storage tanks which both can deliver water if the pump fails, as well as relieving stress on the pump. All the PVP systems, see Figure 8.1, installed as part of the TCP have two elevated storage tanks of 5000 L each which serves this purpose to an extent. Storage tanks also provide flexibility in terms of when water is pumped and when it is tapped. This means that water can be pumped during the day and then tapped the next morning if necessary, making the system more functional. It is estimated that one can pump at a high efficiency for nine hours per day when the sun is out and, depending on the yield of the borehole, the daily amount in this case study varied from 9000 L/d to over 60.000 L/d, the latter far exceeds the capacity of the storage tanks. However, 10.000 L serves as storage for an average of over 1000 people, which means that it provides less than one day of water supply. Expanding the volume of the tanks is therefore recommended to increase the resilience and accommodate for population growth.

Figure 8.1: Schematic drawing of multiple use of water services (MuS), installed in NCA's TCP (WAYD Designs obtained from private email correspondence with NCA staff, 8th of May 2019).

In summary, PV pumps have low O&M costs as the energy is free and little maintenance is required, but they carry a high investment cost. The system is limited in that it does not perform well in the event of cloudy weather and short winter days, but this is not a great concern in Tanzania.

8.1.5 Diesel generator pumps

For diesel generator pumps, the pump itself follows the same principles as for a solar powered pump – it is the source of energy that constitutes the main difference. NCA and 4CCP have not installed any diesel generator pumps as part of the TCP, but there are at least a couple in the Haydom area. Though diesel generator pumps can provide sufficient amounts of water, both in terms of the number of people served and the depth to the groundwater, it does not appear to be a well-functioning or sustainable system based on the ones observed in the fieldwork. The major challenge seems to be the cost of fuel and the fact that one has to travel far to acquire it. As reported in one interview, this can mean that people refrain from using groundwater in the wet season as it is considered too costly. The environmental implications of using fossil fuel to pump water is also a negative factor. One advantage with diesel generator pumps is however the possibility to pump at any time during the day and at all times during the year, as one is not reliant on the sun. This makes the system less volatile. In the Haydom area, it appears that when the pumps require maintenance or repairs there is limited competence and understanding, which led to at least one diesel generator pump not being in use. It should be mentioned that this was only one out of a very small sample, but it is worth noting that this pump system, which was installed by the World Bank, had not placed the same emphasis on community mobilisation. For many decades, diesel or gasoline driven pumps have been used and installed in the developing world, but the cost, transportation of fuel and engine maintenance, has often made it a too expensive option for the rural population (Ramos and Ramos, 2009). With rising oil prices and increasing environmental concerns regarding the use of fossil fuels, renewable energy sources for pumps are considered both more sustainable and also able to provide more resilient systems that are less prone to market fluctuations.

8.2 Results - pump failures

This subchapter will go into detail regarding the pump failures experienced with the India Mark II Extra-Deep Well, and the options that are available to improve the pump and reduce the number of failures. As mentioned earlier, India Mark II hand pumps are common in SSA, but there are a lot of failures related to this type of pump.

When installing any type of pump it is important to consider the ground conditions such as aquifer type, depth and yield, in addition to the population served, local economy and lifetime of the system. During the fieldwork in Tanzania it became clear, that several pump failures were related to these topics. The district engineers and the technicians did not have any systematic overviews of the most typical pump failures. This makes it more challenging to directly answer the research question as the failure rate for different components cannot be quantified. Furthermore, a lack of data makes it harder to improve the management of the system. An obvious advantage of having such an overview is that it is easier to ensure the access to the most needed spare parts, hence making repairs quicker. Additionally, it makes it easier to identify weak components that should be modified or replaced. However, interviews with the district engineers and the technicians employed by 4CCP provided useful data which was used to synthesize the most common problems experienced. Table 8.3 shows the most typical pump failures, what they are caused by and how they can be mitigated. In Appendix 9 a drawing of the hand pump can be seen.

The technicians that were interviewed said that one should not install the India Mark II Extra-Deep Well at a deeper level than 60 m, due to the heavy lifting during repairs and the increased failure rate. Repair of a hand pump was undertaken while the fieldwork was being done in Haydom. This hand pump pumped from a depth of 160 m, way over maximum recommended depth, resulting in the rubber gasket in the cylinder breaking. The rehabilitation process required 10 men and several hours to lift up all the pipes in the rising main, which highlights why it is not desired to pump from a too deep level. Additionally, it underlined the importance of VLOM (see Figure 8.2 and Figure 8.3).

FAILURE	CAUSE	POSSIBLE SOLUTION
The chain connecting the handle arrangements and the head flange breaks	Over use, wrong use, continued use after it is broken and lack of maintenance.	Ensure that the users know how to pump in an efficient and proper way, which avoids too much stress on the chain. It is also important to regularly lubricate the chain with oil, so that it is more moveable and flexible. Lastly, when doing maintenance, it is necessary to handle the chain with care.
The rubber gasket of the check valve (footvalve) and plunger breaks	Mainly due to overuse or pumping at a too deep level, leading to high pressure on the rubber. Material degradation, meaning that the rubber is of inadequate quality or too old.	Install pump based on maximum pumping depth, ensure that there is no overuse. Choose a reputable manufacturer and monitor the condition of components so that they can be changed before they break.
The pump rod creates a hole in the rising main and sockets	Occurs due to friction. There is an 8-inch casing inside the borehole, the rising main of 1,25 to 1,5 inch is therefore difficult stabilize. The movement can cause the socket and rising main to break, leading to reduced pressure, resulting in a heavier pumping.	Use the right dimension of pipes within the borehole and make sure the rising main is stabilized during installation and maintenance.
Corrosion of joints in rising main	If the pH is low and the steel is not galvanized properly or the galvanization has been ruined during installation or repairs, corrosion may occur.	Require a guarantee from the manufacturer and the people doing maintenance/repairs. Only buy components from recognised manufacturers. May replace the stainless-steel pipes with PVC or HDPE pipes if the water has a low pH.
Stress damage in joints	The pipes in the borehole manage the high pressure within them, but the joints are more vulnerable to the high pressure if debris such as small rocks are caught in the threads as well as the material being thinner.	Research should be conducted on how to improve joints by for example reinforcing them with extra metal material or rubber etc.

Table 8.3: Failures, cause and possible solutions for the India Mark II Extra-Deep Well.

Figure 8.2: A lot of people had to help out when lifting up the rising main during reparation of an India Mark II Extra-Deep Well.

Figure 8.3: Reparation of the India Mark II Extra-Deep Well require a lot of people, hence not a VLOM pump.

An increased pump load can cause deterioration of the pipe and the pump components, hence the pumping depth and the number of people served should be considered carefully. Another very important point the technicians made was that they should have a specialised toolbox with high quality tools, elaborated on in the following subchapter. Other interviews and discussions also highlighted the importance of regular and preventive maintenance, including greasing of the chain and general service of the pump every six months. However, it seemed like preventive maintenance was not a widely applied concept in the study area. It appeared that maintenance equalled repairs, as maintenance was largely considered an unnecessary expense. This is a sub-optimal approach, as maintenance can help to reduce the chance of potential failures, and thus it might reduce the costs in the long term. There are, to our knowledge, no clear guidelines at the moment about maintenance strategies when doing COWSO training by 4CCP. It would be beneficial to update the guidelines and include both short-term and long-term maintenance strategies.

There are four anti-corrosion measures that must be in place to avoid corrosion in the hand pump (SKAT and RWSN, 2007). The first step is hot-dip galvanisation of some of the pump components. Doing so leads to the pump being able to tolerate a pH as low as 6.5. Other water quality parameters must however also be considered, as there are some that may influence corrosion. If the pH is lower than 6.5, stainless steel rods should be used (ibid). During interviews the technicians said that they had successfully implemented HDPE and PVC (types of plastic) pipes, in order to avoid corrosion. The next anti-corrosion measurement is electroplating and passivating of some pump components, which consists of putting on a coating of zinc and cadmium on steel and iron (ibid). Following, a chromate conversion coating using zinc and cadmium coatings is applied on the electroplated parts. The final step is painting of the exterior surface of all cast iron components. This should be done by thoroughly cleaning all surfaces and removing rust and grease, before painting with one layer of primer and two layers on enamel paint (ibid). The details about all the anti-corrosion measure can be seen in Appendix 10 However, SKAT and RWSN (2007) suggest that all the steps should be done after set ISO standards (which can be seen in Appendix 10). It is clear how this is a complex process with several steps. Therefore, it is important that when ordering either a pump or just spare parts, one should check that the manufacturer has used the ISO standards during production, to ensure that the pump material is corrosion resistant. Additionally, a component should come with a warranty so that money can be retrieved if it is not produced correctly.

SKAT and RWSN (2007) developed an overview of pump parts, optional parts and installation and maintenance tools, in addition to standard parts for both types of India Mark II pumps. The number of components for each category for both pump types can be seen in Table 8.4.

	India Mark II Pump	**India Mark II Extra-Deep Well**
Pump parts	98	96
Installation and maintenance tools	49	46
Standard parts	62	50

Table 8.4: Components for the two types of India Mark II Pumps (SKAT and RWSN, 2007).

A detailed overview of the pump parts and tool components can be seen in Appendix 11. Having a storage facility where installation and maintenance tools and standard parts are located would increase the resilience of the water supply system. It could reduce the downtime as one would not have to wait for spare parts. India Mark II Extra-Deep Wells are relatively easy pumps for mechanics to maintain and repair, regardless of it not being a VLOM pump. A sufficient number of mechanics and technicians that know how to maintain and repair the hand pump is essential to increase the usable lifetime and overall resilience.

NCA have donated 14 toolboxes to 4CCPs work. Most of the toolboxes are located at the 4CCP office, while some are placed in the villages. It has however been reported by the technicians that the tools that are in the tool boxes are of inadequate quality, in addition to the fact that the toolbox set lacks certain tools that are needed. The actual content of the toolboxes has however not been studied.

8.3 Discussion and recommendations

The three main types of pumps discussed above have both advantages and disadvantages, and some are more suitable under certain conditions than others. Figure 8.4 shows a simplified overview of which pump to choose based on is considered the most important aspects in rural Tanzania.

Initially, it was planned to develop a systematic overview of the most typical pump failures. This proved challenging as not that many hand pumps were included in the case study and little empirical data was available. The solar powered pump systems are newly installed, and no failures have been experienced yet, but it is recommended that a systematic list is developed as failures start to occur. Having such an overview, both for hand pumps and solar powered pumps, can help to improve the resilience of the pump system, and research institutions can then conduct testing on the pump system, to figure out alternative materials or components so that the number of failures might reduce.

Another recommendation is to negotiate at least a 2-years warranty on the pump system and spare parts, particularly for solar powered pumps as they are costly to repair, and most failures happen within the first 18 months. SKAT and RWSN however say that unless otherwise is specified in the contract or order, "the India Mark Hand pumps and its accessories shall be guaranteed for 12 months from the date of installation, or 18 months from the date of supply, whichever is earlier, against faulty workmanship and/or materials" (2007, p. 15). A warranty can help to make sure that the manufacturer produces high quality components. Furthermore, it helps to ensure that COWSOs have sufficient funds when failures occur, and that they are not punished by faults due to production or installation errors.

In future work it is recommended to look at the actual content and quality of the tools that are in the toolboxes and compare this to the standard list produced by SKAT and RWSN (2007). Furthermore, it is encouraged to establish a storage with spare parts for both hand pumps and solar powered pumps, which can potentially reduce the downtime so that the system becomes more resilient. The technicians should also have a car available so that they can bring tools, spare parts and a tripod to ease the repair and maintenance work of the India Mark II pump. The customers should also be taught how to use the pump in a proper way, to reduce the stress on the pump. Lastly, the COWSOs should establish routine maintenance and service of their pump, especially if they have a hand pump, in order to reduce the failure rate.

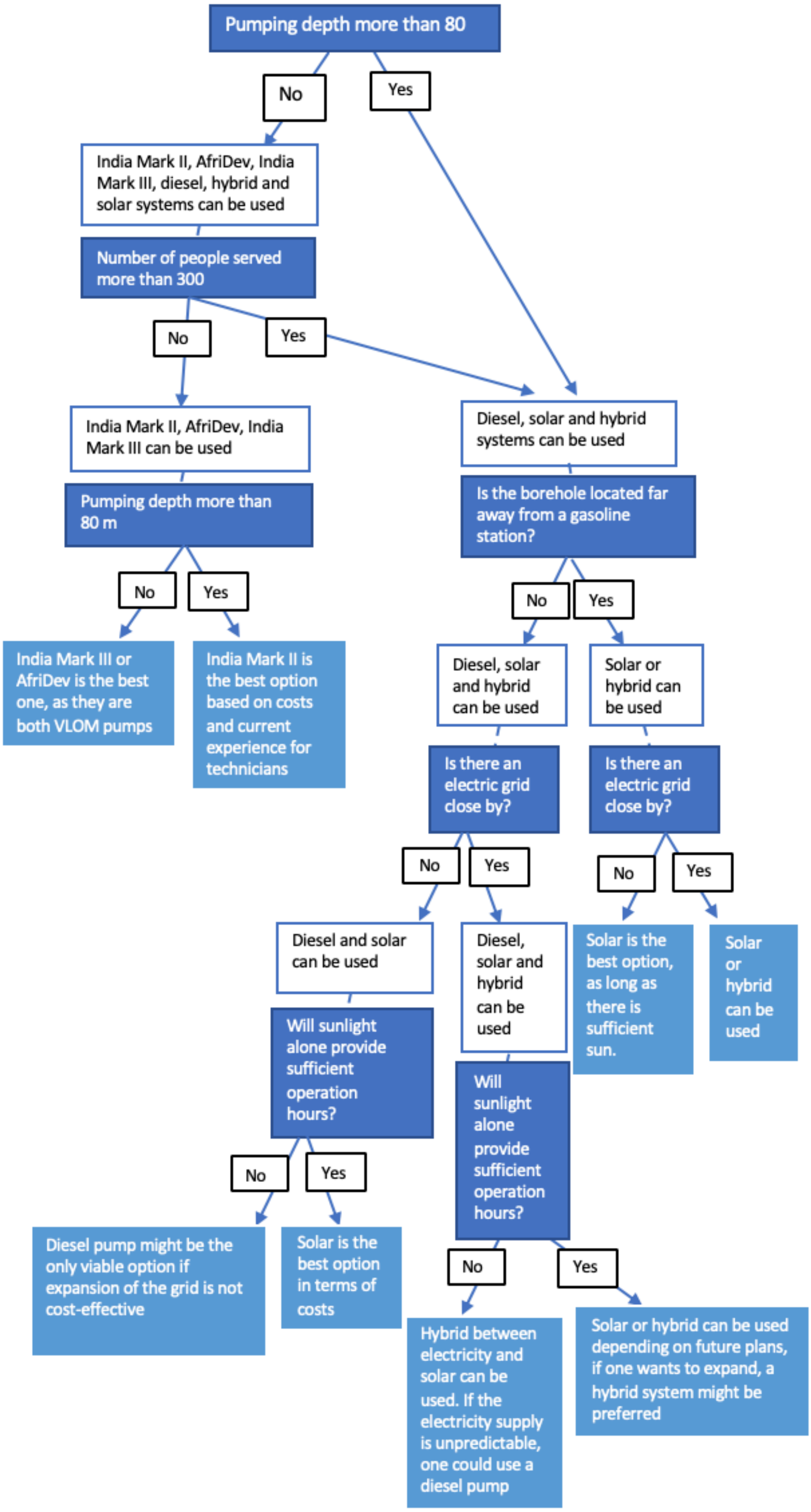


Figure 8.4: Flow chart on how to choose the most suitable pump.

8.4 Pump and pump failures - conclusion

Though the India Mark II experiences high failure rates it is a widely known technology, which is cheap to install and with proper O&M it can provide a cost-effective solution to smaller villages. If the groundwater table is not too deep, VLOM hand pumps such as India Mark III and AfriDev should be considered. It would be both very interesting and beneficial to research on a new generation of hand pumps combining both the open-top feature with the ability to pump from the same depths as India Mark II Extra-Deep Well. A deep well VLOM pump would be a very welcome contribution to the study area, as well as other developing regions with a low groundwater table. However, if the village has more than 300 people it is not recommended to use a hand pump, and solar powered pump systems are considered more sustainable than diesel generator pumps. PV pumps carry a high installation cost, but low O&M costs. This makes them a sound investment for external organisations such as NCA because it can alleviate the water stress experienced by people without burdening them in the future. From both an economic and organisational perspective this is perhaps a more sustainable project which is also more resilient due to its storage capacity.

9 Community Owned Water Supply Organisations

This chapter is dedicated to the analysis of COWSOs and the factors that strengthen their functioning, as expressed in the research question:

> *How can community owned water supply organisations increase their function and contribute to improved management of water supply?*

After a brief description of COWSOs as a concept in Tanzania, the main findings are presented alongside a classification of the COWSOs based on 14 weighted criteria. It is hoped that this framework can be used by the partner organisations and future researchers to monitor progress and focus efforts in the most important areas. The COWSOs are also discussed in relation to the IAM framework developed by the IRC, and an updated model is suggested for asset management for RWS where the service provider is community based.

9.1 Background - COWSOs

According to the World Bank (2017) the national authority responsible for water in Tanzania, is the Rural Water Supply Department, Ministry of Water and Irrigation, while the service authority are the local government authorities. The service providers are COWSOs, a generic term for community-based management structures. Examples of COWSO arrangements include direct management; management through a wider association and a COWSO delegating aspects of operation, maintenance, or management to the private sector.

In Tanzania the National Water Policy (NAWAPO) developed by the Government of Tanzania in 2002 set out the goals and strategies for access to water and development with a vision for 2020 (Fierro et al., 2015). It aims to achieve sustainable development in the water sector through the efficient use of water resources and to increase the availability of water and sanitation services. The government's policy for improved access to sustainable water service are based on three strategic actions:

- Increasing water supply coverage through new projects and rehabilitation of old ones
- Improving water management systems
- Strengthening supervision and monitoring of the sector
  (ibid, p.2)

To realise this vision, COWSOs were introduced in Tanzania in 2009 in the Water Supply and Sanitation Act No. 12, as the only "legal management entities entitled to implement the NAWAPO's community participation (and ownership) principle in rural water supply system" (ibid). The use of COWSOs for RWS is an accordance with SDG 6, target 6.B, which aims to "support and strengthen the participation of local communities in improving water and sanitation management" (UN, n.a.).

The main role of a COWSO is to operate and maintain the water scheme and provide safe water to the consumer (Ministry of Water, 2015). COWSOs are legal entities at the community level who are entitled to make contracts with the private sector on behalf of the community (ibid). Variations of COWSOs are mostly used in rural areas in low-income countries, also known as WASHCOs (water, sanitation and hygiene committees) in other countries. In rural Tanzania COWSOs are, with the aid and support of the district engineer and in many cases also external actors such as 4CCP and NCA, responsible for providing water, collecting tariffs, producing reports and maintaining the water point.

COWSOs are established through the local government framework of village councils following the adoption of the Water Sector Development Strategy. The people that form a COWSO are chosen in a village assembly meeting. The number of members in a COWSO is normally around 10-12 people in the study area. NCA and 4CCP aim for gender balance in the COWSOs they are involved with. It is however not quite clear what is required from a state level. Gender balance does not only entail that women should represent half of the committee members, but also having a woman in a leading position of the COWSO, meaning as a chairperson, treasurer or secretary. A recent study from Vanuatu found that when water committees have women in leading positions, committees meet more regularly, collect more revenues and have a higher functionality (Mommen et al., 2017). It is thought that "since women are the main beneficiaries of water service delivery, they have a vested interest in its success, and their involvement in management decision-making will lead to better performance" (ibid, p. 217). Including women in COWSOs, not just as committee members, but also in leading positions is therefore an important step which may improve the functioning of the COWSO and also empower the women themselves.

It should be pointed out that the position as a COWSO member is a volunteer position and therefore not paid. Furthermore, COWSO members are a part of the committee for three years at a time, as according to national guidelines. The role of COWSOs is to operate and maintain the water supply systems on behalf of the community, though they are themselves members of that community (Ministry of Water, 2006). COWSOs are expected to cover all the costs of O&M of the water supply systems through charges on consumers, and to contribute to the capital cost of their systems (ibid). However, the COWSOs may contract part or all of their O&M responsibilities and investment costs to private companies, individuals or NGOs (ibid). This is visible in how the TCP, carried out by NCA and 4CCP, requires that the local community usually contributes with 15% of the instalment cost for a borehole and pump. After instalment, the COWSOs are however expected and required to collect tariffs to support future maintenance, repairs and a potential expansion of the system. Performance monitoring and regulation of COWSOs will be the responsibility of the Ministry responsible for Water, but delegated to the district councils (ibid). External organisations will in most cases follow-up on the projects they are involved with, but it is not clear to which extent the monitoring process is formalised from a legal perspective.

It is also worth reflecting over the fact that the responsibility of water supply falls within the community itself. Though there is training for the COWSO members there can be large variations from one village to another in terms of the COWSO's functioning based on the motivation, competence and capabilities of the people living there. Furthermore, the relationship the COWSO members have with the district engineer and other supportive structures is also likely to vary and thereby impact the quality and sustainability of a given water supply system.

9.2 Results - General findings and classification of COWSO

9.2.1 General findings

This section explores some of the general findings from the interviews conducted in relation to four main factors:

- The function of a COWSO
- The requirements for COWSO members
- The main challenges facing COWSOs
- Measures taken for transparency and accountability

As discussed in Chapter. 4 (Method, p. 24), the answers received are impacted by both translation and our identities as external researchers, but it is here attempted to synthesise answers and viewpoints that were recurrent and somewhat general.

9.2.1.1 Function of COWSO

The main tasks of a COWSO were reported to be supervision of the water project and its sustainability. This refers both to direct maintenance (which often meant repairs) and cleaning of the water point and surrounding area, but also to associated tasks such as collection of tariffs and depositing money in the bank account. Ensuring the security and safety of the water point was stated to be the responsibility of the COWSO and this includes both fencing as well as employing a night guard for the solar powered pumps. Furthermore, it was mentioned in several interviews that COWSOs should produce reports and present them at quarterly village meetings, as well as cooperating with local government, the district engineer and the partner organisation.

From the interviews it was clear that the overarching purpose of a COWSO is to provide water to its local community, as stated by the NAWAPO, and it seems that all the COWSOs have a good understanding of their core functions and its importance. In certain COWSOs it was also emphasised that the committee functions as leaders on issues related to water and should participate in mobilisation of the community for the improvement of water services.

9.2.1.2 Requirements for COWSO members

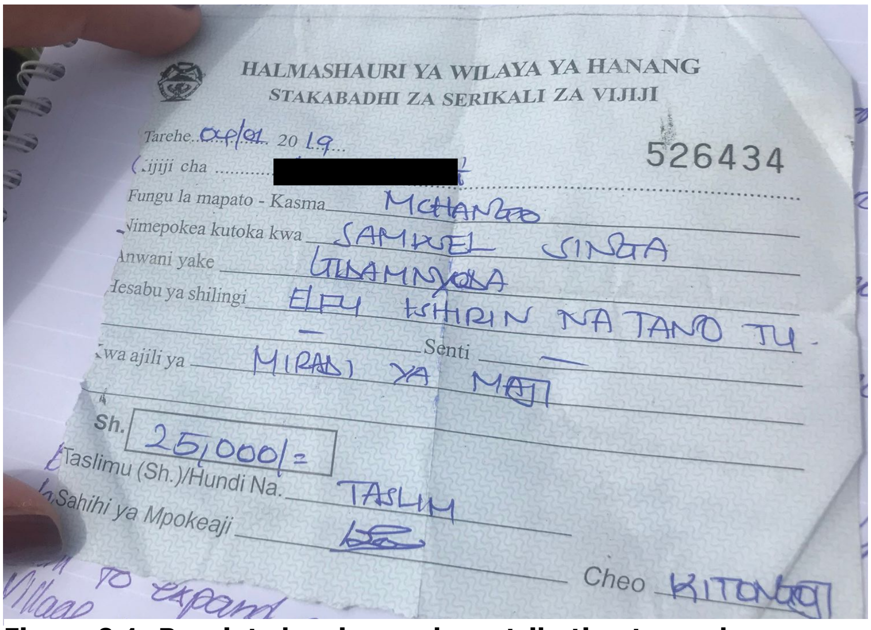
The interviews also dealt with what requirements are necessary for COWSO members. Seeing as this is a voluntary and unpaid position that is held for three years it was hypothesized that it might be difficult to 'recruit' COWSO members, but this did not appear to be a major issue. However, it seems that out of a committee of 10-12 people certain members might be less active and committed. Again, there was largely a consensus on what was required of COWSO members and literacy and numeracy was mentioned in every interview. Additionally, the members must be over 18 years old and a resident of the local village. A willingness to work and volunteer, as well as being an honest person was brought up as desired personality traits several times. So was accountability, but this might also be due to the translator translating multiple responses in Kiswahili into one English word. Furthermore, gender balance is required, and women were therefore stated to be given priority in most, though not all, cases. In one village they also said that the committee members should be in good health and not be known to have a problem with alcohol, the latter was related to the committee being responsible for handling the water tariff. Another village pointed out how they wanted to avoid village leaders as part of the COWSO committee, most probably to prevent a mixing of roles if a conflict were to occur. Seeing as many of the same factors were mentioned in all the interviews, this indicates that the training has been successful in terms of communicating the requirements set out in the standard. However, this meant that it could be challenging to identify what the community itself saw as important requirements for its committee.

9.2.1.3 Main challenges

The major challenge reported from the interviews were limited funds. The price of water is decided in the village assembly meeting were the COWSO is present and it seemed to be an important principle that the price should be manageable for all the members of the community. Still, lack of funds was frequently pointed out as a restriction both in terms of maintaining the current system and the possibility for expansion. Another challenge that was brought up on several occasions was the lack of experience within the COWSO. The members are involved for three years at the time and though they receive training from 4CCP it was reported that there was a need for further training. It should be mentioned that this is also the responsibility of the district engineer’s office. Additionally, it was thought that the lack of continuity when changing the members after three years would pose a problem, but it was clarified that not all the members are obliged to be replaced. Furthermore, in at least three villages it was said that the local villagers had an insufficient understanding of the importance of tariffs and contributions, which makes the COWSO’s work more challenging. It was however quite surprising to hear that volunteering was not repeatedly mentioned as a challenge. This was only specifically brought up on two occasions and then in relation to travel time and associated costs for the members.

9.2.1.4 Transparency

Transparency and accountability are crucial as money is collected and a service is to be provided. Additionally, the region is known to struggle with corruption. NGOs such as NCA are dependent on avoiding corruption both for their reputation but also for financial support from for example NORAD. In one village, which is yet to install a pump, they had developed a system of providing receipts for the contributions made from each household (see Figure 9.1). This is an important and very positive feature. In another village the exact opposite unfortunately happened. Money was collected and then the person responsible disappeared and there were no receipts or records to show how much each household had contributed. This quite understandably both angered and discouraged the community. Collaboration with PETS is an important indication of how transparency and accountability is approached. PETS are also a volunteer committee on a village level responsible for ensuring that money is used for its intended purposes and their mobilisation and training is also carried out by 4CCP. In all the villages interviewed where there was a PETS committee it was reported that the COWSO and PETS committee collaborated, though the intensity varied. In the villages that did not yet have a PETS committee it is advisable to establish this as soon as possible. Another important feature for increasing accountability is the production of quarterly reports by the COWSO which are presented at the village assembly meeting.



HALMASHAURI YA WILAYA YA HANANG
STAKABADHI ZA SERIKALI ZA VIJIJI

Tarehe ... 20 19 ... 526434

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Fungu la mapato - Kasma MCHANGO

imepokea kutoka kwa SAMWEL SINGA

Anwani yake

Hesabu ya shilingi ELFU ISHIRIN NA TANO TU

Senti

wa ajili ya MIRADI YA MAJI

Sh. 25,000/=

Taslimu (Sh.)/Hundi Na. TASLIM

Sahihi ya Mpokeaji

Cheo KITONGOJI

Figure 9.1: Receipt showing cash contribution towards a pump.

9.2.1.5 Overall takeaway

What became clear from visiting the COWSOs and conducting interviews and perhaps particularly from travelling around with Nelson Faustini (4CCP), Manfred Arlt (NCA) and Zachayo Makobero (NCA) was the importance of non-technical factors. As the responsibility for water supply is given to the lowest administrative level when the community itself is in charge, the functioning of a RWS system very much depends on the specific group and even individuals within that group. Though it does seem to largely be successful, it is found that this is mainly due to an emphasis on community mobilisation and making both the COWSO and community members engaged. The TCP started in Tanzania in 2015, so these are also young projects. Having created ‘soft structures’ that can continue to support the physical infrastructure installed, and thereby continue to deliver water in the future is crucial for sustainability. One could criticise that water provision is not taken on more directly by the state itself. However, since very little, it not no taxes are paid by village members the contract with the state in terms of services provided is not the same as one might be used to in other parts of the world. It became clear that ‘soft factors’ were often equally, if not more, important than the physical conditions as illustrated by village L and village M (names anonymised). They are both part of the final stages of the TCP and are yet to have a pump installed, though a borehole has been drilled. In village L the borehole has a very low yield, but the community has very high expectations for the water project and has been very committed, particularly visible through the money collected for implementation despite it being the farming season. Their plans do however go beyond the capacity of the borehole and the physical limitations then becomes the restriction. Village M, on the other hand, has four times the yield but the expectations and associated plans for the water project are much more muted. The chairperson of the village did express that water was a number one priority, but few COWSO members were present and there were no clear plans and limited visions such as a ‘veggie garden’ or expanding the project – though this was discussed when explicitly brought up. The COWSO and the community had also not decided on a tariff and thought they would do so once the project was up and running, which is not advisable. The community then becomes the limiting factor and not the physical conditions.

9.2.2 Classification of COWSOs

To further analyse the functioning of COWSOs it is decided to divide the COWSOs into three groups based on an assessment of their functioning – red, orange and green.

To decide which class each COWSO is in, points are given based on 14 different factors. Each factor is given a score of either 0, 0.5 and 1, where 0 is no attainment and 1 is full attainment. The 14 factors were developed to reflect the information found in interviews and attempt to cover what was considered the most important factors for IAM and a sustainable and resilient water supply. The 14 factors and their requirements are listed in Table 9.1.

Factor	Requirement	Weighting
Improved source or not	To have a pump or having it installed before dry season this year (2019)	2
Year of instalment and year of COWSO	The COWSO should be established before instalment of the pump	2
Number of people connected to the water point	Should be within design criteria for hand pump or motorised pump	2
Gender balance COWSO	Should be an equal distribution of men and women (more women is accepted)	1
Frequency of COWSO meetings	At least one meeting per month	1
Reports	Must produce reports every 3 months	3
Minutes of meeting (MoM)	Should take MoM every meeting	2
Budget and financing	To have a budget and financing plan with income and expenses	3
Legally registered	COWSO must be legally registered	3
Bank account and available funds	Must have bank account and 0,5 mill TSH available	3
Relationships others (Village Leader, District Engineer, PETS)	Committee should visibly cooperate with all three	3
Back-up supply	Must have an alternative supply (storage tank is considered sufficient for solar powered pumps)	1
Technician and toolbox	Should have a technician and toolbox or be in direct contact with one	2
Future plans	Committee should have stated plans and a vision for the future	2

Table 9.1: Weighting of different factors used when assessing the COWSOs.

Additionally, as can be seen in Table 9.1 the 14 factors are weighted from one to three. The lowest weighting is 1, middle 2 and most important 3. This does not mean that those listed with a weighting of 1 are not important, but after discussions with Manfred Arlt (NCA) and consulting literature related to sustainability it is found that adequate funding of O&M and capital replacement is particularly important. The production of reports, having a budget, being legally registered, having a bank account with funds and having a strong relationship with associated partners is therefore emphasised. Taking minutes of meeting is also important, but this was not included in the earliest interviews. Hence, there is insufficient data related to this and it could therefore not be emphasised to the same extent.

A report from 2017 developed by the World Bank Group and their Water Global Practice provided an in-depth sustainability assessment of rural water service delivery models, based on 16 countries. They applied an analytical framework with five key areas or 'building blocks' for sustainability, namely:

- Institutional Capacity;
- Financing;
- Asset Management;
- Water Resource Management and Security; and
- Monitoring and Regulation.
  (ibid, p. 14)

Their study also 'scored' their study subjects (countries) based on attainment of a set of factors and presented it by colour-coding, a methodology which is also adopted here. The World Bank study did an assessment on a country level basis and not on specific organisations, so the scale is a major difference. As can be seen by Figure 9.2, Tanzania did not score well, and asset management is a particular challenge. Lockwood et al. developed a paper summarising the World Bank report, where they argue that the "low scores for asset management are not surprising, as this is a relatively new concept for rural water supply" (2017, p.3).

Country	Institutional capacity	Financing	Asset management	Water resource management	Monitoring and regulation	Total sector score
Benin	6	4	5	2	3	20
Bangladesh	4	1	2	2	1	10
Brazil	6	5	5	8	5	29
China[a]	5	5	6	5	7	28
Ethiopia	5	4	2	2	2	15
Ghana	3	5	5	2	4	19
Haiti	3	1	2	2	3	11
India[b]	6	5	5	3	5	24
Indonesia	5	4	2	3	4	18
Kyrgyz Republic	2	3	3	3	2	13
Morocco	7	5	5	7	5	29
Nepal	3	3	2	3	3	14
Nicaragua	5	4	5	4	6	24
Philippines	3	4	2	3	6	18
Tanzania	3	3	2	5	3	16
Vietnam	3	5	4	5	3	20
Average all countries	4.3	3.8	3.6	3.7	3.9	19.3

Figure 9.2: Aggregate score for sustainability building blocks, by country (World Bank 2017 p.xvi).

The World Bank study also assed delivery models and divided them into five categories:

- Community-based management
- Local government provision
- Public utility
- Private sector
- Supported self-supply
  (2017, p.1)

It was found that community-based models were present in all the countries, though in Tanzania only one main model is applied – COWSOs. As can be seen by Figure 9.3, on average, community based models got a fairly low score, though better than local government provision and supported self-supply. This indicates how community-based models, such as COWSOs, are in need of support and improvement, but also a step in the right direction for RWS.

SDM scores	Community-based management	Local government provision	Public utility	Private sector	Supported self-supply
Bangladesh	13	10		21	
Benin		10		19	
Brazil	21				
China	16		37	29	
Ethiopia	7				8
Ghana	9			13	
Haiti	5			13	
India	28				
Indonesia	23				
Kyrgyz Republic	15				
Morocco	26	21	34	36	
Nepal	14				
Nicaragua	20				
Philippines	14	18	26	25	
Tanzania	17				
Vietnam	8	18		24	
Average all countries	**16**	**15**	**32**	**22**	**8**

Figure 9.3: Sustainability scores for service delivery models, by country (World Bank, 2017 p.xix).

Another interim study conducted for the World Bank, focuses directly on community-based management models. Based on a review of literature and project documentation, it finds five main groups of factors which appear to affect post-project sustainability in a significant way. They are:

- technical
- financial
- community and social
- institutional and policy
- environmental

(Lockwood et al., n.a., p.39)

Within these five main groups there is a hierarchy of factors, where the two most prominent are tariff collection to cover recurrent costs and the presence of some form of long-term external support. Other important aspects include preventative maintenance and spare parts availability; community management capacity, user satisfaction and WTP; continued training and hygiene education interventions; and water source production and quality (ibid).

The factors developed in this thesis are therefore meant to capture these dimensions, alongside assessing the information that was available when conducting in depth-interviews with the COWSOs. With the 14 factors and the given weighting, a COWSO could potentially achieve a score of 30. It is important to emphasise that this is an exercise done to provide a framework which makes it easier for both 4CCP and NCA, and potentially other similar organisations, to track the progress made.Thus, it may function as a tool to best concentrate efforts where they are most needed. Additionally, it might be used as a tool for assessing the training of the COWSOs. This is not meant to portray certain villages in a negative light and contrast them with those who perform better. Seeing as this Master's thesis is publicly available, it is therefore decided to anonymise the villages (as with WTP), though a non-anonymised version will be sent to both 4CCP and NCA.

As can be seen from Table 9.2, the COWSOs are divided into three categories based on an assessment of their capabilities and associated function. Textbox 9.1 list the criteria for the three different groups are presented alongside typical characteristics

Name of village	A	B	C	D	E	F	G	H	I	J	K
Improved source or not	1	1	0	0,5	1	0,5	0,5	1	0	1	1
Creating COWSO before instalment of pump	1	1	1	0	1	0	0,5	0	0,5	1	1
Number of people connected to water point	1	1		1	0,5	0	0,5	1		1	0
Gender balance in COWSO	1	1	1	1	1	0,5	1	0	1	0	1
Frequency and regularity of meetings	1	0,5	1	1	1	1	1	0,5	0	0,5	1
Making regular Reports	0,5	0,5	0	1	1	0,5		1	1	0,5	1
Taking Minutes of Meeting			0	1	1			1	0,5	1	1
Creating a Budget	0,5	1	0	0	1	0,5		0,5	0	0	0,5
Being Legally Registered	1	1	1	0,5	1	1	1	1	1	0,5	1
Having a Bank Account with Funds in it	1	1	0,5	0,5	1	1	0,5	0,5	1	1	1
Strength of Relationships with District Engineer, PETS and Village Leaders	1	1	0	0,5	1	1	0,5	1	1	0,5	0
Availability of Back-up Solution	1	1		0,5	1	0	0	0	0	0	0
Access to Technician and Toolbox	0,5	1	0	0	1	0	1	0	0	0	0
Having Future Plans and Visions	1	1	0	1	1	1	0,5	0,5	0,5	0,5	0
Total Score	24	26	8,5	17	29	16,5	14	19,5	16	17	18,5

Table 9.2: Scoring of the different COWSOs interviewed during the fieldwork.

TEXTBOX 9.1

Red: 0-16,9
Basic requirements such as being legally registered and having a bank account, but insufficient funds. COWSO does not meet regularly enough and there is a lack of paperwork. No visions or clear plans.
Immediate and extensive action required.

Orange: 17-23,9
Basic requirements such as being legally registered and having a bank account, have some funds. COWSO meets fairly regularly and reports are produced for transparency, but weak relationships and limited options in the case of pump failure. Limited visions and plans.
Action required.

Green: 24-30
Improved source and backup solution. Basic requirements such as being legally registered and having a bank account met, have significant funds. Gender balance and very strong relationships. COWSO meets regularly and reports are produced for transparency, as well as a budget. Clear visions and plans for the future.
Follow-up and guidance advised.

To illustrate how the differences in institutional capacity and COWSO functioning are manifested, three examples are presented.

Red - C:
C is a village where a borehole has been drilled but no pump has been installed. They started collecting money for the project after meetings with 4CCP but took no receipts. The village executive officer (VEO) then disappeared with the money and people were understandably both very angry and frustrated. 4CCP are now dealing with the case and though the VEO is not being charged for corruption, a process is underway to make him repay all the money. C is a poor village which has suffered from droughts for four years and they lack social cohesiveness, in addition to a clear vision for the water project. When visiting the village, it was quite striking how desperate the situation was and how defeated the people were, as they had tried to collect money and then it backfired. Instead of being angry and utilising that anger for improvement, there was a sense of despair and inaction. The water that was currently being used was either very dirty surface water or overpriced water from a private open well. C was also presented as a place suffering from 'donor syndrome' as people were used to receive both maize and medicine for free and therefore had trouble mobilising to implement positive change. C serves as an example of how important it is to mobilise the whole community and how crucial both transparency and bookkeeping is. The water point has a good yield and if they can turn some of their despair around to positive frustration, while learning from what went wrong the first time, they may achieve a positive transformation as access to clean water would drastically impact the village.

Orange - H:
This village has a hand pump which was installed in 2015 and another one which has been installed through a 4CCP programme. They charge an annual fee for water, which is collected in April by the COWSOs accountant. They have several sub-villages and though they receive reports from all, they are sometimes severely delayed. The COWSO only meets every three months during the village assembly, this appears to mainly be due to the members being from different sub-villages. When they have issues with the pump, they either contact the district engineer directly or if it is a minor issue, they find a village technician. They do take minutes of meeting, have a bank account with some limited funds in it and keep receipts when they have bought equipment. However, distance to the water point is a major challenge, which means that many people are not using it – particularly in the wet season. This results in limited funds and though it is considered important to expand the system and install more taps, they have not been able to mobilise the community sufficiently so that this is possible, as of now.

Green - B:
B is a fairly small village not too far from HLH. The water point has a low yield, but the community is very organised and highly motivated. They managed to collect money and approached 4CCP themselves before the project had actually started. It is said that B i provided the idea of having villages contribute a percentage of the cost, as to increase a sense of ownership and avoid failed projects and 'donor syndrome'. A solar powered pump was installed in B in 2018 and it appears to be very well looked after. The COWSO has been selling water to non-residents at a higher price and has thereby collected money which can be used for their project's sustainability and potential expansion. They have a bank account with sufficient funds and very strong relationships with both the village leaders, 4CCP and the district engineer. B has been as an example village for other villages and has shown how important local initiative is, and how motivation and cooperation is perhaps more important than the physical conditions.

9.3 Discussion and recommendations

9.3.1 COWSO and IAM

Having a well-functioning COWSO is important for a sustainable and resilient water supply. Therefore, the IAM framework developed by the IRS is used to assess and analyse the functioning of COWSOs (see Figure 9.4). This framework is intended to be used within the organisation itself, not by external observers, but it provides a very useful starting point. As some of the elements are less applicable for COWSOs and some are lacking, an updated version for rural IAM where COWSOs are in charge of water supply will therefore be suggested at the end of the chapter.

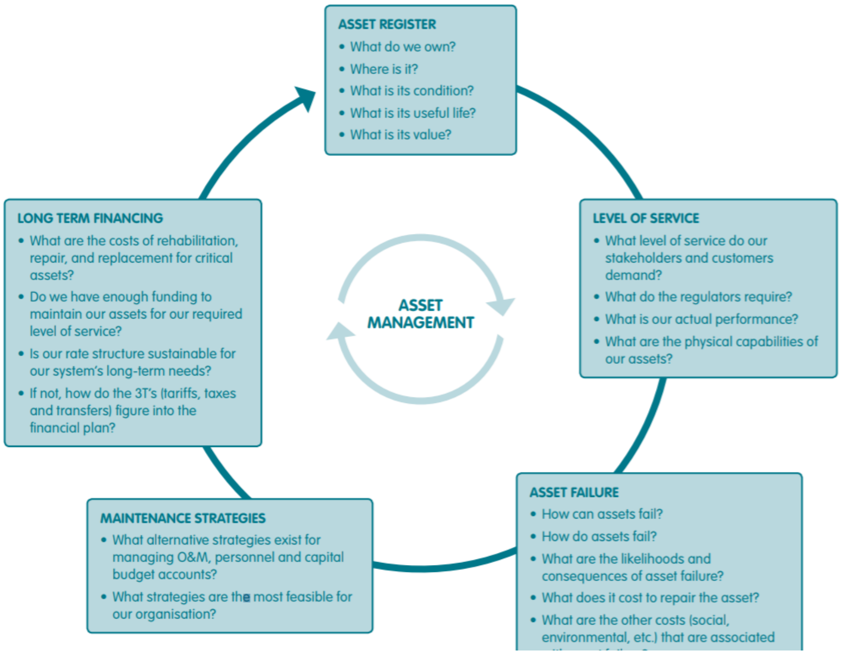

Figure 9.4: IRC Five pillars of IAM (Boulenouar and Schweitzer, 2015, p.3).

9.3.1.1 Asset register

Having accurate and detailed knowledge of assets often represents the first step when implementing IAM and constitutes an important component of improved management (Boulenouar and Schweitzer, 2015). In the rural water sector, the development of asset registers is most often related to water point mapping activities. Mapping activities can complement IAM, but to be effective these activities must involve detailed data collected on a continual basis. Therefore, information regarding the condition, performance and value of the assets should be regularly collected and entered into the asset register (ibid).

The TCP pumps installed in the study area by NCA and 4CCP have either been India Mark II Extra-Deep Well or solar powered pumps. For hand pumps the physical infrastructure therefore consists of the pump itself, as well as the down-hole components. Furthermore, a solid foundation for secure drainage is also needed. Additionally, there should be a mechanism to lock the pump and a surrounding fence, though this is often made up of trees and bushes. It appears that knowledge about the pump and its various components, varies a lot from village to village, mainly depending on whether there is a trained technician living in the village. For the solar powered pumps the system is a bit more complex with the solar panels, the pump itself, raised storage tanks (including their supporting concrete structure) and tapping points. All the solar powered pumps have metal fences surrounding them, as theft and vandalism is more likely, and more costly if it were to occur.

The positioning of the water point tends to not be in the middle of the village. It should be noted that people often live very spread out, which makes sense as they are mostly relying on agriculture. In several villages a compromise has been reached in terms of positioning of the water point between two or more sub-villages. Though this is logical, it often results in everyone having to walk quite far and therefore not meeting the requirements of basic coverage according to the JMP's drinking water ladder. In many cases it was also a stated objective to have the water point as close as possible to the local school. However, the positioning of the water point is also largely dictated by the natural conditions and where testing has shown the existence of a productive borehole.

The condition of the solar powered pumps were very good, owning largely to the fact that they are newly installed and that there are few moving parts so they are less prone to wear and tear (see Figure 9.5). The newer hand pumps, or those that had recently been renovated, seemed to be in a good condition, though there were several examples where both the pump itself and the tapping station was in clear need of maintenance (see Figure 9.6).

As discussed in the previous chapter, the expected lifetime for a solar powered pump is dependent on both the panels and the pump itself. The solar panels have an expected lifetime of about 25 years, while the pumps are estimated to last between 10-20 years depending on the quality (Solar Mango, n.a.). This of course relies on the optimal O&M. The expected lifetime for the India Mark II hand pump will vary depending on the manufacturer but the working lifespan is found to be 15-20 years (Parry-Jones et al., 200, p.16). This type of pump requires more maintenance and repairs and ideally the components should be replaced incrementally when needed so as to increase the overall lifetime of the pump.

Figure 9.5: Solar powered pumping system, both clean and with a good fencing system.

Figure 9.6: Hand pump in poor condition with both lack of fences and a concrete base.

When estimating the value of the infrastructure, a question becomes whether one also includes the preliminary work done. The cost of a borehole is 14.000 USD and for a solar powered pump the whole project normally costs 30.000 USD in total, meaning that the panels, pump and elevated storage tanks total 16.000 USD. For the India Mark II Extra-Deep Well the cost of drilling is essentially the same and though the cost of the pump may vary with the supplier it is estimated to be around 2500-3000 USD for a good quality pump. This is only the direct financial value of the physical components and it was made very clear in the interviews that a safe water supply holds value far beyond this. There are other economic costs associated, such as productive time lost due to unsafe water supply sources and time spent collecting water, but also less quantifiable values such as health and improved living conditions, as explored in the introduction.

Seeing as the assets are confined to a small geographical area and mostly out in the open, it seems that the COWSOs have a good understanding of what assets they have. However, the value of the assets and concerns regarding lifetime seems limited. This is probably due to the fact that there are 'civilians' and not trained professionals who are in charge of the management on the COWSO level. Greater understanding of the physical assets and their associated value could perhaps improve the way they are managed – thereby increase the sustainability of the projects. This should therefore be included as a part of the COWSO training. Another useful approach is tools such as EpiCollect 5, which is a programme where an app can be downloaded, to record information about a water point and its geographical position. This provides an opportunity for organisations such as 4CCP and NCA to have up to date information about for example the yield, number of households connected and the condition of a water point. Having sufficient information is a crucial first step in improved management of assets (see Figure 9.7).

View	Delet	Edit	Title	Created At	village name	COWSO name	location of the vi...	water point photo	types of pump	district name	year of construct...
			8443c901-878...	8th Mar, 2019	Getanyamba	Endagew Chini	-4.225469, 35.094288		hand pump	Mbulu	01/10/2015
			7f386d33-6507...	8th Mar, 2019	Getanyamba	Endagew chini			hand pump	Mbulu	10/10/2015
			1b2e4caf-0ef8-...	8th Mar, 2019	Getanyamba	Endagawa chini			soler	Mbulu	06/10/2018
			fa4f80d8-6d10-...	8th Mar, 2019	Getanyamba	Endagew Chini	-4.20911, 35.050236		soler	Mbulu	06/10/2018
			2bd4975f-ecbb...	8th Mar, 2019	Endagew	Shule ya secondary			hand pump	Mbulu	15/10/2015
			c6e13515-eac...	8th Mar, 2019	Endagew	Endagew School	-4.224778, 35.038272		hand pump	Mbulu	01/11/2015
			e8fb1e2f-02e2-...	8th Mar, 2019	Dilghangh	Dibagi	-4.40652, 35.031509		soler	Mbulu	31/12/2019
			2da8af21-9e7f-...	8th Mar, 2019	Dilghang	Dibagi			hand pump	Mbulu	18/10/2019
			8498dd63-379...	8th Mar, 2019	Haydom	Hang'wa Project	-4.18343, 35.011279		soler	Mbulu	01/03/2018
			6b231a2f-2d0d...	8th Mar, 2019	Haydom	Hang'wa			soler	Mbulu	17/10/2018
			142666fc-a903...	8th Mar, 2019	Bassonyagwe	Dulabits			soler	Mbulu	22/08/2019
			3033ef8c-0c9b...	8th Mar, 2019	Basonyagwe	Dulabits	-4.145006, 35.049569		soler	Mbulu	31/12/2019
			7de3f2c7-0ce6...	8th Mar, 2019	Endanachan	Endanachan			soler	Mbulu	08/03/2019
			8f00424d-44a5...	8th Mar, 2019	Endanachan	Endanachan	-4.120219, 35.052125		soler	Mbulu	01/08/2018
			4fce7fe6-4345-...	8th Mar, 2019	Murkuchida	Juamamu			soler	Mbulu	09/10/2019
			65d5347e-757...	8th Mar, 2019	Murkuchida	Juwamamu	-4.083999, 35.099582		soler	Mbulu	31/12/2019
			b3fbf75b-9482-...	8th Mar, 2019	Endamily	EDMASOB			soler	Mbulu	01/08/2018
			e75b8b93-c24...	8th Mar, 2019	Endamilay	Edmasob	-4.04627, 35.141385		soler	Mbulu	01/08/2018
			dc0a8d15-e70...	7th Mar, 2019	Endagulda	MTUE MAMA NDOO ...			soler	Mkalama	21/12/2019
			67277dfb-b702...	7th Mar, 2019	Endagulda	MTUE MAMA NDOO ...	-4.084387, 35.000551		soler	Mbulu	31/12/2019
			4774a472-240...	7th Mar, 2019	Hilamoto	Huruma			hand pump	Mkalama	03/11/2017
			20a88f86-4c73...	7th Mar, 2019	Hillamoto	Huruma	-4.097999, 34.956219		hand pump	Mkalama	01/11/2017
			50407ceb-016...	7th Mar, 2019	Munguri	School			soler	Mkalama	31/12/2015
			8fa8ea43-9777...	7th Mar, 2019	Munguri	School - no COWSO	-4.017844, 34.839579		soler	Mkalama	31/12/2015

Figure 9.7: Logging of borehole information in EpiCollect5. The entries can be changed based on the information one wants to store.

9.3.1.2 Level of service

"Meeting an agreed level of service in the most cost-effective manner is the primary objective of IAM" (Boulenouar and Schweitzer, 2015, p.4). It is crucial that the service levels are clearly defined, with agreed indicators and corresponding benchmarks or targets. In the rural water sector, the benchmarks will most likely be the national standard for basic services with indications of accepted distance, quality, quantity and reliability of service (ibid). In this case study benchmarks or targets set out by the JMP drinking water ladder has been used to assess the situation.

What is somewhat unique about COWSOs is that the consumers and the providers are one and the same, thus there appears to be a alignment between what the customers and stakeholders expect. All major decisions are done alongside the VEO and the villagers in the village assembly meetings where the COWSO present a report every three months. Several COWSOs were considering expanding their current system and it appeared that expectations quite rapidly increased once a water supply system was in place. For the villages that had not yet installed a pump, there was great variation in terms of expectations. One village (village L) had plans to install an associated irrigation plot and bring water to a nearby school by either pumping or gravitation, though the site had a very low yield and all this would not be possible if only relying on solar power. Another village (village C) however had no clear plans and stated that they would be happy with any sort of water supply, despite a high yield. This is however likely due an unfortunate situation with the village executive officer, see classification of village C (p.85).

When people have paid, they expect that the promised service is provided. Still, there were many cases were the situation did not meet the requirements of JMP drinking water ladder, such as long waiting times at the water point or having to walk a great distance, most people seemed to accept this because it still represented a form of progress. There were different approaches to queuing reported. In some villages elderly people were given priority, while in others it was based on a first come, first serve. Certain villages had limits to how many buckets one person could fill at a time (2 buckets), particularly in the dry season. This was intended to reduce the waiting time, while other villages had no restrictions. In some places it was considered acceptable for people to leave their buckets in the line while attending to other activities and return at a later point, whereas other villages considered this to be a source of conflict and something that should be avoided. What was common was however that each community saw their way of doing things as the best available option, which indicates a participatory process.

The role of regulators is not quite clear when it comes to COWSOs as they are under the jurisdiction of the district, but it varies how involved they are. Because the project is community owned, they largely function as the regulators, though everything they do must be in accordance with the national guidelines. An example of this is how members are involved in COWSOs for three years. This was stated in every interview and people were aware of this and referenced the national guidelines. However, not every member must be replaced, which improves continuity and transferral of competence and experience.

The actual performance of COWSOs varied greatly. Some had regular meetings, produced financial reports, were in close contact with 4CCP or the district engineer and had clear plans for how to improve and expand the water project. Others were basically non-existing and did not even charge for water. In terms of supplying water, all the existing water points visited were functioning, though some hand pumps were in need of pretty urgent repair. It therefore seemed as if the main obstacle for COWSOs was mobilising the community to collect enough money to cover their percentage of the instalment costs required by NCA. Though this is arguably a much needed and very important process because it increases the sustainability of the project and creates ownership, it is also very reliant on one or more members of the community taking responsibility and showing initiative. For the physical capabilities the major challenges were with the hand pumps as these are being used beyond capacity, both in terms of population and depth in most cases.

9.3.1.3 Asset failure

In-depth technical knowledge of how each asset deteriorates and fails, and what can and should be done to prevent this represents a cornerstone of IAM (Boulenouar and Schweitzer, 2015). In the water sector it is common to categorise assets into three groups: pipelines, civil structures and electrical/mechanical assets. They have different deterioration patterns and require different maintenance treatments. Pipelines generally deteriorate progressively over a long time span but are hard to maintain preventively, civil structures also deteriorate progressively but they are easier to perform preventive maintenance on, while electrical/mechanical assets are prone to more abrupt failures (ibid). The three categories mentioned above are more relevant for motorised systems than for hand pump systems.

Interviews with the COWSOs revealed somewhat limited knowledge of the assets they were in charge of, unless a technician was part of the committee. Again, this is not surprising, seeing as it is a volunteer position taken up by the local community. The important factor then becomes the relationship with the district engineer, and whether they can receive the help and guidance needed. The steps that were taken if an asset failed was to first contact the district engineer. He would then send a technician to identify the problem. After that, necessary spare parts would be ordered if this was not available locally, before returning to do the repair. This would therefore take a minimum of two days, and if the COWSO did not have enough money available in their bank account for spare parts, it could take several weeks while the money was being collected. This highlights the importance of having sufficient funds in the account, but when inquiring about budgets, where planned maintenance or potential repairs were included, this was not produced in many of the villages. Seeing as none of the places interviewed had a backup solution in case of pump failure this largely meant that people had to use surface water, as it was the only available option. The solar powered pumps have a buffer with their storage tanks, usually 10 000 L, which gives some flexibility of approximately one day. However, seeing as they are new and there is little experience with repairs and few needed parts if they were to break, it is uncertain how long it would take to repair/replace the pump or the solar panels. The lack of an alternative water source is something that quite drastically reduces the resilience of the water supply system. For the hand pumps the likelihood of asset failure is quite high and for both type of pumps the consequences are severe, particularly if it were to happen in the dry season when people do not have collected rainwater to rely on. Unfortunately, hand pumps in particular are more likely to break in the dry season because they are being used intensely.

9.3.1.4 Maintenance strategies

Once the modes of failure are understood, maintenance models and replacement strategies can be developed. This is dependent on the available budget (Boulenouar and Schweitzer, 2015). In the rural water sector, maintenance strategies are often constrained by limited capacity – both in terms of financial and human resources. As a result, a 'run to failure and do nothing' approach is common, as opposed to perpetual or light renewal with some replacements (ibid).

One major lesson from the COWSO interviews was the fact that maintenance and repairs was seen as synonymous, and preventive maintenance was not a pursued strategy. For example, there did not appear to be any routines in place to oil the chain of the hand pump, which is a fairly simple but still important operation. When asked about routines for O&M, all COWSOs responded by describing the process that takes place when the pump fails. This may partly be due to translation, but it appears to be a widespread phenomenon. The villages that had a technician were able to repair small and simple issues themselves, which saved both time and in some cases money.

4CCP have two technicians that work part-time for them and are employed at the HLH. A suggested maintenance strategy is therefore to have one technician take on all the 50 boreholes or so that are in the local area, and travel to each borehole twice a year to do preventive maintenance. This could increase the lifetime of the pumps and also the resilience of the system through improved management of the assets.

Several COWSOs struggled with limited budgets and would therefore have issues if a big cost were to occur. Some of them therefore considered having a yearly lump sum to be collected after the harvest, in addition to the water tariff. This was however mainly proposed as a measure to increase the funds to make it possible to expand the system, and not as a way of ensuring funds for maintenance and potential repairs.

Another maintenance strategy is toolboxes made for the India Mark II hand pump, which can be in the village itself or in the 4CCP office, as discussed in the previous chapter. These are standard toolboxes, but they were criticised both for their lack of certain tools and the quality of the tools. Two COWSOs specifically mentioned that they had considered spending part of their budget on having a member of their village trained as a technician so that if an issue were to occur they would be capable of solving this quickly, particularly if they also had the toolbox and some often used spare parts in the village office. This is considered a feasible and sustainable strategy, but mainly relevant for hand pumps as the electrical work in a solar powered pump requires extensive competence and sophisticated tools.

9.3.1.5 Long term financing

To create a realistic and executable plan, the service providers must understand the costs of the asset system and its components over their full life-cycle and the chosen maintenance strategy (Boulenouar and Schweitzer, 2015). In addition, it is critical to assess the extent to which "tariffs can be used to cover those costs and the extent (if any) to which locally generated taxes or government transfers will be required" (ibid, p.5).

Ensuring predictable and sufficient funds is crucial for creating resilient and sustainable systems. The cost of water is discussed in greater detail in chapter 10 Willingness to pay (p. 95). The COWSOs interviewed were all legally registered and had a bank account, except for two were there was some ambiguity. The COWSOs are required to put the money collected from tariffs into the bank account, but it often seemed to be quite delayed and seeing as the tariffs are cash payments this is problematic from a transparency perspective. It should be noted that most places charge per bucket, as recommended by 4CCP. Some COWSOs had very little money in their account (30.000 TSH), while others had several million TSH. Those who had very large sums (10,4 mill TSH) were however often saving up for the instalment of a pump. It therefore varied if the COWSOs had enough funding to maintain their required level of service because the income flow could be quite limited, while the expenses could be large. In the wet season, some COWSOs collected the same amount of money over several months as they did in one day in the dry season. It is therefore important to have a budget where both expenses and incomes are accounted for so that one can better plan. Though no COWSOs could present any prepared budgets, the main sources of income were through tariff collection. The expenses were reported to mainly consist of repairs and maintenance, salary for the tariff collector and the night guard if applicable.

If they had a budget it would be easier to decide on a water tariff, which is both sufficient and fair, at the village assembly meeting. This could also improve the transparency and accountability of the water committee from the perspective of its customers. The long-term needs of the systems vary depending on whether they are hand pumps or solar pumps. In both cases there is a higher chance of issues in the beginning and towards the end of the lifetime, as illustrated by the bathtub-curve in Figure 9.8. For hand pumps more maintenance will be needed, though this will be less challenging and less expensive than that for solar powered pumps.

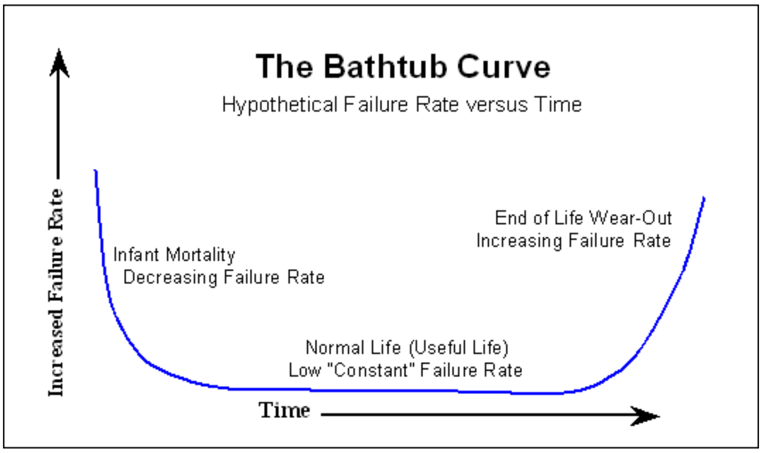

Figure 9.8: Bathtub curve explaining failure rate during lifetime (Wilkind, n.a.).

The 3T's mentioned in the IRC framework; tariffs, taxes and transfers, are important for the functioning of the COWSOs. The tariffs collected range from 15-50 TSH per bucket and this is actually quite high when one calculates based on the percentage of the average yearly income spent on water. In general people pay very little taxes, which is as argued a reason for why water provision can be legitimised to be the responsibility of the community. The transfers from NCA are crucial as they lay most of the foundation for the water supply system through covering 85% of the instalment cost. There are however no transfers once the system is in operation and it is therefore very important that the community is mobilised so that the water supply system can continue to operate in the future.

9.3.1.6 Suggested IAM framework for sommunity based management

The above analysis has attempted to assess how the COWSOs in the study area fare from the perspective of asset management according to the framework presented by the IRC. Based on the results from the fieldwork certain amendments have been made to the framework to make it more applicable when assessing community based RWS, see Figure 9.9. Some rephrasing has been done to make the framework more available to external assessments. Additionally, the expected downtime of pump failure and the alternative source of water has been added to Asset Failure, while availability of spare parts and tools is added to Maintenance and Repair Strategies, as well as the needed rate structure for improvement and expansion of the system is added to Long Term Financing. Finally, for a community-based water supply system, the functioning of the water committee itself is crucial. This is therefore included as factor be assessed when attempting to improve asset management.

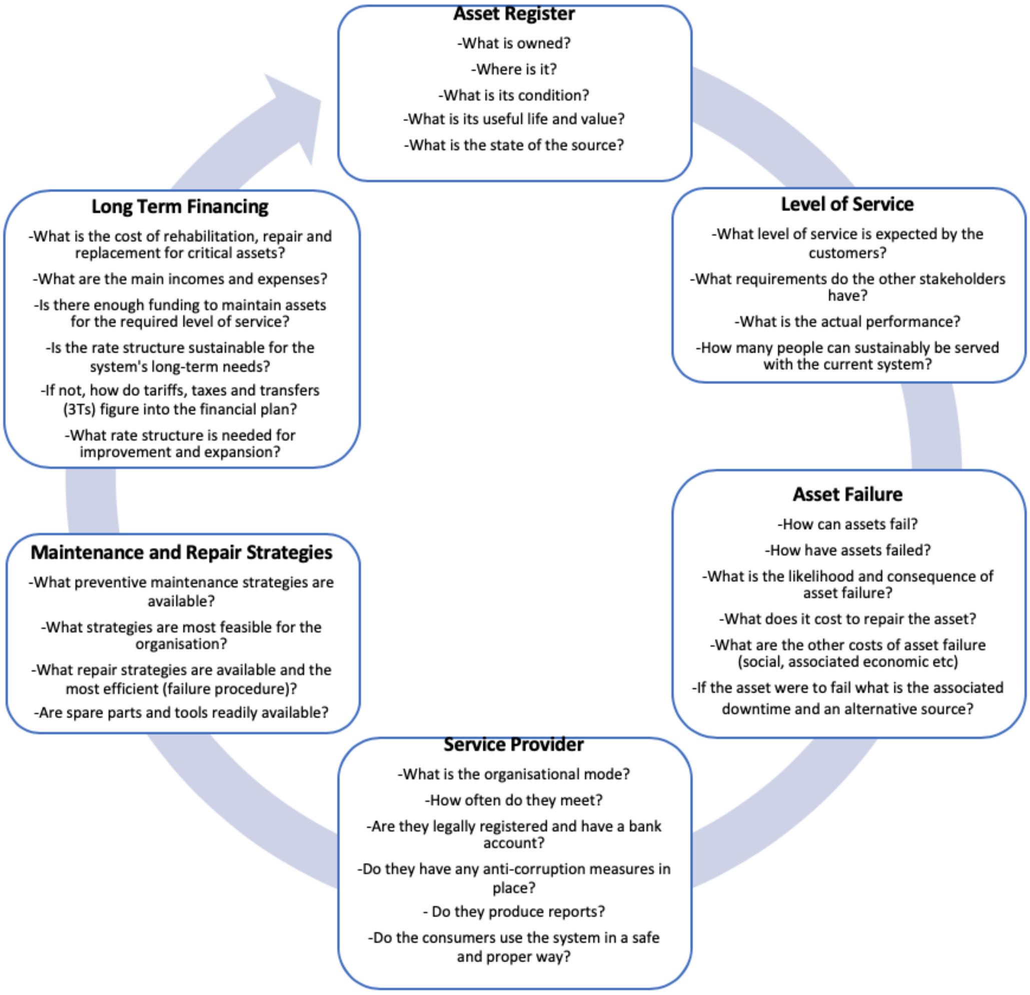

Figure 9.9: Suggested updated figure rural IAM assessment, particularly with COWSOs in mind.

9.3.2 Recommendations

Based on the analysis some recommendations can be put forward. It is advised to emphasise the most important aspects in the training of the COWSOs and highlight the necessity of taking minutes of meeting and a budget for improved transparency and accountability. Furthermore, it would be beneficial for each COWSO to develop a (digital) document including the nature-based conditions, the yield of the borehole, the number of people served, an estimation for average incomes and potential improvements and expansion of the system, including associated prices. This is a tool for better management which can also help to further improve the current system in the future. This can take the form of action plans with a 5- or 10-year perspective, which should include an estimated budget so that current tariffs can be assessed both in terms of O&M in the near future, but also as the physical components reach the end of their lifetime. For water points with solar panels and a high yield, future expansion could be the development of 'veggie gardens', which can provide a source of income.

The whole community should be trained in how to safely operate the pump, this is particularly relevant for those villages that have a hand pump. The COWSOs should also have at least one formal meeting with the district engineer per year so that (s)he is informed about their situation and potential challenges. It is further recommended that the COWSO should be well-established before a pump is installed, which entails having suggested tariffs as well as areas of responsibility for the members of the committee. It is also advisable for new COWSOs to go on a 'field visit' to an existing and well-functioning COWSO to learn directly from them. Additionally, it is thought to be better if not the entire COWSO committee is replaced after three years to ensure some continuity and transfer of information and experience.

9.4 COWSO - conclusion

It was hypothesised that COWSOs were good at fairly distributing water and resolving water related conflicts because they directly included consumers, but that they were lacking in capabilities related to long-term planning and technical improvement. Though not necessarily false, the initial understanding was limited and did not provide a nuanced enough picture. This analysis of the functioning of COWSOs has attempted to emphasise the importance of non-technical factors in water provision and how COWSOs are crucial for IAM and resilient systems that are adaptable and will continue to function in the future. Seeing as the responsibility for water supply falls on the lowest administrative level, the functioning of the committee is to a certain extent reliant on what in Norwegian is called a 'fire soul' – someone who goes beyond what their mandate requires and puts in extra effort for the greater good and motivates and engages those around them. This can obviously make the functioning of a committee vulnerable. It is very impressive to see the important work that 4CCP and NCA does, and particularly their emphasis on community mobilisation. This is something that is often lacking in development work, and while travelling around several examples of failed projects where just the technical infrastructure had been implemented were observed.

The framework provided with 14 factors and the associated scoring, alongside the suggested version of an asset management framework for rural water supply relying on a community based approach, attempts to provide a more tangible approach to the functioning of COWSOs. It is hoped that this may make lofty terms like resilience and sustainability and make them more quantifiable and thereby more available to improvement through direct and targeted measures.

10 Willingness to pay

Enough and predictable funding is crucial for long-lasting water supply systems. To achieve this a sufficient but fair tariff must be applied. During the fieldwork in Tanzania 107 WTP surveys were conducted to address the research question:

> *What are the factors that affect willingness to pay for water and what are appropriate tariffs, both for current and improved services?*

The results from these surveys are presented after a brief summary of previous WTP surveys in Tanzania. Additionally, a discussion of the findings and the advantages and disadvantages of a per bucket versus an annual fee is included, alongside recommendations for tariffs.

10.1 Background

Sufficient long-term financing is a key factor for IAM and needed to achieve a resilient water supply system. A water tariff that, at minimum, covers costs associated with O&M and repairs must be collected. The tariff should be integrated with other measures so that it ensures environmental, economic and social objectives at a cost-efficient level. Hence, the tariff should be high enough to ensure that the waterpoint can fulfil its objectives, simultaneously it must be low enough to make people use the improved source rather than surface water. Thus, the fine line needs to be determined, and this threshold may vary between COWSOs, depending on the social and economic standing of the customers. Furthermore, the tariff needs to be collected in an efficient way. Alternatives for payment can be seasonal charge, annual fee or payment per bucket (20 L). Additionally, payments can be in the form of cash, mobile payment or bank transfer, either at the water point or beforehand.

A global meta-analysis on WTP for improved water services was conducted by Van Houtven et al. (2017). An important topic analysed in the study was how the low rates of sufficient water supply and sanitation affected household demand and WTP in the developing world. The major findings were that in addition to several demographic, political and socioeconomic factors, one should also recognise and consider the economic benefits resulting from improved drinking water services.

Related to the research question a few hypotheses were formulated, as described in Chapter 1.2 (Research questions, p.1).

1. Women are willing to pay more as they have more to gain from improved water services
2. People are willing to spend at least 3-5% of their household's average yearly income on water
3. People with poor current service would be willing to spend more on water
4. The closer the tap is to one's home, the more the customers are willing to pay
5. A yearly fee for water is preferred compared to a per bucket fee, to encourage use of groundwater in the wet season

Van Houtven et al. (2017) found in their study that the WTP in Tanzania was 0,10 to 0,23% of GDP per capita, as illustrated in Figure 10.1. Using a shared currency converted by relative PPP is beneficial when comparing WTP between different countries (ibid).

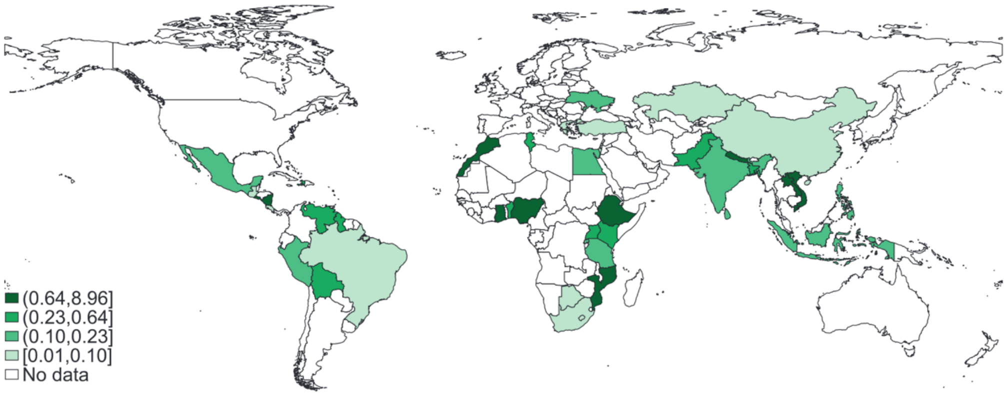

Figure 10.1: Average WTP estimates for sample study countries as percentage of GDP per capita. WTP estimates are per household per month, and normalized to 2008 USD calculated at PPP (Van Houtven et al., 2017).

Using a percentage of GDP per capita might not be the best way to set a tariff as taking an average for the whole country is not ideal in a country with large differences where a significant percentage of the population rely on subsistence farming. This is also a low percentage compared to UNDP's threshold, recommending that 3-5% of the household's income should be spent on water (Watkins, 2006). UNDP's approach to setting an appropriate tariff level is found to be better than a percentage of GDP as one can set different tariffs in different villages/regions based on the median household income. Additionally, it is a concept that is easier to grasp, hence also implement.

Overall, research conducted on WTP has found that there is a high positive correlation between income and WTP. Furthermore, people have a higher WTP for private connections compared to public ones. Lastly, results "strongly suggest that households' WTP for proposed improvements in water access declines as their baseline water availability improves" (Balderjahn, 2003, p. 402, quoted in Breidert et al., 2006). It appears that estimating WTP is sensitive to scope and that the levels increase systematically with improvements (ibid). According to a study from 2006, estimations for private water access in the Manyara region (where Mbulu is situated) ranged from 28 to 30 USD, equal to 64.400 to 69.000 TSH per household per month (Van Houtven et al., 2017). Singida (where Mkalama is situated) had WTP estimations ranging from 24 to 28 USD, equal to 55.200 to 64.400 TSH per household per month. This analysis assumed an average household size of six people and used the national/ regional per capita income for households. National income data was accessed from the World Bank and the subnational ones were obtained from Tanzania's National Bureau of Statistics (see Figure 10.2)

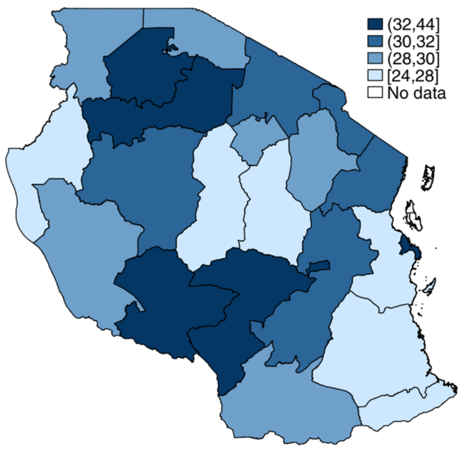

Figure 10.2: WTP for private water access, USD per household per month (Van Houtven et al., 2017).

Kaliba et al. (2009) conducted a WTP survey in Singida and Dodoma region. They found that the average user paid very low fees on a monthly basis, even when accounting for inflation. The study however also identified that the users who paid per bucket (20L) had an average yearly cost that was 44% higher than those who paid an annual fee.

Furthermore, the study found that in the Dodoma Region family size and satisfaction with the current system was a highly statistically significant variable (ibid). In other words, a large family must do more frequent trips, thus being more likely to want to improve the water service. The satisfaction "with reference to project performance implied both an increased demand and willingness to commit resources for improvement" (ibid, p. 128). On the other hand, age, wealth and cash contribution were found to be negative and statistically significant variables. This implies that an old and rich respondent is less likely to want to improve the service as they may not be involved in fetching water or because they have their own private well. Cash contribution being identified as a negative factor may be due to 'contribution fatigue' as respondents who contributed more during project initiation or development were more likely to say 'no' to questions regarding water improvements (ibid). In Singida, they found a higher WTP amongst women than men, which is expected as they are the ones usually responsible for collecting water. This was however not found as a statistically significant factor in Dodoma region (ibid).

In 2018 a project report on tariff calculations for life cycle cost analysis (LCCA) was written as a part of a module at NTNU. An Excel sheet model was developed where the purpose was to calculate a tariff for water, required to cover O&M and other costs, for the India Mark II. The results from the study can be seen in Figure 10.3.The input data here is based on 1695 people, the average number of people served by a hand pump in the study area. As the figure indicates, the model depends on what type of expenses one wants to include, in addition to whether or not the COWSO is supported financially by an external organisation such as NCA. This calculator can give some indication on what the tariff should be, but a drawback with the calculator is that it does not take into consideration pumping from a deeper level than design depth and exceeding capacity in terms of people. Lastly, the tariff calculator is not designed for solar powered pumps.

Figure 10.3: Example of tariff calculation tool (Fyllingen et al., 2018).

10.2 Result – WTP surveys

10.2.1 Background information about respondents

To get an overview of the group of people that participated in the surveys, this sub-chapter will present some general information about the respondents. Of the 107 respondents 45,8% were women and 54,2% were men. Figure 10.4 shows the age distribution, where the median age was 43 years and the average age was 44,8 years. As the figure indicates, a large portion of the respondents were in the age group 40 to 50 years and it would have been preferable to have a better age distribution. However, participants older than 70 can be difficult as the life expectancy in Tanzania in 2016 was 62 years for men and 66 years for women (WHO, n.a.b). Furthermore, the younger groups are typically studying or not married, and therefor typically were not present at the COWSO meetings. Still, a study where a larger percentage of the respondents are young and old would be interesting. The youngest person who participated was 22 years old, while the oldest one was 100 years old.

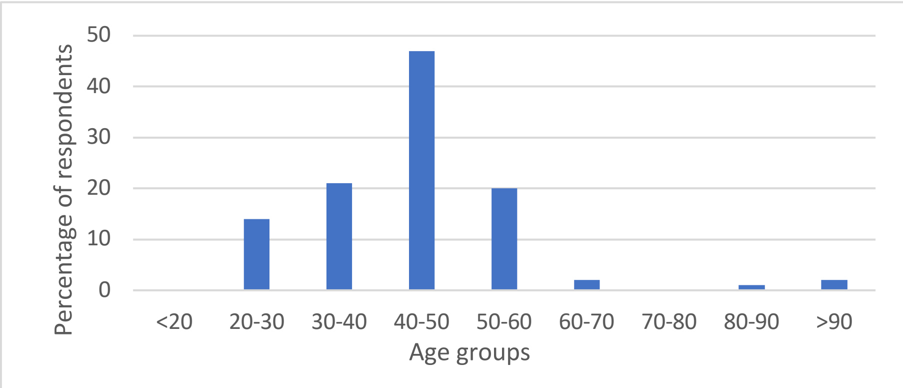

Figure 10.4: Distribution of the respondents ages.

A table of the respondent's household average yearly income can be seen in Table 10.1. As one can see from the table, 18,7% of the respondents did not know the household's income. This mainly applied to women, and it is probably due to them working in the house and therefore not participating in the formal labour market. One can from the table see that there is quite a big difference between the median and the average household's annual income. The reason for this is that a few people have a relatively high income. As median is not affected by extreme values in the same way as an average, it is decided to use median as the value for income in calculations.

	TSH	USD
Max income	6.000.000	2.609
Min income	100.000	43
Median income	550.000	239
Average income	1.032.155	449
Unknown income	18,69%	

Table 10.1: Household average yearly income in TSH and USD.

There are multiple sources of water for drinking, cooking and hygiene, as indicated in Figure 10.5. It is a fairly even distribution between hand pump, motorised pumps (solar, electric and diesel) and non-improved source (rainwater harvesting, surface water and traditional dug wells). As the figure indicates, there are some people who use multiple sources. Seasonal variability, tariff level, time and distance to the source are some of the reasons for why people use multiple sources.

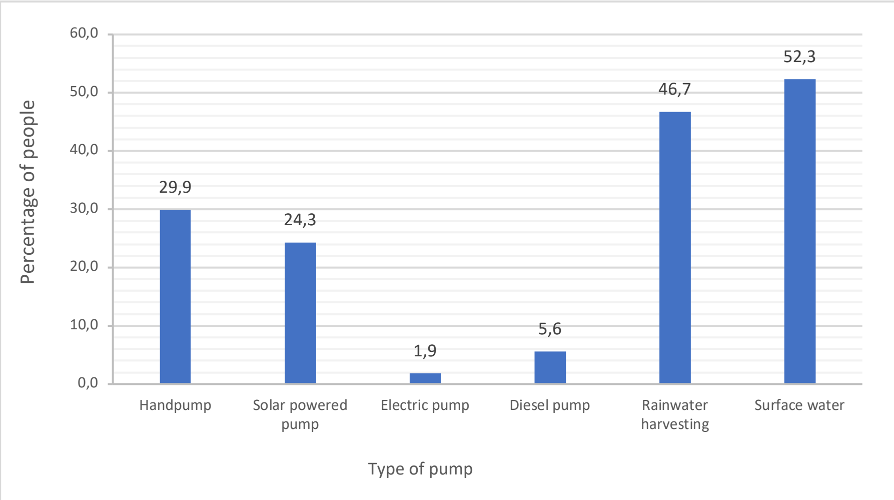

Figure 10.5: Overview of households source of water, where some people use multiple sources, given in percentage.

After personal information was collected in the survey, five scenarios or factors were investigated in terms of WTP:

- Using less than 30 minutes when fetching water. This is a roundtrip that includes walking both ways to the water point and waiting time at the well.
- Collecting water from a solar powered pump, which is less energy demanding than a hand pump.
- Tap shared with five neighbouring households to improve service in terms of distance to source.
- Tap in house, which is the closest alternative in terms of distance to source
- Downtime pump – pump never out of function for more than two days consecutively maximum 4 times a year. This was a factor as downtime is a big problem associated with India Mark II pumps, and says something about the resilience of the system.

Analysis of the data from the surveys shows that there was an increased WTP if the source was closer to the house, as seen in Table 10.2. There was also, as expected, highest WTP for tap in house. Furthermore, there was a high WTP for reducing the downtime of the pump. In the following sub-chapters 10.2.2-10.2.6, further analysis of the WTP surveys will be discussed.

WTP	Max	Min	Median	Average
<30 min	500,0	15,0	50,0	78,0
Solar powered pump	500,0	3,0	50,0	76,0
Five neighbours	1000,0	7,0	100,0	119,0
Tap in house	1000,0	6,0	100,0	122,0
Downtime pump	1000,0	20,0	50,0	104,0

Table 10.2: Summary of WTP for different improved services, currency given in TSH/bucket where a bucket is 20L.

10.2.2 Gender and WTP

The first factor analysed in relation to WTP, is gender. An analysis in Excel using median values for the 107 surveys gives the same WTP for women and men, for all five types of improved services, as seen in Figure 10.6**.** However, when using average values there are some differences in WTP for women and men, as seen in Figure 10.7. As one can see from the graph, the WTP is higher for men than women for all types of improved services, except from the aspect where reduction of time spent on collecting water is addressed.

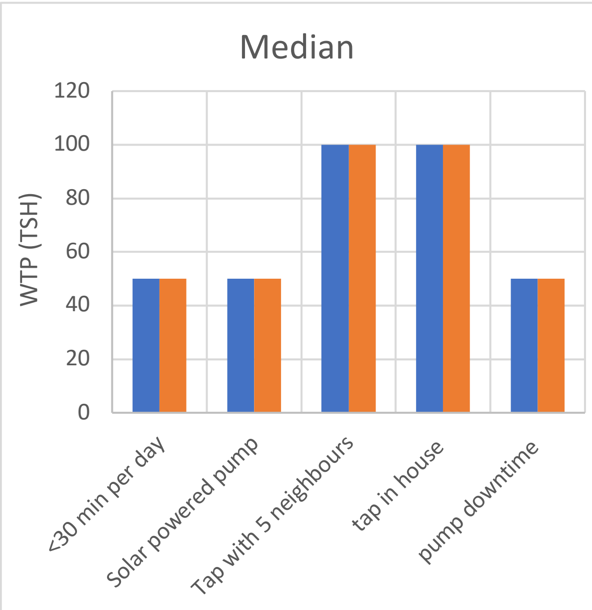

Figure 10.6: WTP using median values for women and men, given in TSH/bucket (20 L bucket).

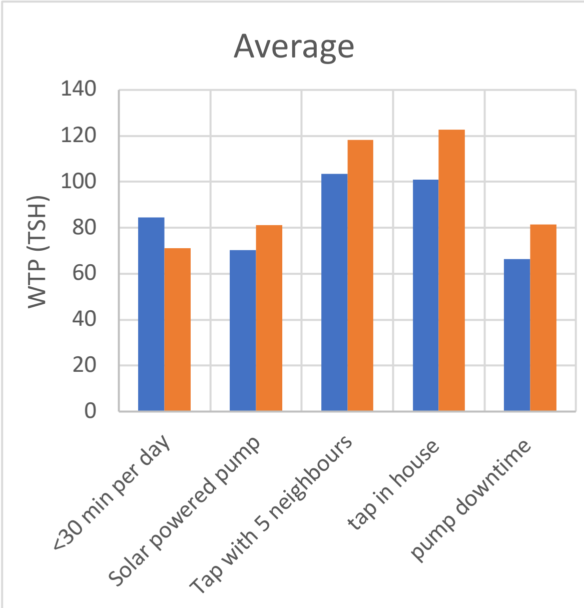

Figure 10.7: WTP using average values for women and men, given in TSH/bucket (20 L bucket).

When asking who was in charge of collecting water the most predominant answer was mother and child(ren), see Figure 7.5 (p. 57). In 26,2% of the cases, the mother alone was in charge of collecting water and in 18,7% of the cases child(ren) alone were in charge of collecting water. Additionally, the mother partook collecting water in 62,6% of the cases and child(ren) were involved in water collection in 57,9% of the cases.

As mothers are mainly responsible for collecting water, it is logical that females are the ones who want to reduce the time spent collecting water. A study done in western Kenya showed that women often sleep less than men in response to the time demand of their various tasks at home such as fetching water and other domestic tasks (Crow et al., 2012). Also, having to carry a 20L jerry can on your head for several kilometres every day is very tiring and may lead to injuries. Both the lack of sleep and the heavy load of carrying water can be the reason for why women see the value spending led than 30 minutes to a greater extent than men. Additionally, a study done in Nigeria (Ogunniyi et al., 2011) showed that male household heads had a lower WTP than females. The study proposed that this could be explained by the fact that females are usually responsible for water collection, thus more likely to "perceive the strain of walking long distances when collecting water" (ibid, p.665).

However, the notion that women have a higher WTP in relation to distance is not supported by the data from the surveys, as they are not willing to pay more for a tap shared with five neighbours or a tap in house compared with males. This might be because of the social aspect of collecting water. It is hypothesised in many studies that for women, water collection is a way of getting out of the home and meeting friends. When conducting the field work, this was however not mentioned as a motive for the women. Still, the social aspect could also explain why the women are on average willing to pay 104 TSH/bucket for tap shared with five neighbours and 101 TSH/bucket for tap in house. On the other hand, when looking at median values, they are willing to pay the same for tap with five neighbours and tap in house. Nevertheless, both genders are still willing to pay more for both a tap shared with five neighbours and tap in house, than for using less than 30 min every day to collect water. This was counter to initial assumptions, as it was hypothesised that women are willing to pay more than men.

One can from Figure 10.7 see that men are willing to pay more for both solar powered pumps and reduced pump downtime, compared to women. As men are generally the ones earning money, they might have more knowledge about economics and what different services require in terms of O&M costs and repairs. A study done in 2003 in Uganda indicated that higher education, stable jobs and higher income, all would increase the WTP (Kayaga et al., 2003). This was thought to be because "they have a higher opportunity cost for time spent collecting water from off-plot alternative sources and prefer engaging in other more productive tasks" (ibid, p.126). As solar powered pumps are less energy demanding to collect water from and a pump out of function will result in time spent on searching for water other places, men are perhaps more likely to see the value of the opportunity cost.

As median values are found to be more representative than average ones, one might conclude that in the study areas of this thesis, there are no differences in WTP when looking at gender. This contradicts a few previous studies done on WTP for water in SSA, as they often tend to conclude that females have a higher WTP than males, but it is hypothesised that this is due to a lack of insight in the household's economy.

10.2.3 Village location and WTP

The next factor analysed in terms of WTP was the location of the villages, as seen Figure 10.8, where median values are used. The entries from A to E are solar powered pumps and F to K are hand pumps.

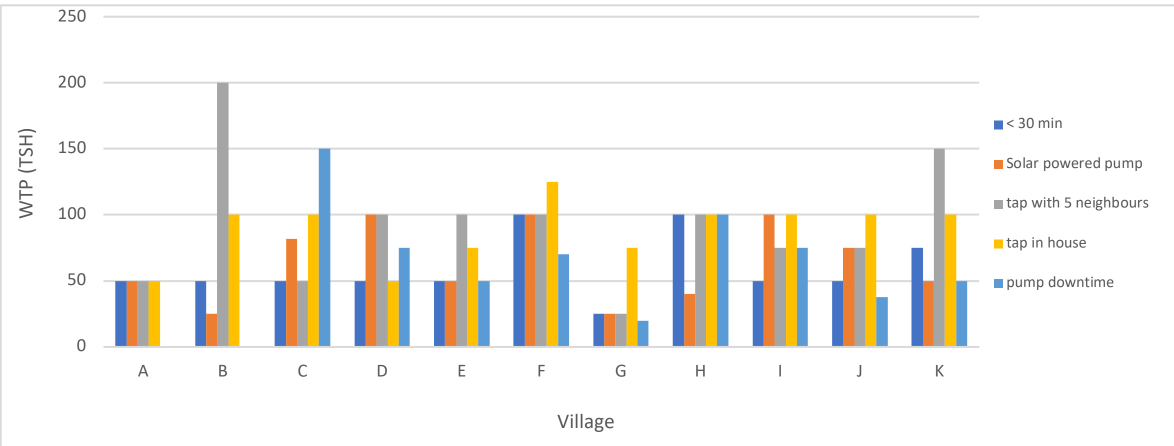

Figure 10.8: WTP for different types of improved services for all the villages visited during the field work.

If one compares village location with the graph, it is not possible to draw a direct connection between location and WTP. Village C and village F are the only places in the Rift Valley, and although village F has a general high WTP and village C has a high WTP on pump downtime, there is too small a sample size and perhaps too small geographical area to identify significant differences. The reasons for why different villages have varying WTP could be more due to factors other than location. In future work it is therefore suggested to either increase the number of studied villages in the Rift Valley, or to look at whether there is any connection between employment/work sector and WTP and between ethno-linguistic groups and WTP.

Figure 10.9 shows an average WTP for all 5 types of improved services for the three different classification of COWSOs. The graph is made of median WTP for all service where the respondents are first grouped by village, then an average value for all services are calculated based on their COWSO achievement. WTP is highest for the green COWSOs, closely followed by the yellow, while red is significantly lower. Even though the sample size is low, the WTP is in line with expected outcomes. The first important thing to note, is that all COWSOs can have a higher tariff that what they currently do have, especially for those only collecting 30 TSH/bucket. Green and yellow COWSOs might have the highest WTP as they all have an improved source, hence they have seen and experienced the importance of having safe and clean water, resulting in the community being more eager to expand and improve their system. The explanation for why green COWSOs have a slightly higher WTP than yellow ones, might be because they have a higher functioning COWSO and hence consumers are hypothesised to trust the organization to a greater extent. This might also explain the difference between green and yellow versus red. It is also possible that the correlation could be the other way around in the form that a high WTP results in well-functioning COWSOs, as a result of better mobilisation and perhaps financial situation. Regardless of the small sample size, the indication from the surveys conducted is that an increased functioning of COWSOs increases the WTP. This highlights how community mobilisation factors into the WTP, and by extension also the sustainability of the project. The opposite is clearly illustrated in failed projects where there has been a lack of community mobilisation.

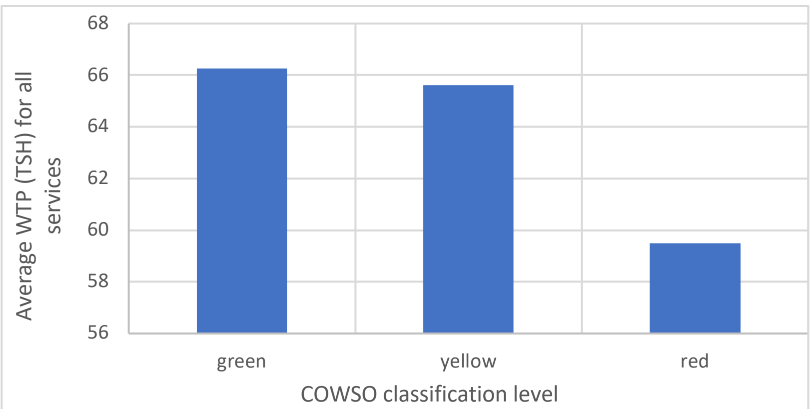

Figure 10.9: WTP from respondents divided into the classification of their COWSO.

10.2.4 Income and WTP

The 107 surveys were divided into ten groups based on income, where the income interval groups can be seen on the x-axis in Figure 10.10. Furthermore, the mean values of the five different improved services for each of the income interval groups was then calculated and plotted. As expected, the lowest income group has the lowest WTP, while the highest income group has one of the highest WTP. However, even though the WTP is increasing with income, there is a big drop at an income level of 500.000 TSH. One can from the figure see that there is a high WTP for an income from 200.000-500.000 TSH. This might be explained by the type of employment, which might make them more dependent on a stable and safe source or a source close to home. The rapid increase in WTP from 200.000-500.000 TSH and the sudden drop at 500.000 TSH is mainly due to a low WTP for a tap shared with five neighbours, tap in house and downtime pump. This implies that for using less than 30 minutes every day to collect water and having a solar powered pump, the WTP is generally the same for all the income groups. Consequently, deciding a tariff to support the system can be done without excluding members of the community.

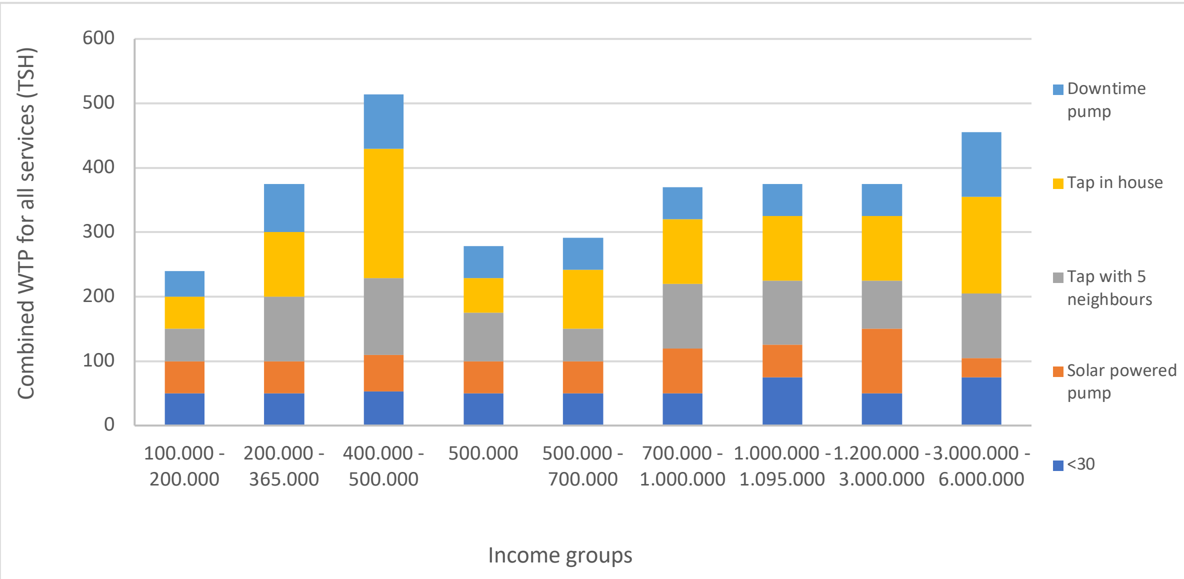

Figure 10.10: WTP where the respondents are divided into income groups.

Figure 10.11 illustrates the median WTP over all the five factors for a year's average use (8 buckets per household, 365 days per year), plotted as a percentage of income that they are willing to pay for water. As the graph indicates, the trend line has a negative exponential decay, with a R-squared value of 0,95. This means that the people in the lowest income group have a higher WTP in percentage of their income than the people in the highest income group, and since the graph is an exponential decay it flattens out towards the end.

Kayanga et al. (2003) concluded in their study done in Uganda that a higher income would increase the WTP. Similar studies done other places in SSA show a corresponding tendency. The surveys done in this thesis also show that a higher income generally increases the WTP, but it does not increase at the same rate as income. A trend line for the income in Figure 10.10 gives a R-squared value of only 0,28. In disciplines where one attempts to analyse human behaviours, it is common to have a R-squared value of less than 50% because humans are harder to predict than for example a physical process

(Minitab, 2013). Still, a R-squared value of 0,28 is too low to pose a reliable statement that an increase in income increases the WTP, even though it seems like there is a tendency towards it. The data however indicates that there are other underlying factors that affect the WTP to a greater degree than the income.

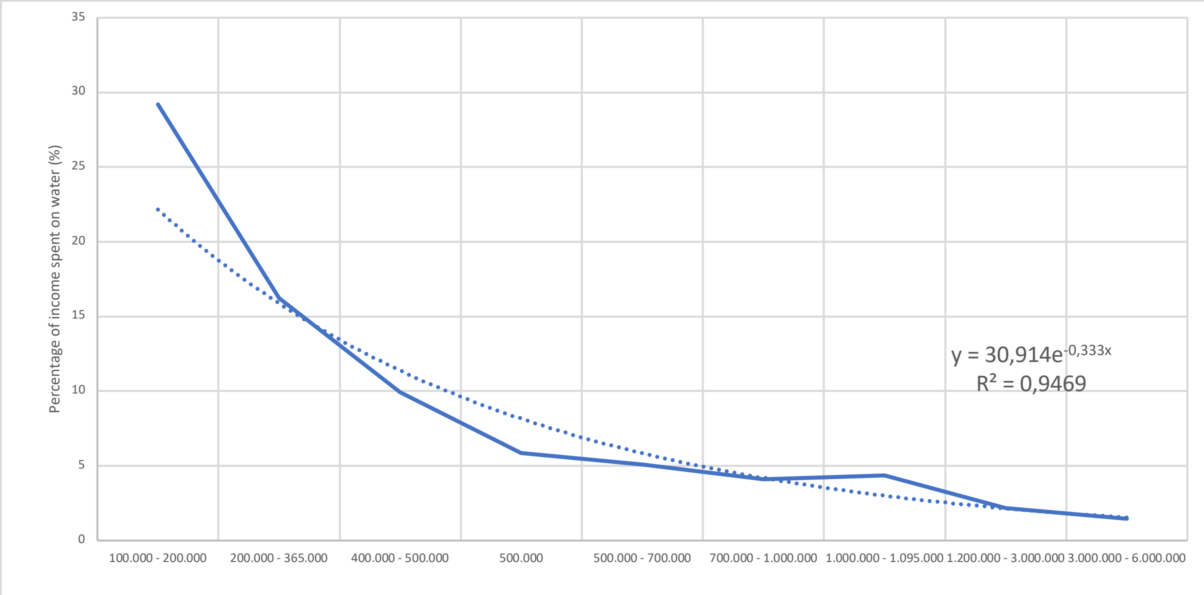

Figure 10.11: WTP as a percentage of income versus income.

10.2.5 Time and WTP

80 of the 107 respondents gave information regarding waiting time, distance to source, the number of buckets used per day and the number of buckets collected each trip. Dividing these respondents into 10 groups based on their mean round-trip time, plotted against mean WTP for less than 30 minutes, solar powered pump, tap shared with five neighbours and tap in house, gave the graph that can be seen in Figure 10.12. One can see that there is a positive linear regression line with a R-squared value of 0,63. This indicates that there is a positive relationship between time spent on fetching water and WTP. Logically, people who have a longer round-trip time thus have a higher WTP.

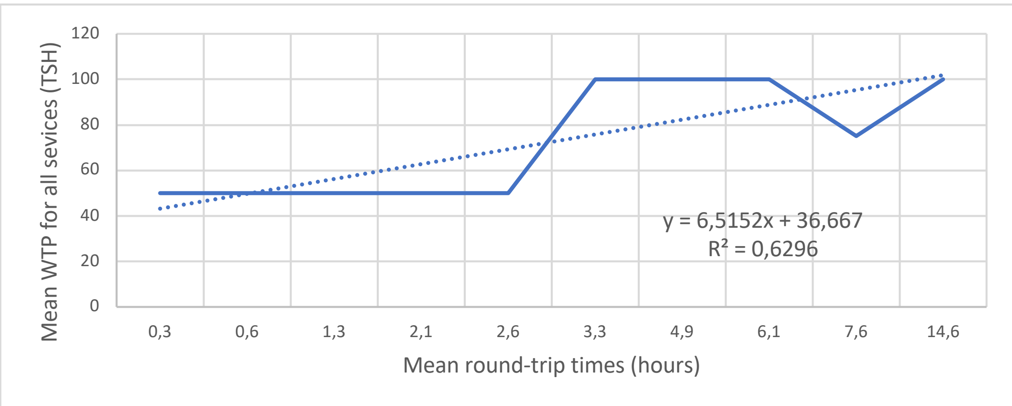

Figure 10.12: Mean WTP for using less than 30 minutes, solar powered pump, tap shared with five neighbours and tap in house, plotted against roundtrip time spent on collecting water.

Using linear regression for the same time-interval groups, one can from Figure 10.13 see that the service with the highest R-squared value and steepest positive slope, is the one for tap shared with five neighbours. The reason for this might be that the further away from the waterpoint one lives, the more interested one is in expanding the water supply network, so that there are more taps where some of them are closer to the house. For the tap in house alternative, the WTP is almost the same (100 TSH/bucket) for all the distance groups. There is also a slight positive increase in WTP for using less than 30 minutes to collect water, but it is not as good a correlation as tap shared with five neighbours. No conclusion can be drawn about neither solar powered pumps, nor tap in house as the R-squared value is too low. There might be other factors that affect the WTP for solar powered pump and tap in house, than distance to source.

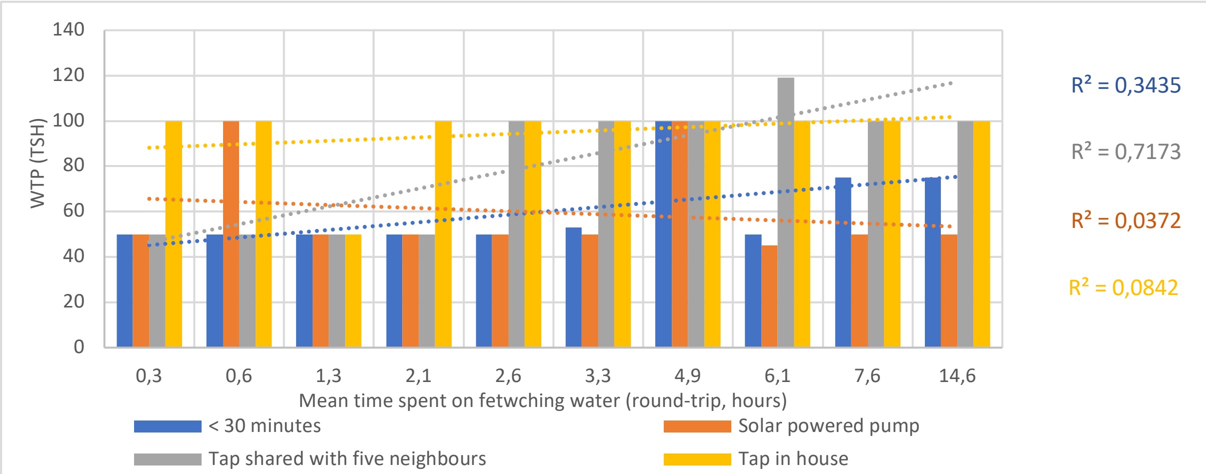

Figure 10.13: WTP plotted against roundtrip time spent on collecting water for four types of improved services.

10.2.6 WTP for current versus improved service

WTP for current versus improved service can be seen in Figure 10.14. In this graph, the people using both a pump and surface water/rain water harvesting are included in their respective pump groups, but people who only use surface water or rain water harvesting are included in the group called surface water. Additionally, other motorised pumps such as electric or diesel generator pumps have been included in the solar powered pump group. In the different groups there were 32, 34, 41 people for hand pump, solar powered pump and surface water respectively. The fairly even distribution between the different types of pumps makes this part of the analysis more reliable.

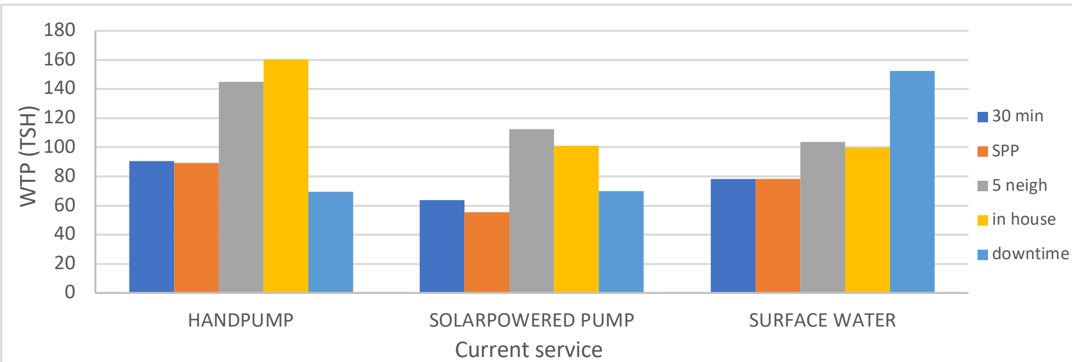

Figure 10.14: WTP (given in TSH on the y-axis) for all types of improved services divided based on current service.

WTP for using less than 30 minutes is higher for hand pump and surface water users. This can be explained by long waiting times at the hand pump or the time used on searching for surface water, especially in the dry season. Similarly, the WTP for solar powered pumps is higher for hand pump and surface water users, assumed to be for the same reasons.

For a tap shared with five neighbours WTP is by far highest for hand pumps. This is somewhat surprising as it will be a lot easier to expand a network connected to a motorised pump, such as a solar powered pump. However, as the queue is generally longer at a hand pump compared with a solar powered pump, the total time used might explain why the WTP is significantly higher for hand pump users, than for those relying on a solar powered pump. The same trend and underlying reasons can be seen for the option tap in house.

The WTP for the downtime of the pump is almost the same for hand pump and solar powered pump users. The ones using surface water, however, have a much higher WTP for a reduction in the pump downtime. Even though they do not have a pump within their area, they might understand to a greater extent what searching for surface water is like and the health effects risks an unimproved source entails.

10.3 Discussion – Tariff amount and type

10.3.1 Annual fee versus Payment per bucket

When deciding an appropriate tariff, one should also consider the type of payment. The two main options that are being used in rural Tanzania is either an annual tariff or payment per bucket. Most of the villages visited during the fieldwork use payment per bucket, which is considered fairer by 4CCP and many villagers. Table 10.3 shows the results from the COWSO interviews regarding types of payments. If one calculates the actual payment per bucket for the users currently paying an annual fee, one gets the results given in the column furthest to the right. With the exception from the minimum value, it is generally 3,5 times more expensive to pay a per bucket fee than an annual fee.

	Annual fee (TSH)	Per bucket (TSH)	Per bucket fee based on annual sum (TSH)
Max	20.000	200	55
Min	3.000	30	1
Median	20.000	40	1
Average	14.375	45	13

Table 10.3: Overview of current tariffs.

Table 10.4 shows the percentage of income the households use on water – overall percentage used on water, annual fee and per bucket fee. As the table indicates there are some households that use more money on water than their income, because of the respondent(s) saying that they have a very low income. In this case it was a female respondent, which as explained previously, often do not participate in paid labour and hence does not necessarily know the actual household income. Additionally, it might be explained by confusion during translation between the two words income and surplus. When looking at the percentage of a household’s income used on water, the respondents paying per bucket generally pay 4-5 times as much as the ones paying annually.

	Overall	Annual	Per bucket
Max	365%	20%	365%
Min	0%	0%	0%
Median	10%	2%	9%
Average	24%	5%	21%

Table 10.4: Percentage of income currently spent on water.

UNDP has set an affordability threshold of 3-5% of household income spent on water (Watkins, 2006). Assuming a median income of 550.000 TSH/year one can calculate a tariff for a per bucket fee and an annual fee for different percentage levels. In Table 10.5 this has been done for the current situation based on a consumption of 5 buckets per day for a household of eight people (12,5 l/pd) and for 20 l/pd, the amount stipulated to be necessary for basic needs such as drinking, cooking and hygiene (WHO, 2011). Table 10.5 indicates that 9 TSH/bucket represents 3% of median household income, or preferably 6 TSH/bucket if one wants to assure that people collect the sufficient amount required to cover basic needs. Using the tariff calculator developed by Fyllingen et al. (2018) a fee of 16 TSH/bucket is needed.

Percentage of household income spent on water	Per bucket fee (12,5 l/pd)	Per bucket fee (20 l/pd)	Annual fee (20 l/pd) (TSH)	Annual fee (USD)
2 %	6,0	3,8	11.000	4,8
2,50 %	7,5	4,7	13.750	6,0
3 %	9,0	5,7	16.500	7,2
3,50 %	10,5	6,6	19.250	8,4
4 %	12,1	7,5	22.000	9,6
4,50 %	13,6	8,5	24.750	10,8
5 %	15,1	9,4	27.500	12,0
10 %	30,1	18,8	55.000	23,9
15 %	45,2	28,3	82.500	35,9
20 %	60,3	37,7	110.000	47,8
25 %	75,3	47,1	137.500	59,8
30 %	90,4	56,5	165.000	71,7
35 %	105,5	65,9	192.500	83,7
40 %	120,5	75,3	220.000	95,7
45 %	135,6	84,8	247.500	107,6

Table 10.5: Calculation of what a set percentage of an average household income gives as a tariff.

The tariff calculator developed by Fyllingen et al. (2018) classifies tariffs for hand pumps depending on several types of combinations of costs. The first category is direct costs which includes regular O&M costs. Category number two is institutional costs which refers to costs related to supportive activities before, during and after construction. Examples of these costs include; monitoring, evaluation, planning or management, counselling or assistance with unforeseen technical problems, as well as training of various interest groups. The third category is rehabilitation costs related to the borehole as slurry, corrosion and similar issues can reduce the capacity of the borehole and the quality of the water. This category does not cover the replacement of pump components, as these expenses are covered in direct costs. Lastly, the category investments costs, includes expenses related to construction of the borehole and procurement and installation of the hand pump. By using the calculator, the tariffs presented below would cover the following costs for hand pumps:

- Direct costs: 2,45 TSH/bucket or 4416 TSH/year
- Direct costs + institutional cost: 3,73 TSH/bucket or 6720 TSH/year
- Direct costs + rehabilitation costs: 2,45 TSH/bucket or 4416 TSH/year
- Direct + institutional + rehabilitation costs: 3,73 TSH/bucket or 6720 TSH/year
- Direct + institutional + rehabilitation + investment costs: 16 TSH/bucket or 28800 TSH/year

These calculations are based on the pumps serving 1695 people, which is what the hand pumps in the study area serve on average. Furthermore, eight people per household consuming five buckets per day has been assumed. Additionally, the fee is converted by xe.com with the exchange rate from the 6th of June 2019. Though it is useful for estimations, a limitation with using this calculator is that it is not developed for solar powered pumps and that the tool does not consider increased rehabilitation costs potentially brought on by serving too big a population. However, the tariff calculator shows that it is possible to cover even investment costs with a relatively low tariff.

The advantages and disadvantages of an annual fee compared to a per bucket fee are presented in Table 10.6. This assumes that people pay an annual fee based on the number of people in the household.

Advantages of an annual fee	Disadvantages of an annual fee
- Will most likely increase the consumption - Easier to do financing plans and budgets - Large households are more likely to use the service (Engel et al., 2005) - Less chance of corruption as is easier to provide a receipt for the payment - Consumers less likely to use an unsafe source during wet season as there are no financial incentives to do so - Do not have to pay a wage for the person sitting next to the pump collecting money	- Need to find out what time of year is the best to collect the fee - How can one separate between domestic and commercial consumption? - Poorer households might find it difficult to pay such a large sum of money (Engel et al., 2005) - People might find it unfair since some use more water than others

Table 10.6: Advantages and disadvantages with using an annual fee compared to a per bucket fee for water.

It should be further investigated whether the residents in the study area are capable of, and willing to, pay a sufficiently high enough annual fee to cover the necessary costs of the system. If an annual fee were to be implemented, it would be imperative to charge this fee at a time when it is the easiest for the most people to pay. In an agricultural community this would for example be after the season’s harvest.

10.3.2 Recommendations

The five factors investigated in the WTP survey, namely, spending less than 30 minutes, a solar powered pump, tap shared with five neighbours, tap in house and the downtime of the pump were chosen to reflect a variety of scenarios. Conducting WTP analysis is important for IAM as one wishes to provide a given service at a manageable risk and cost. Spending less than 30 minutes is in direct relation to the JMP’s drinking water ladder requirement for basic service, while a tap shared with five neighbours or in house would often qualify as an improved service. Spending less than 30 minutes applies to both hand pumps and solar powered pumps, as does downtime. However, it was found when conducting surveys that a downtime of no more than two days consecutively, maximum four times per year was actually considered too high, particularly by those who currently had well-functioning systems.

Based on results from the WTP surveys 50 TSH per bucket for hand pumps is considered an appropriate price in the study area. This is in line with current tariffs and according to the tariff calculator it more than covers the direct, institutional, rehabilitation and investment costs. Still, to justify this tariff the downtime of hand pumps should be drastically reduced and an optimisation of the queuing system should be developed to reduce the total time spent collecting water.

For solar powered pumps a suitable tariff would be approximately 60 TSH as a slightly higher tariff is needed to ensure the sustainability of the system, seeing as the cost of repair for PV pumps is much higher when it does occur. 60 TSH represents a small increase from the current average tariff. However, a tariff of 60 TSH would according to our calculations based on the average income in the study area and WHO recommended consumption (20 l/pd) result in households spending 32% of their annual income on water. This is ten times higher than the UNDP affordability threshold of 3%. Nevertheless, though the water consumption in the study area should be increased, 20 l/pd is much higher than the actual consumption, which skews the calculation. Furthermore, it is hypothesised that the incomes reported in the WTP surveys are lower than actual incomes, due to both translation issues and protection of private information for tax purposes.

For a tap shared by five households an approximate tariff of 100 TSH per bucket is recommended based on the WTP surveys. This relatively high tariff indicates that there exists a high WTP for improved services that reduce the roundtrip time. Increasing the number of taps was frequently mentioned by COWSOs as a planned or wanted improvement of their systems. An expanded system with pipes and taps relies on more maintenance, which in turn requires sufficient funding. However, in some cases a significantly lower WTP was reported for sharing a tap with five neighbours than their current system, perhaps indicating that collaboration with neighbours was considered challenging.

The highest overall WTP was, not surprisingly, for a tap in house. A recommended tariff for this service is 100 TSH and above. This is the most convenient solution for the consumer and represents a 'final step' in improvement of water services in the study area. This was illustrated by how it seemed unattainable to many of the people interviewed. A tap in house is generally found to increase the overall water consumption, which would be a positive development. An increased consumption is however seen to require a high borehole yield and possibly hybrid systems where a solar powered pump is connected to the grid or a diesel generator. Furthermore, a water tap on the premises requires an annual fee of 36.500 TSH per person, 292.000 for an average household of eight people, based on the per bucket fee. If installing taps in house, it is recommended to also install meters and charge per cubic metre of water to make the system more equitable. Additionally, one should consider charging a potentially higher tariff for a consumption over a given threshold based on water needed for domestic use, seeing as livestock keeping and agricultural use is secondary to drinking water purposes.

In general, a high WTP was found for water compared to the economic conditions in the study area. This illustrates how the importance of water for livelihoods is very much clear for people living in a rural low-income setting. People were also surprisingly willing to pay for water considering the country's socialist history, where water was virtually free, or as a gift from God. This could however also be due to the community mobilisation done by NCA and 4CCP, hence it is not clear if villages outside 4CCP's catchment area see water as a commodity that should not be paid for, as discussed in Chapter 2.2 (Tanzania's history, p. 10).

10.4 WTP - conclusion

As seen in the previous sub-chapters there are numerous factors affecting WTP. The ones studied in this thesis are; gender, location of village, income, time spent fetching water and the relationship between current and improved services. The improved services that were analysed were; using less than 30 minutes per roundtrip to fetch water, getting water from solar powered pump, sharing a tap with five neighbouring households, having a tap in house and ensuring that the pump is never out of function for more than two days consecutively, maximum four times per year. For gender there was no significant difference in WTP for the different improved services, while for the location of the villages there was not enough data to draw a conclusion. Higher incomes will generally give a higher WTP for an improved service. However, the study also showed that the poorest respondents had a relatively high WTP, probably because they recognise that they 'waste' a lot of time fetching water. This is reflected by the fact that more time spent collecting water also gave an increase in WTP. For current versus improved services the respondents with the overall highest WTP were the ones relying on surface water, then the ones using a hand pump and lastly the ones using solar powered pumps. The survey also showed the dramatic difference between paying an annual fee versus a per bucket fee.

In this chapter the goal was to investigate what factors affect the demand and WTP for current and improved services. The hypotheses were:

1. Women are willing to pay more as they have more to gain from improved water services
2. People are willing to spend at least 3-5% of their household's average yearly income on water
3. People with a poor current service would be willing to spend more on water
4. The closer the tap is to one's home, the more the customers are willing to pay
5. A yearly fee for water is to be preferred to a per bucket fee

For the first hypothesis the surveys and analysis conducted showed that men generally have a higher WTP than women when looking at average values, except from when it comes to spending using less than 30 minutes. However, when looking at median values there was no difference in the WTP for women and men. Hence, one cannot confirm the hypothesis, but a larger sample size or a different methodology could change the outcome. People had a varying WTP when looking at percentage of household income spent on water. The poorest people were willing to use almost 30% of their income on water, while the richest ones were only willing to use 2%. The average household was willing to spend 5% of their income. Therefore, the second hypothesis was confirmed. The third hypothesis was also strengthened as the ones using surface water had the overall highest WTP. A tap closer to home gave a higher WTP according to the surveys and analysis conducted in this thesis. An annual fee might be preferable from the perspective of the COWSO, but a per bucket fee is probably preferred by consumers as it is considered farer.

Other social factors that could be interesting to analyse if one were to conduct a similar WTP survey could be:

- Education level
- Job / employment
- Tribe or ethno-linguistic group
- Size of household

Furthermore, it could be worthwhile to investigate the optimal time of collecting an annual fee, and the potential interest amongst COWSOs and other community members in having an annual fee.

11 Conclusion

This Master's thesis has focused on how to increase the resilience of RWS systems by applying IAM as a framework. The research has been done through the use of a case study, aiming to answer five research questions. The questions were addressed through literature, and fieldwork with NCA and 4CCP over seven weeks in the area around Haydom, northern Tanzania. This thesis has sought a more holistic understanding of RWS, going beyond simply the technical infrastructure.

The NAWAPO vision sets out that Tanzania's rural population should have 85% water coverage by 2020. According to our research, this goal is unlikely to be met as approximately 42% of the rural population in the study area currently have access to an improved water source. Drinking water from an unimproved source poses a health risk. Furthermore, an average of 2,8 hours per day spent collecting water is time that could have been spent on education or income generating activities. Therefore, the existing system must be improved and expanded. The villages in the study area had an average consumption of 12,5 l/pd, which is significantly lower than the 20 l/pd recommended by the WHO to ensure sanitary and sustainable livelihoods. Even though the amount of water available per person is already worryingly low, it is expected to decrease in the future due to population growth and climate change. Raising water consumption by addressing the nature-based, technical, organisational and financial limitations must be made a priority.

The nature-based conditions create the foundation for the water supply system. The main challenges are a deep groundwater table, seasonal precipitation, a low yield per capita and climate change. The depth of the groundwater table makes it challenging to install a well, both in terms of the organisational capacity required and for the technical equipment itself. However, as abstraction occurs from a deep confined aquifer the groundwater is generally of good quality, particularly in terms of pathogens and pollution. One quality parameter though presents an issue; seven out of nine samples indicated fluoride levels in excess of the WHO threshold. To reduce fluoride related diseases the Tanzanian limit should be lowered from 8 to 3 mg/l. Precipitation varies greatly according to the seasons, which makes rainwater harvesting a vulnerable water source. Furthermore, abstraction from joints and fractures may lead to a low or unpredictable borehole yield, which is challenging in a water stressed country with a high rural population, such as Tanzania. As such, management of water sources is crucial, especially when considering the predicted effects of climate change leading to a potential reduction in groundwater recharge.

In the study area, hand pumps and solar powered pumps are installed by NCA. It is important to choose a pump based on the required technical functions in accordance with local conditions and capabilities. The solar powered pumps are new and yet to experience failures or require extensive repair. The main reasons for India Mark II Extra-Deep Well pump failures seem to be that the design criteria have been exceeded, both in terms of the pumping depth and the population served. Due to a lack of available data, this thesis has not been successful in systematically collecting and quantifying the reasons for pump failure in the hand pumps. However, based on more anecdotal evidence, corrosion of the joints in the rising main and damages to the cylinder, particularly the foot valve and rubber gasket, are frequent issues. Corrosion can be addressed by replacing the metal pipes with PV or HDPE pipes or ISO certified galvanisation. Problems in the cylinder appear to mainly be caused by the pumping depth and improper use. It is therefore important to respect the design criteria and educate about proper operation of the pump and the importance of preventive maintenance. The foot valve and other rubber parts seem to be a weak component in the hand pump. Therefore, it is necessary to choose a reputable manufacturer which provides warranties. Though hand pumps have low investment costs they often have high O&M costs compared to solar powered pumps. The best available solution, which will meet the JMP drinking water ladder basic coverage requirement, is a hybrid system with large storage tanks. This would increase the operating hours and provide a buffer in case of pump failure.

RWS in Tanzania is undertaken by COWSOs and strengthening their functioning is therefore an important step to improve the resilience. Their organisational capacity was found to vary greatly depending on the capabilities and motivation of the committee and its individual members. Even though COWSOs consist of volunteering members and represent the lowest administrative level, they can function well and meet the needs of the local community. However, the organisational mode requires formalisation to improve asset management. The framework developed to increase the sustainability and transparency of COWSOs, based on 14 weighted criteria, is intended for internal and external assessment and monitoring. Since the service provider is so crucial for the overall water supply and its resilience, this has been suggested to be included as a factor for rural IAM. Lack of resources and limited training were repeatedly mentioned as major challenges facing the COWSOs. Further strengthening of their capacity through training and community mobilisation, is therefore needed to maintain and improve the water supply systems.

From the perspective of a COWSO, an annual water tariff would make it easier to plan ahead and cover unforeseen expenses. For an annual tariff to be successful, transparency is required, and it is therefore necessary to produce receipts, detailed budgets and financial plans which can be presented to the community, as well as collaboration with PETS committees. A tariff based on the number of people in a household would be a more equitable solution than a general fee. It must be emphasised that a water tariff has to be inclusive and attainable for all members of the community. WTP analysis found that gender did surprisingly not affect WTP. Even though water collection is mainly the responsibility of women and children, it is hypothesised that women have less insight into the household’s economy and are therefore not willing to pay as much. When it came to location of the villages and WTP the results were inconclusive. The functioning of COWSOs and WTP was however found to be positively correlated, most likely due to a virtuous cycle of investment and service provided. A higher income also gives a generally higher WTP, but based on the percentage of the household’s income spent on water there is negative exponential growth. A higher WTP for increased roundtrip times was also identified, reflecting the lost opportunity cost of collecting water. Additionally, those who currently use hand pumps or surface water had a higher overall WTP than those already using a motorised pump. This expresses how people with a worse current system are more willing to pay for improvements. Establishing a tariff which covers the short and long-term costs of the system is essential for its sustainability and the findings from the WTP surveys suggest that a slight increase in tariffs is possible in the study area.

However, it is a resource constrained environment where the cost of water might be a factor that limits a household's consumption. Furthermore, habit or lack of understanding may also contribute to the low water usage. To improve the water situation in the study area change is needed on several levels. The community must be mobilised, and the district and state should, if possible, allocate more resources to implement needed strategies such as climate adaptation. One of the main findings from the fieldwork was that non-technical factors are more vulnerable and varying, and therefore often more decisive for a water supply system. That does however not dismiss the fact that increasing the robustness of the technical infrastructure is important, particularly for hand pumps as they are prone to failures. It is worth investing a bit more in materials, production and installation, as well as preventive maintenance to lower overall life cycle costs. Furthermore, it is crucial to ensure that the infrastructure represents 'appropriate technology' so that it does not add to the list of failed projects.

To summarise, the physical conditions lay the foundations in which a water system operates and is managed. The reduction of pump failures and their associated downtime, improved functioning of water committees to better manage assets and a sufficient and fair tariff established through WTP, can increase the resilience and sustainability of RWS systems. Though IAM is not a widespread concept in rural settings, particularly in developing countries, even basic IAM can reduce long-term costs and increase the lifetime of the physical assets. This is however reliant on both sufficient data and competence and it is therefore something that must be pursued by the water committees, the district engineers and external organisations. IAM can also increase the resilience of water supply systems and thereby make them more robust and adaptable to future changes and challenges, which is crucial in an area that is expected to experience more water stress in the future. A resilient water supply system is found to better cope with both internal and external stressors and is therefore more sustainable in the long run. Water is an essential element for both individual lives and for the development process in general. It should be prioritised at all levels, as it is imperative to create a virtuous cycle which can lift people out of poverty, improve gender relations, increase educational attainment and lead to healthier lives and well-being.

12 Future work

The work done in this thesis has left some questions unanswered and revealed some new aspects that should be investigated. One important step to improve the management of assets and make systems more resilient, is to properly formalise and systematise pump failures. This should include which component and probable cause, the frequency and the associated downtime of the failure. Universities and NGOs could collaborate to develop an extra-deep VLOM pump. Seeing as it is hard to change the natural conditions, many places are in need of a hand pump which can pump from a depth of 80 meters or more. It should however be open-top so that the cylinder and other parts can be maintained and repaired without having to pull out the entire rising main. This would be useful for this specific study area but also applicable elsewhere. Further work assessing the business potential of having a local technician that visits all hand pumps in the area regularly or one that specializes in solar powered pumps would also be an important step to increase the resilience of the water supply system. It could for example be worth investigating the opportunities for a course to train certified technicians.

Investigations into how to reduce fluoride levels in the drinking water is another topic in need of further research. It would be useful to assess the potential and required size of tanks for sedimentation. If successful, this could help to open up some abandoned wells and thereby increase the amount of available water.

It would also be interesting to apply the framework developed for assessing COWSOs as a more action research-based project. This would of course require time and might call for adjustments in the framework, but it would be useful to implement measures and then document potential changes. Additionally, further investigations into the advantages and disadvantages of an annual water tariff would represent a positive contribution. The amount and time of year are both important aspects to establish, to ensure that it does not become unfair.

Additionally, tariff calculators that include the degradation of a pump when it is being used beyond capacity, both in terms of population and pumping depth, would be very useful for finding a tariff which can cover the O&M- and life cycle costs. This could be useful for both hand pumps and solar powered pumps as such a tariff calculator could be used at the village assembly to discuss and justify a tariff. For WTP in the study area it could also be relevant to look at WTP in relation to employment or ethno-linguistic groups, though the latter might be a sensitive topic so its purpose must be clearly articulated.

Finally, further work should include sanitation in its assessment of the water situation in a rural area. The potential of developing a dry sanitation system, alongside hygiene promotion programmes, which protects and improves precious water sources, is a vital component of a sustainable system.

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Appendices

Appendix 1: Schedule for field work

Appendix 2: Interview questions for COWSOs

Appendix 3: Interview questions for district engineer

Appendix 4: Interview questions for local authorities

Appendix 5: Interview questions for FDGs

Appendix 6: Interview questions for doctors and dentists at HLH

Appendix 7: WTP survey

Appendix 8: 4CCP Waterpoint data base

Appendix 9: India Mark II Extra-Deep Well

Appendix 10: Anti-corrosion treatment

Appendix 11: Part list for India Mark II Extra-Deep Well

Appendix 1: Schedule for field work

This table shows the schedule for out field work with date, program and where the

DATE	PROGRAM	PLACE
22/01/2019	Introduction to Mbulu District Executive Director and Mbulu District district Commissioner. Interview with district engineer	Mbulu DC office
23/01/2019	COWSO interview, WTP surveys and pH testing	Endanachan
28/01/2019	COWSO interview, WTP surveys, FDG group and pH testing	Endagew CHini
29/01/2019	Introduction to Mkalama District Executive Director and Mkalama District district Commissioner. Interview with district engineer	Mkalama DC office
30/01/2019	COWSO interview, WTP surveys, FDG group and pH testing	Endagulda
31/01/2019	SWASH session with all the students at Hilamoto Primary school and COWSO interview	Hilamoto
04/02/2019	COWSO interview, WTP surveys and pH testing	Guye
	Inspection of two 'veggie garden' project	Haydom
05/02/2019	Meeting at 4CCP with NCA with a presentation of 4CCPs work	Haydom
	COWSO interview and fluoride and pH testing	Haydom
06/02/2019	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA	Dilling'ang
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA. Fluoride and pH testing	Basotu
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA. Fluoride testing	Endagew chini
07/02/2019	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA	Basonyangwe
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA. Fluoride and pH testing	Endanachan
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA	Murukchina
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA. Fluoride and pH testing	Endamilay
08/02/2019	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA	Endagulda
	Informal COWSO interview and inspections with Manfred Arlt and Zachayo Makobero from NCA. Fluoride and pH testing	Munguli
09/02/2019	Observing at SWASH forum with 34 participating schools	Haydom (4CCP office)
11/02/2019	Interview with Nelson Faustini and Manfred Arlt	Haydom
	Interview with the Bishop of Mbulu, district engineer for Mbulu and district engineer for rural areas in Mbulu	Mbulu
12/02/2019	COWSO interview, WTP surveys and fluoride and pH testing	Mntamba
13/02/2019	COWSO interview, WTP surveys and fluoride and pH testing	Endamilay
17/02/2019	Interview with elderly politician (Yona Assecheck) about climate change	Haydom
19/02/2019	Inspection of HLH water source. Fluoride and pH testing	Haydom
20/02/2019	COWSO interview, WTP surveys and fluoride and pH testing	Gentanyamba
	SWASH meeting and insprecion at Getanyamba Primary School	Gentanyamba
26/02/2019	COWSO interview and WTP surveys	Genda'a
27/02/2019	COWSO interview and WTP surveys	Hayeda
	SWASH meeting and inspection of rainwater harvesting tanks	Mewandani
28/02/2019	Tour at HLH	Haydom

	Informal interview with local dentist	Haydom
01/03/2019	Interview with paediatrician	Haydom
	Skype interview with Gwen Berge (Head of NCA office in Tanzania)	Skype
03/03/2019	Inspection of wastewater facility at HLH with Norwegian plumber Magne Øydvin and Norwegian dentist Kristian Trægde	Haydom
04/03/2019	COWSO interview, FDG group and WTP survey	Gidarudagew
05/03/2019	Participating in reparation of hand pump	Genda'a
06/03/2019	Collection of data for Epicollect 5	Different villages
07/03/2019	Collection of data for Epicollect 5	Different villages
08/03/2019	Collection of data for Epicollect 5	Different villages
07/05/2019	Interview with Norwegian dentist Kristian Trægde about dental fluorosis	Telephone

Appendix 2: Interview questions for COWSOs

These are the prepared questions used as a starting point for the COWSO interviews

Water situation

1. How would you describe the water supply situation in rural areas Tanzania?
2. What are the main challenges facing water supply in rural areas Tanzania?
3. What (positive) effects have there been, as a result of installing water services in this area?
4. How many households are connected to this borehole?

Hydrogeology and climate

1. How would you describe the local hydrogeology? (ground conditions, precipitation patterns,
2. temperature changes, depth to groundwater table)
3. Has there been experiences of wells drying out (due to over-pumping)?
4. Is there a seasonal variation in available groundwater?

Water consumption

1. Are there estimates for average water consumption?
2. How often do most households collect water?
3. Who in a household usually collects water?
4. Do you have any thoughts about the safety of the water?

Water sources

1. What (positive) effects have there been, as a result of installing water services in this area?
2. What are the reasons for water consumers not using groundwater? (cost, taste, proximity, habit etc)
3. If a pump fails, are there any backup solutions?
4. What water sources do people use in case of pump failure?
5. Do water consumers collect water on a daily basis, or for longer periods of time?
6. A high fluoride content can lead to dental and skeletal problems, has this been reported or noticed as an issue?
7. Are there other quality parameters that are significant?

WTP

1. What improvements in services are most wanted and needed?
2. How much are people on average capable of paying for improved water services?
3. How does factors such as age, gender, social standing etc affect the WTP for water?
4. Do you think it is better to have a fee per bucket or a seasonal/annual fee?
5. How can the reliability of water services be improved?
6. How do the users of agricultural water differ from domestic users?
7. Would a solar powered pump used for 'veggie gardens' fall under the same 'jurisdiction'?

Remote monitoring

1. If acquired, how is data stored and systematized?
2. How do you now report pump failures? And who reports it?

3. What do you think are the potential uses of remote monitoring?
4. What are the steps in failure procedure?

COWSOs

1. How would you describe a COWSO and its function?
2. What factors are important for a well-functioning COWSO?
3. What are the main challenges facing COWSOs?
4. What kind of support would be beneficial for a COWSO to receive in order to ease the work of a COWSO and help in order to achieve its objectives.
5. How does the process of choosing people for COWSOs work, and what factors are taken into consideration (age, gender, experience)?
6. For how long are people usually involved in COWSOs?
7. How often does your COWSO meet?
8. How is a budget and financing planned?
9. Is the COWSO legally registered?
10. Does the COWSO have a bank account?
11. How often is an audit conducted?
12. In what way is the responsibilities of COWSOs and district engineer shared? Is there any possibility to improve these shared responsibilities?
13. What is the relationship between your COWSO and village officials?
14. Do you collaborate with PETS?
15. What is your future plan for your COWSO?

O&M and repairs

1. What are the main reasons for pump failure both for hand pumps and solar powered pumps? (a weak component, clogged filters, mishandling, vandalism, inadequate maintenance, wrong instalment)
2. Is vandalism of water supply system a big issue?
3. Do you suspect vandalism and theft would be a bigger issue for solar powered pumps? If so,how could this be mitigated?
4. Is there an overview of the most typical failures?
5. What is the usual downtime of a pump after failure?
6. How long does it typically take to acquire a spare part?
7. What are the most important factors to ensure the best possible operation and maintenance?
8. What are the main challenges in terms of operation and maintenance for water supply systems? (storage with needed parts, more people, more funds etc)
9. How does the communication and collaboration with maintenance and repair personnel work?
10. What are the steps taken when a pump failure is reported?
11. Do you know of any action plans of how to reduce pump failures and associated downtime?

Appendix 3: Interview questions for district engineer

These are the prepared questions used as a starting point for the interviews with the district engineer

Water situation

1. How would you describe the water supply situation in rural areas Tanzania?
2. What are the main challenges facing water supply in rural areas Tanzania?

Hydrogeology and climate

1. How would you describe the local hydrogeology? (ground conditions, precipitation patterns, temperature changes, depth to groundwater table)
2. Has there been experiences of wells drying out (due to over-pumping)?
3. Is there a seasonal variation in available groundwater?
4. Are the rock type in the aquifer known?

Data handling (remote monitoring)

1. How is data regarding water consumption, pumping and pump failures acquired?
2. If acquired, how is this stored and systematized?
3. Is there a way of verifying water data?
4. What do you think are the potential uses of remote monitoring?

O&M and repairs

1. What are the main reasons for pump failure both for hand pumps and solar powered
2. pumps? (a weak component, clogged filters, mishandling, vandalism, inadequate
3. maintenance, wrong instalment)
4. Is there an overview of the most typical failures? (Potentially for guarantees)
5. How long does it typically take to acquire a spare part?
6. What are the most important factors to ensure the best possible operation and
7. maintenance?
8. What are the main challenges in terms of operation and maintenance for water supply
9. systems? (storage with needed parts, more people, more funds etc)
10. What are the steps taken when a pump failure is reported?
11. Are there any action plans of how to reduce pump failures and associated downtime?
12. How are pumps prioritised in terms of repair and maintenance?

COWSOs

1. How does the process of choosing people for COWSOs work, and what factors are taken into consideration (age, gender, experience)?
2. In what way is the responsibilities of COWSOs and district engineer shared? Is there any possibility to improve these shared responsibilities?

Solar powered yards

1. How do the users of agricultural water differ from domestic users?
2. Would a solar powered pump used for ‘veggie gardens’ fall under the same ‘jurisdiction’?

Water sources

1. A high fluoride content can lead to dental and skeletal problems, has this been reported ornoticed as an issue?
2. Are there other quality parameters that are significant?
3. What improvements in services are most wanted and needed? (long term)
4. Beyond the topics now discussed, what roles and activities are taken under the district engineer?

Appendix 4: Interview questions for local authorities

These are the prepared questions used as a starting point for the interviews with the local authorities

Water situation

1. How would you describe the water supply situation in rural areas Tanzania?
2. What are the main challenges facing water supply in rural areas Tanzania?
3. What strategies and goals are being pursued, both short and long-term?
4. What (positive) effects have there been, as a result of installing water services in this area?

Data handling (remote monitoring)

1. How is data regarding water consumption, pumping and pump failures acquired?
2. If acquired, how is this stored and systematized?
3. Is there a way of verifying water data?
4. What do you think are the potential uses of remote monitoring?

Appendix 5: Interview questions for FDGs

These are the prepared questions used as a starting point for the FDGs, where local members of a community were divided based on gender

Establishing current context

1. How much water does your household consume on average?
2. How far is it to your water point?
3. How often does your household collect water?
4. Who in the household collects water?
5. How do you pay (per bucket or annual/seasonal fee)?
6. How much do you pay?
7. What happens if a pump fails and how long is the usual down time?
8. Quantity: do you feel like you have sufficient water? If not, is the limiting factor the cost, distance, weight etc?
9. Quality: are there parameters that are unsatisfactory with your water? Taste, odor, clarity, cleanliness etc
10. What are the main reasons for pump failure both for hand pumps and solar powered pumps? (a weak component, clogged filters, mishandling, vandalism, inadequate maintenance, wrong instalment)
11. Is there an overview of the most typical failures? (Potentially for guarantees)
12. How long does it typically take to acquire a spare part?

Brainstorming wanted/needed

1. What (positive) effects have there been, as a result of installing water services in this area?
2. What do you expect from a water service?
3. What can be done to improve water services?
4. Examples: Amount of water, distance to water source, fee, waiting time at water source,quality of water, reliability of water source
5. Do you have to wait in a queue for a long time? Is this problematic? How can this be organized in a better way?
6. Would you prefer to have the water fee per bucket, on a seasonal or annual basis?

Appendix 6: Interview questions for doctors and dentists at HLH

These questions were used as an outline for conversations with dentist and doctors at HLH about fluorosis and other waterborne diseases.

1. A high fluoride content can lead to dental and skeletal problems, has this been reported or noticed as an issue?
2. If so, is this more of an issue in certain areas or for certain groups (for example age)?
3. Are there any recommended practices to reduce fluoride levels or potential impacts?
4. Are there other quality parameters that are significant?
5. Has the instalment of hand pumps reduced the amount of water related diseases?

Appendix 7: WTP survey

The following questions were used during the WTP surveys

General information

- District: ________________________
- Age: __________________________
- Gender:
  - ☐ Male
  - ☐ Female
- Status:
  - ☐ Mother
  - ☐ Father
  - ☐ Son
  - ☐ Daughter
  - ☐ In-law
  - ☐ Grandmother
  - ☐ Grandfather
  - ☐ Other (please specify) _____________________
- Number of people in household: ________________
- Who in the household is usually in charge of collecting water: _________________
- Average yearly income (for household) ______________

Current water system

- What is your daily source of water for drinking and cooking? (Tick as appropriate, multiple ticks are fine)
  - ☐ Hand pump
  - ☐ Solar powered pump
  - ☐ Rainwater harvesting
  - ☐ River or pond (if yes, please answer next question)
  - ☐ Other (please specify) ________________________
- If you use a river or pond, what is the main reason for this?
  - ☐ Price of water
  - ☐ Distance to well
  - ☐ Failure and downtime at well
  - ☐ Waiting time at well
  - ☐ Taste, odour
  - ☐ Habit, tradition
  - ☐ Other (please specify) ____________________
- What is the distance to your water source?
  - ☐ 0 - 50 m
  - ☐ 50 - 100 m
  - ☐ 100 - 300 m
  - ☐ 300 - 1000 m
  - ☐ More than 1000 m (please specify) ________________

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

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

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

- How much water is normally collected each trip? ____________________

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

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

- How much do you currently pay for water? ____________________

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

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

- What percentage of your household's income is spent on water? _______________

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

Willingness to pay (1 jerry can)

- How much are you willing to pay for using less than 30 minutes for a round trip of collecting water?
  - ☐ 10 TSH
  - ☐ 25 TSH
  - ☐ 50 TSH
  - ☐ 75 TSH
  - ☐ 100 TSH

- 125 TSH
- 150 TSH
- More ________
- Stated limit ______

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

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

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

- How much are you willing to pay if the pump was never out of function for more than 2 days consecutively, maximum 4 times per year?
  - 10 TSH
  - 25 TSH
  - 50 TSH
  - 75 TSH
  - 100 TSH
  - 125 TSH
  - 150 TSH
  - More ________
  - Stated limit ______

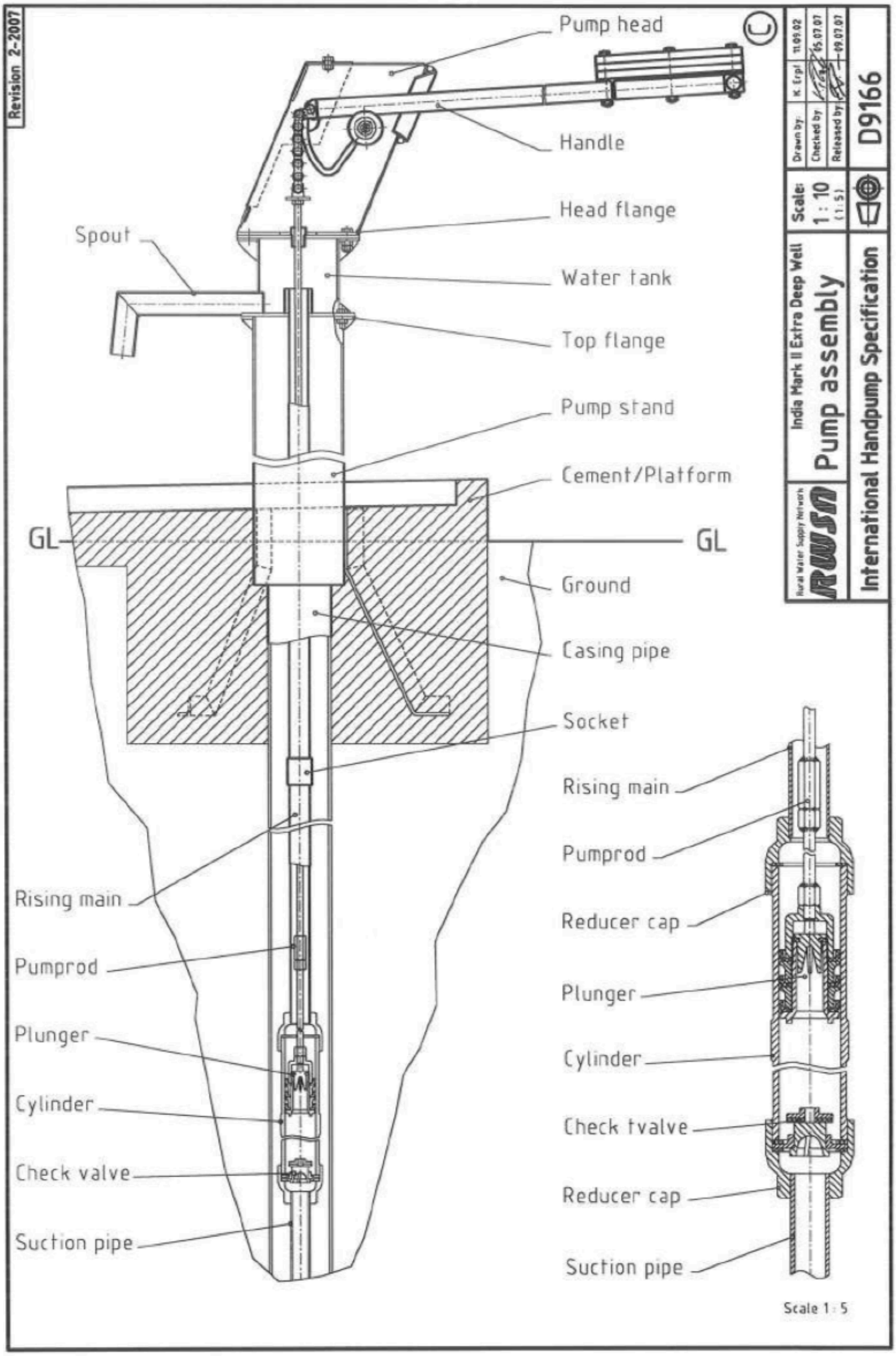
Appendix 8: 4CCP Waterpoint data base

This excel sheet shows the waterpoint that 4CCP and NCA have either installed or rehabilitated during the TCP

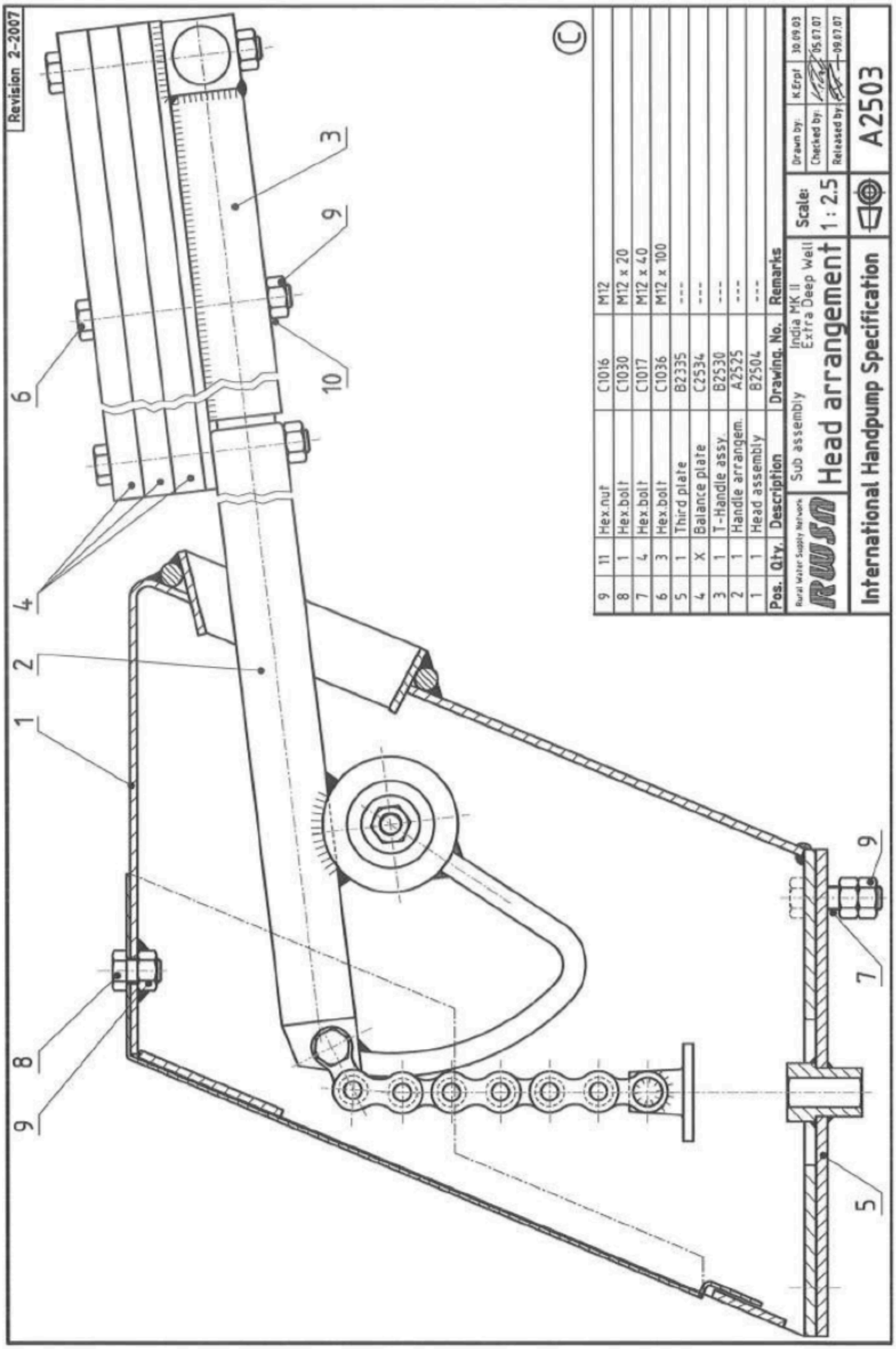
4CCP WATER POINT DATA BASE SINCE 2015 UP TO 2018												
	VILLAGE	WARD	DISRICT	REGION	TYPE	DISCHARGE LITER PER HOUR(LT)	DEAPTH PER (M)	YEAR OF CONSTRACTION/REHABILITATION	No of MALEs	FEMALE	TOTAL NUMBER OF USERS WATER(PEPIE) M&F
1	QANDACH	LABAY	MBULU	MANYARA	In progress	1500LT	96M	2018	1100	1300	2400
2	ENDAMILAY	ENDAMILAY	MBULU	MANYARA	SOLAR POWER	6000LT	150M	2018	510	820	1330
3	BASONYAGWE	HAYDOM	MBULU	MANYARA	In progress	5000LT	104M	2018	402	498	900
4	MURKUCHIDA	ENDAMILAY	MBULU	MANYARA	In progress	6000LT	90M	2018	698	1500	2198
5	ENDANACHAN	ENDAMILAY	MBULU	MANYARA	SOLAR POWER	5500LT	130M	2018	480	720	1200
6	ENDAGEW CHIN	GETARER	MBULU	MANYARA	SOLAR POWER	1500LT	102M	2016	580	620	1200
7	HAYEDA	GETARER	MBULU	MANYARA	HAND PUMP	1500LT	98M	2017	240	610	850
8	GENDA	DINAM	MBULU	MANYARA	HAND PUMP	700LT	162M	2018	425	625	1050
9	GUYE	DONGOBESH	MBULU	MANYARA	In progress	7500LT	120M	2018	1400	1600	3000
10	MAMAGI	DINAM	MBULU	MANYARA	In progress	4500LT	123M	2018	650	850	1500
11	GIDIHIM	DONGOBESH	MBULU	MANYARA	In progress	7200LT	125M	2018	1000	1200	2200
12	DILING'ANG	BASOTO	HANANG'	MANYARA	In progress	2000LT	123M	2018	700	1200	1900
13	QALODARER	GETARER	MBULU	MANYARA	In progress	400LT	78M	2018	550	650	1200
14	MNTAMBA	MNTAMBA	MKALAMA	SINGIDA	GENERATOR	7896LT	75M	2012	1500	1956	3456
15	MATERE	MWANGEZA	MKALAMA	SINGIDA	In progress	3500LT	66M	2018	500	700	1200
16	HILAMOTO	MWANGEZA	MKALAMA	SINGIDA	HAND PUMP	3000LT	70M	2017	450	615	1065
17	ENDAGULDA	MWANGEZA	MKALAMA	SINGIDA	In progress	5800LT	66M	2018	1000	1300	2300
18	KINYAMBULI	NKINTO	MKALAMA	SINGIDA	HAND PUMP	2000LT	85M	2016	1000	1300	2300
19	ENDABASH	HAYDOM	MBULU	MANYARA	HAND PUMP	1500LT	75M	2017	100	113	213
20	ENDAGEW SHULE	GETERER	MBULU	MANYARA	HAND PUMP	1500LT	98M	2015	400	592	992
21	MUNGULI	MWANGEZA	MKALAMA	SINGIDA	SOLAR POWER	7000LT	120M	2015	200	265	465
22	KIKARANGA "A"	MWANGEZA	MKALAMA	SINGIDA	HAND PUMP	1500LT	74M	2015	300	505	805
23	ISENE	MATONGO	MKALAMA	SINGIDA	HAND PUMP	2300LT	78M	2015	800	1000	1800
24	MWANGEZA	MWANGEZA	MKALAMA	SINGIDA	HAND PUMP	1000LT	105M	2017	1100	1189	2289
25	QALODAGANUWY	LABAY	MBULU	MANYARA	In progress	2500LT	110M	2018	1000	1300	2300
26	BISGETA	GETARER	MBULU	MANYARA	HAND PUMP	1500LT	95M	2017	400	563	963
27	NKINTO KAMBIYA FISI	NKINTO	MKALAMA	SINGIDA	HAND PUMP	3000LT	85M	2017	500	515	1015
28	HARAR	HAYDOM	MBULU	MANYARA	In progress	5952LT	103M	2018	850	693	1543
29	GIDBIYO	HAYDARER	MBULU	MANYARA	In progress	3200LT	120M	2018	900	1100	2000
30	ISALE	IMBORU	MBULU	MANYARA	In progress	2300LT	156M	2018	600	900	1500
31	HIDET	HIDET	HANANG	MANYARA	In progress	7800LT	66M	2018	1950	2050	4000
32	FITSA	HAYDOM	MBULU	MANYARA	In progress	3000LT	78M	2016	215	415	630
33	ENDARKHADAT	HAYDOM	MBULU	MANYARA	In progress	688LT	150M	2018	550	750	1300
34	GIDARUDAGEW	HAYDOM	MULU	MANYARA	HAND PUMP	6500LT	95M	2016	900	1027	1927

Appendix 9: India Mark II Extra-Deep Well

Drawing of pump assembly for the hand pump (SKAT and RWSN, 2007)



Drawing of the head arrangements for the hand pump (ibid)



Appendix 10: Anti-corrosion treatment

This detailed anti-corrosion treatment with pump components and ISO standard are set

5.0 Anti-Corrosion Treatment

The India Mark Handpumps shall be given the anti-corrosion treatment as specified below:

5.1 Hot Dip Galvanizing:

The following pump assemblies shall be galvanized according to ISO 1461, "Protection against corrosion: hot dip galvanized coatings on fabricated ferrous products: requirements and tests":

The coating thickness should be between 70 to 80 μm in average.

Head assembly	Mark II and III	see Fig. B2304
Head assembly	Extra Deep well	see Fig. B2504
Front cover assembly	all pump types	see Fig. B2320
Handle assembly	Mark II and III	see Fig. B2326
Handle assembly	Extra Deep well	see Fig. B2526
T-Handle assembly	Extra Deep well	see Fig. B2530
Balance plate	Extra Deep well	see Fig. C2534
Third plate assembly	all pump types	see Fig. B2335
Water tank assembly	Mark II & Extra Deep-well	see Fig. B2340
Water tank assembly	Mark III	see Fig. B2621
Stand assy. (3 legs)	all pump types	see Fig. B2348
Stand assy. (3 legs)	all pump types	see Fig. B2347
Stand assy. (Bottom fl)	all pump types	see Fig. B2055
Stand assy. (Bottom fl)	all pump types	see Fig. B2221
Pumprod assembly	all pump types	see Fig. B2373
Lifting spanner (1 ¼")	Mark II & Extra Deep-well	see Fig. B2545
Lifting spanner (2 ½")	Mark III	see Fig. B2535

Hot dip galvanized pumprods can be used in waters with a pH value greater than 6.5. (Note: there are other parameters that can also influence corrosion). In all other cases, Stainless Steel rods should be used.

5.2 Electroplating and Passivating:

The Chain coupling C2330, Spacer C2332, Axle washer C2334, Connecting tool assembly B2420, Pipe clamp assembly A2470, Pipe clamp assembly A2472, Bearing mounting assembly, Lifting adapter assembly, Chain supporter C2476, Axle punch C2477, Vice plate assembly B2516, Handle assemblies B2557 and B2448, Vice flange assembly B2444 and all bolts and nuts of Free cutting Steel shall be electroplated and passivated to ISO 2081/2082, Fe/Zn12C ("Electroplated coatings: coatings of zinc and cadmium coatings on iron and steel"). The coating thickness should be between 15 to 18 μm in average.

5.3 Chromate Conversion Coating:

The electroplated parts shall be given a chromate conversion coating, Type C to ISO 4520, "Protection against corrosion: chromating on electroplated zinc and cadmium coatings".

5.4 Painting:

The exterior surface of all cast iron components shall be given the following treatment:

a) Surface to be treated needs thoroughly cleaning from rust and all grease.
b) One coat of Quality Red Oxide Primer to be applied (corrosion protection).
c) Thereafter, two layers of Quality Gloss Enamel Paint are required.

Appendix 11: Part list for India Mark II Extra-Deep Well

This part list for the India Mark II Extra-Deep Well is produced by SKAT and RWSN (2007)

Partslist for the India Mark II Extra Deepwell Handpump (Revision 2-2007)

Part No	Qty	Description	Dimension	Material	Standard	Remarks
D9166	1	Pump assembly	none	none	none	none
A2503	1	Head arrangement	none	none	none	pre-assembled
B2504	1	Head assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2506	1	Back plate	4 x 98 x 628	E235	ISO 630	machined / bent
C2313	2	Side plate	4 x 345 x 386	E235	ISO 630	machined
C2314	1	Axle bush left	Ø45 x 32	E355	ISO 630	machined
C2316	1	Axle bush right	Ø45 x 25	E355	ISO 630	machined
C2317	1	Bottom end plate	4 x 40 x 90	E235	ISO 630	machined
C2318	1	Top end plate	4 x 80 x 90	E235	ISO 630	machined
C2319	1	Flange	6 x 190 x 250	E235	ISO 630	machined
B2507	1	Bracket assembly	none	none	none	welded to ISO 9692,
C2508	2	Bracket plate	4 x 35 x 131	E235	ISO 630	machined
C2509	1	Bottom plate	4 x 35 x 53.5	E235	ISO 630	machined
C2510	1	Top plate	4 x 43 x 53.5	E235	ISO 630	machined
C2512	2	Filler rod	Ø12 x 60	E185	ISO 630	machined
B2320	1	Front cover assembly	none	none	none	welded to ISO 9692,
C2321	1	Front cover plate	2 x 272 x 450	E235	ISO 630	machined / bent
A2525	1	Handle arrangement	none	none	none	pre-assembled
B2526	1	Handle assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2527	1	Bearing housing	Ø70 x 50	E235	ISO 630	machined
C2328	1	Chain guide	12/12 x 228	E235	ISO 630	machined / bent
C2529	1	Handle bar	38/38 x 1170	E235	ISO 630	machined
B2346	1	Chain assembly	none	none	none	welded to ISO 9692, machined
C2330	1	Chain coupling	Ø50 x 30	E355	ISO 630	machined, electroplated to ISO 2081/82,
C2332	1	Spacer	Ø35/20.2 x 21	E235	ISO 630	machined, electroplated to ISO 2081/82,
C2333	1	Handle axle	Ø25 x 147	Stainless Steel	ISO 15510	machined, X5CrNi 18-9, bright
C2334	1	Axle washer	Ø30/13 x 4	E235	ISO 630	machined, electroplated to ISO 2081/82,
B2530	1	T-handle assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2531	1	T-Bar	38/38 x 400	E235	ISO 630	machined
C2532	1	Plate	6 x 145 x 300	E235	ISO 630	machined
C2533	1	Tube	Ø38/3 x 225	ST 320	ISO 630 (ISO 559)	machined
C2534	X	Balance plate	16 x 145 x 300	E185	ISO 630	machined, hot dip galvanized to ISO 1461,
B2335	1	Third plate assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2336	1	Flange	6 x 190 x 250	E235	ISO 630	machined
C2337	1	Guide bush	Ø30 x 40	E355	ISO 630	machined

Part No	Qty	Description	Dimension	Material	Standard	Remarks
B2340	1	Water tank assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2341	1	Flange	6 x 190 x 230	E235	ISO 630	machined
C2342	1	Riser pipe holder	Ø55 x 50	E235	ISO 630	machined
C2343	1	Tank pipe	Ø165.1/4.85 x 154	ST 320	ISO 630 (ISO 559)	machined (6" pipe, NB150, medium)
C2344	1	Flange	6 x 190 x 230	E235	ISO 630	machined
C2269	2	Gusset	6 x 30 x 30	E235	ISO 630	machined
C2345	4	Gusset	6 x 40 x 40	E235	ISO 630	machined
B2367	1	Spout assembly	none	none	none	welded to ISO 9692,
C2368	1	Spout pipe	Ø48.4/3.25 x 280	ST 320	ISO 630 (ISO 559)	machined (1 1/2" pipe, NB40, medium)
C2369	1	Spout end	Ø48.4/3.25 x 130	ST 320	ISO 630 (ISO 559)	machined (1 1/2" pipe, NB40, medium)
B2348	1	Stand assembly NB150	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2292	1	Stand pipe	Ø165.1/4.85 x 605	ST 320	ISO 630 (ISO 559)	machined (6" pipe, NB150, medium)
C2053	1	Flange	6 x 190 x 230	E235	ISO 630	machined
C2054	3	Leg	EA 40x40x6-530	E235	ISO 657-1	machined, welded to ISO 9692,
C2052	2	Gusset	6 x 22 x 22	E235	ISO 630	machined
A2540	1	Cylinder assembly	none	none	none	none
C2351	1	Cylinder	Ø82 x 304	GG20	ISO 185	cast, machined
C2352	1	Brass liner	Ø65.3/0.9 x 310	Copper-zinc alloy	ISO 426-1	CuZn37 (CuZn20Al2 or CuZn28Sn1)
C2353	2	Reducer cap	Ø90 x 80	GG20	ISO 185	cast, machined
C2354	3	Sealing ring	Ø78/67 x 4	Nitrile Rubber	ISO 3302-1 (M2)	moulded / 70-80 Shore A
C2365	X	Riser pipe	Ø42.4/3.25 x 3000	ST 320	ISO 630 (ISO 559)	NB32, medium, hot dip galvanized GI pipe (1 1/4")
C2366	X	Socket	Ø48 x 48	ST 320	ISO 630 (ISO 559)	for hot dip galvanized GI pipe (1 1/4")
A2541	1	Plunger assembly	none	none	none	pre-assembled
C2355	1	Plunger body	Ø49 x 53.5	Copper-zinc alloy	ISO 426-2	cast, machined, CuZn38Pb4
C2542	1	Follower	Ø60 x 84	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2357	1	Spacer	Ø60 x 29	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2543	1	Spacer	Ø60 x 26	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2358	1	Upper valve	Ø33 x 40	Copper-zinc alloy	ISO 426-2	cast, machined, CuZn38Pb4
C2359	3	Cup seal	Ø63.5 x 14	Nitrile Rubber	ISO 3302-1 (M2)	moulded / 75-85 Shore A
C2360	1	Rubber seating	Ø45/19 x 4	Nitrile Rubber	ISO 3302-1 (M2)	moulded / 70-80 Shore A
A2423	1	Check valve assembly	none	none	none	pre-assembled
C2361	1	Check valve	Ø41 x 49	Copper-zinc alloy	ISO 426-2	cast, machined, CuZn38Pb4
C2362	1	Check valve seat	Ø77 x 14	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2363	1	Seat retainer	Ø47 x 10	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2364	1	Rubber seating	Ø32/10 x 4	Nitrile Rubber	ISO 3302-1 (M2)	moulded / 70-80 Shore A
A2370	1	Pumprod arrangement	none	none	none	Mild Steel (MS)
B2373	X	Pumprod assembly	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,

Part No	Qty	Description	Dimension	Material	Standard	Remarks
C2372	1	Rod	Ø12 x 2990	E235	ISO 630	machined (bright)
B2555	1	Plunger rod assembly	none	none	none	Stainless Steel (SS)
C2556	1	Rod	Ø12 x 490	Stainless Steel	ISO 15510	machined, X5CrNi 18-9, bright
OPTIONS:						
C2331	1	Bearing housing	60 x 60 x 50	E355	ISO 630	machined
B2347	1	Stand assy. NB175/150	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461,
C2378	1	Stand pipe	Ø193.7/4.85 x 345	ST 320	ISO 630 (ISO 559)	machined (7" pipe, NB175, light)
C2379	1	Stand pipe	Ø165.1/4.85 x 255	ST 320	ISO 630 (ISO 559)	machined (6" pipe, NB150, medium)
C2295	1	Reducer	Ø195 x 20	E235	ISO 630	machined
A2414	1	Plunger assembly	none	none	none	pre-assembled
C2408	2	Spacer	Ø60 x 22	Copper-zinc alloy	ISO 426-2	machined, CuZn38Pb4
C2409	3	Leather Cup seal	Ø62 x 15	Leather	none	processed, machined
A2380	1	Pumprod arrangement	none	none	none	Stainless Steel (SS)
B2383	1	Pumprod assembly	none	none	none	welded to ISO 9692,
C2382	1	Rod	Ø12 x 2990	Stainless Steel	ISO 15510	machined, X5CrNi 18-9, bright
INSTALLATION AND MAINTENANCE TOOLS						
B2420	1	Connecting tool assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2421	1	Rod	Ø12 x 200	E235	ISO 630	machined
C2422	1	T-bar	Ø12 x 200	E235	ISO 630	machined
A2470	1	Pipe clamp assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2471	2	Clamp	6 x 50 x 313	E235	ISO 630	machined, bent
A2478	1	Bearing mounting assy.	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2479	1	Bearing holder	Ø50 x 38	E355	ISO 630	machined
C2480	1	Pressure plate	Ø50 x 20	E355	ISO 630	machined
C2476	1	Chain support	Ø48.4/4.05 x 60	ST 320	ISO 630 (ISO 559)	machined (1 1/2" pipe, NB40, heavy)
C2477	1	Axle punch	Ø25 x 160	E355	ISO 630	machined
A2515	1	Pipe vice assembly	none	none	none	none
B2516	1	Vice plate assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2517	1	Base plate	12 x 190 x 230	E235	ISO 630	machined
C2518	1	Vice plate	40 x 120 x 257	E235	ISO 630	machined
C2519	1	Fixed jaw, 1 1/4"	40 x 61.5 x 72	Tool Steel	ISO 630	machined, hardened
C2520	1	Clamping jaw, 1 1/4"	40 x 68.5 x 82	Tool Steel	ISO 630	machined, hardened
C2523	1	Side plate	6 x 35 x 70	Tool Steel	ISO 630	machined, hardened
C2524	1	Guide	24 x 40 x 65	Tool Steel	ISO 630	machined, hardened
B2557	1	Handle assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82

Part No	Qty	Description	Dimension	Material	Standard	Remarks
C2558	1	Spindle	Ø30 x 140	E235	ISO 630	machined
C2559	1	Handle bar	Ø12 x 180	E235	ISO 630	machined
C2560	3	Handle knob	Ø20 x 14	E235	ISO 630	machined
A2443	1	Pumprod vice assembly	none	none	none	none
B2444	1	Vice flange assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2445	1	Flange	6 x 190 x 230	E235	ISO 630	machined
C2446	1	Pressure piece	40 x 50 x 50	E235	ISO 630	machined
C2447	1	Thread piece	30 x 40 x 50	E235	ISO 630	machined
C2413	2	Handle	Ø8 x 172	E235	ISO 630	machined, bent
B2448	1	Handle assembly	none	none	none	welded to ISO 9692, electroplated to ISO 2081/82
C2449	1	Spindle	Ø30 x 140	E235	ISO 630	machined
B2545	1	Lifting spanner, 1 1/4"	none	none	none	welded to ISO 9692, hot dip galvanized to ISO 1461
C2546	1	Hook plate	6 x 115 x 163	E235	ISO 630	machined
C2547	1	Gripping plate	6 x 36 x 182	E235	ISO 630	machined
C2538	1	Spanner handle	33.8/4.05 x 1200	ST 320	NB25 (1"), heavy	GI pipe, hot dip galvanized
C1152	2	Spanner (New Standard)	16 A/F	Chrome alloy	none	for hex. bolts & nuts of M10 (New ISO Standard)
C1137	2	Spanner	17 A/F	Chrome alloy	none	for hexagonal bolts and nuts of M10
C1153	2	Spanner (New Standard)	18 A/F	Chrome alloy	none	for hex. bolts & nuts of M12 (New ISO Standard)
C1005	2	Spanner	19 A/F	Chrome alloy	none	for hexagonal bolts and nuts of M12
STANDARD PARTS:						
C1012	X	Hexagonal coupler	M12 x 20	Class 8.8	ISO 4032	none
C1015	X	Hexagonal coupler	M12 x 50	Class 8.8	ISO 4032	none
C1016	23	Hexagonal nut	M12	Class 8.8	ISO 4032	none
C1017	10	Hexagonal bolt	M12 x 40	Class 8.8	ISO 4014/4017	none
C1030	1	Hexagonal bolt	M12 x 20	Class 8.8	ISO 4017	none
C1032	1	Chain	25.4 (1") Pitch	Spring Steel	ISO 4348	ISO Chain No. 16-B
C1033	1	Hexagonal bolt	M10 x 40	Class 8.8	ISO 4014/4017	none
C1034	1	Hexagonal lock nut	M10	Steel/Polyamide	ISO 7040	none
C1035	2	Ball bearing	Ø47/20 x 14	6204-2Z	ISO 15	(Toyota Koyo UK 6204 RS)
C1036	4	Hexagonal bolt	M12 x 100	Class 8.8	ISO 4014	none
C1053	X	Hexagonal coupler	M12 x 20	Stainless Steel	ISO 4032	X5CrNi 18-9
C1055	X	Hexagonal coupler	M12 x 50	Stainless Steel	ISO 4032	X5CrNi 18-9
C1150	4	Hexagonal bolt	M10 x 50	Class 8.8	ISO 4017	none
C1151	3	Dowel pin	Ø8 x 40	Tool Steel	ISO 2338	hardened

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