TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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RURAL WATER SUPPLY TECHNOLOGY SELECTION IN ACHIEVING SUSTAINABLE DEVELOPMENT GOAL 6 IN AMHARA, ETHIOPIA

Master of Science Thesis

Examiners: Adjunct Professor Tapio S. Katko and Dr. Pekka Pietilä
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ABSTRACT

KAISA KUISMANEN: Rural Water Supply Technology Selection in Achieving Sustainable Development Goal 6 in Amhara, Ethiopia
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This Master's thesis was done for a rural water supply development project, COWASH. To date, it has mainly implemented basic water point supplies, hand-dug wells with hand pumps and on-spot spring protections. Many of these have come to the end of their lifetime. It is necessary to analyze whether there are better options to achieve the Sustainable Development Goals and Ethiopian Growth and Transformation Plan targets. The SDGs set high targets for future development, focusing on sustainability and resilience to end poverty in all forms. Goal 6.1 covers drinking water and is the focus in this study.

The study area is a part of Yeloma kebele, a small rural village in Ethiopia. Currently the only sources of drinking water are hand-dug wells with hand-pumps. Three technical options were included, a hand-dug well with hand pump, a piped water supply (larger solar scheme) and an extended water point supply (smaller solar scheme). The three options were compared based on their life-cycle costs, which were calculated for 10 years. Water safety, water availability, water quantity, functionality, management of the water supply system and social issues were also included in the comparison. In the field work phase household and WASHCO questionnaires were conducted for basic information on the community. Water quality was tested in existing wells.

Based on the life-cycle costs hand pumps were clearly found to be the cheapest option and smaller solar the most expensive. However, hand pumps in this area cannot come any closer to the SDGs. Both solar schemes have the possibility of improving water quality and reducing collection times. The smaller solar schemes cannot achieve all the possible technical advantages, as there is a problem with water quantity and joined standposts cannot be built closer to the households. The larger scheme could provide enough water for separate household connections.

Solar pumping is a major opportunity to improve service levels. It is necessary to analyze the effectiveness for each scheme separately. In the study area, solar pumping might be a suitable trial system for a school in need of large quantities of water for drinking and sanitation use.

TIIVISTELMÄ

KAISA KUISMANEN: Maaseudun vesihuoltoteknologian valinta kestävän kehityksen 6 tavoitteen saavuttamiseksi Amharassa, Etiopiassa
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Diplomityö tehtiin COWASH-hankkeelle, joka on maaseudun vesihuollon kehitysyhteistyöprojekti. Tähän mennessä COWASH on enimäkseen toteuttanut käsin kaivetuttuja kaivoja käsipumpuilla ja lähdesuojauksia vesihuollon tarpeisiin. Moni näistä vesipisteistä on tullut elinikänsä päätökseen. On tarpeen analysoida, onko parempiakin vaihtoehtoja saavuttaa YK:n kestävän kehityksen tavoitteet sekä Etiopian hallituksen asettamat tavoitteet kasvulle ja kehitykselle. Kestävän kehityksen tavoitteet asettavat korkeita päämääriä tulevaisuuden kehitykselle, ja keskittyvät köyhyyden poistamiseen koko maailmasta.

Tutkimusalue on osa Yeloma-nimistä kylää Etiopian maaseudulla. Tällä hetkellä ainoat juomaveden lähteet ovat käsin kaivetut kaivot käsipumpuilla. Kolme teknistä vaihtoehtoa valittiin vertailuun. Perinteinen vesipiste käsipumpulla, laajennettu vesipiste, sekä isompi putkitettu laitos. Kaksi jälkimmäistä olisivat aurinkovoimalla toimivia vedenpumppausjärjestelmiä. Kolmea vaihtoehtoa vertailtiin elinkaarikustannusten perusteella, mitkä laskettiin kymmenelle vuodelle. Vedenlaatu, saatavuus, veden määrä, toimivuus, vesipisteen hallinnointi ja sosiaaliset näkökohdat otettiin lisäksi huomioon. Kenttävaiheessa yhteisön piirteitä tutkittiin tekemällä kyselyt alueen kotitalouksille sekä vesi- ja sanitaatiokomiteoille. Lisäksi tutkittiin alueen juomaveden laatua.

Elinkaarikustannusten perusteella käsipumput olivat selkeästi halvin vaihtoehto, ja laajennettu vesipiste kallein. Kuitenkaan käsipumpuilla kyseisellä alueella ei päästä kestävän kehityksen tavoitteita lähemmäksi. Aurinkovoimalla toimivat pumppausjärjestelmät mahdollistavat jonotusaikojen lyhentämisen ja vedenlaadun parantamisen. Näistä pienempi ei kuitenkaan voi saavuttaa kaikkia teknisiä hyötyjä, sillä kaivojen antoisuus ei ole riittävä eikä hanapisteitä voi sijoittaa lähemmäksi kotitalouksia. Isompi putkitettu laitos taas voisi mahdollistaa yhteyden jokaiseen kotitalouteen.

Aurinkovoimalla toimiva vedenpumppaus on iso mahdollisuus parantaa palvelun tasoa. Sen kannattavuus tulee analysoida jokaisessa tilanteessa erikseen. Tutkimusalueella pienempää järjestelmää voisi kokeilla koululle, jossa vedelle olisi suuri tarve juomavetenä ja sanitaatiotarpeisiin.

PREFACE

I would like to thank my supervisors Adjunct Professor Tapio S. Katko and Dr. Pekka Pietilä for instructing me. Thank you to Arto Suominen, Chief Technical Advisor for COWASH, for the opportunity to work with the project, and for supervising and supporting me during my stay in Ethiopia.

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Tampere, 15.11.2018

Kaisa Kuismanen

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

CDF	Community Development Fund
COWASH	Community-led Accelerated WASH
CMP	Community Managed Project Approach
EFY	Ethiopian Fiscal Year
ETB	Ethiopian Birr
GTP	Growth and Transformation Plan
HDW	Hand-dug well
HP	Hand pump
JMP	WHO/UNICEF Joint Monitoring Program
MDG	Millennium Development Goals
MFI	Micro-Finance Institution
MoWIE	Ministry of Water, Irrigation and Electricity
O&M	Operation and Maintenance
OWNP	One WASH National Program
RWSEP	Rural Water Supply and Environment Program
SDG	Sustainable Development Goals
W	Watt
WASH	Water, sanitation and hygiene
WASHCO	Water, Sanitation and Hygiene Committee
WHO	World Health Organization

1. INTRODUCTION

The lack of safe drinking water affects millions of people all around the world. Drinking water in many places is collected from sources that are often contaminated, such as rivers, lakes or unprotected wells. Waterborne diseases especially affect communities without access to basic water and sanitation services.

There has been significant progress in the last decades in improving water services. However, the recent WHO & UNICEF (2017) report showed that still as many as 2,1 billion people lack access to safe drinking water globally. There are 4,5 billion people without safe sanitation and 0,9 billion practice open defecation. (WHO & UNICEF 2017)

In 2015 the United Nations General Assembly member states all agreed on the 2030 Agenda (Transforming our world: the 2030 Agenda for Sustainable Development) to end poverty and for the world to move to a more sustainable and resilient path. The UN Member States are all committed to “leaving no one behind” and to “end poverty in all its forms”. (UN-Water 2018) The Sustainable Development Goals (SDGs) were created as a part of the agenda to follow the Millennium Development Goals (MDGs).

The SDGs consist of 17 goals, and each goal is further divided into 169 more specific targets, specifying outcomes and means of implementation. (UN-Water 2018) The targets have been designed to be relevant and applicable universally, in low-, middle-, and high-income countries. The SDGs include the social, environmental, and economic aspects of sustainable development and aim for an integrated approach to these dimensions. Every government is responsible for incorporating the SDG targets in their own strategies and national policies. SDG 6 covers water, sanitation and hygiene. Goal 6.1 is specifically focused on drinking water issues, and therefore is mainly discussed in this study. (WHO 2017)

Ethiopia was one of the few Sub-Saharan countries to achieve the Millennium Development Goal target to halve the population without access to an improved water supply by 2015. Regardless of these efforts and progress, millions of Ethiopians still lack access to safe drinking water or basic sanitation. (World Bank Group 2015)

The Ethiopian government has set high goals for the development of Ethiopia in the future. Water and sanitation are some of the key elements in improving living standards, promoting gender equality, and reducing poverty. (World Bank Group, 2015; IUSHS, 2017) The vision for Ethiopia is to become a middle-income country by 2025. The objective of the second growth and transformation plan (GTP-2) is to contribute towards the country's vision by improving water supply and wastewater management. This is to be done mainly by utilizing low cost technologies and mobilizing communities. (OWNP 2018c)

1.1 COWASH

The Government of Finland has supported the Ethiopian water sector since 1994, when the Rural Water Supply and Environment Program (RWSEP) started in Amhara region. Up to date nearly 5 million people have been provided access to basic safe water supplies in five regions. This is due to the three bilateral projects between the governments of Finland and Ethiopia. These projects are RWSEP (1994-2011), FinnWASH (2008-2016) in Benishagul-Gumuz Region and Community-Led Accelerated WASH (COWASH), which is implemented from 2011 to 2019. There are nearly three million beneficiaries from the COWASH project by now and it is currently implemented in 76 rural districts (woredas). (cmpethiopia.org 2018)

Figure 1 shows all the regions in Ethiopia, and the location of Yeloma kebele in Amhara region south of lake Tana. The darker blue areas on the map are COWASH woredas in 2015.

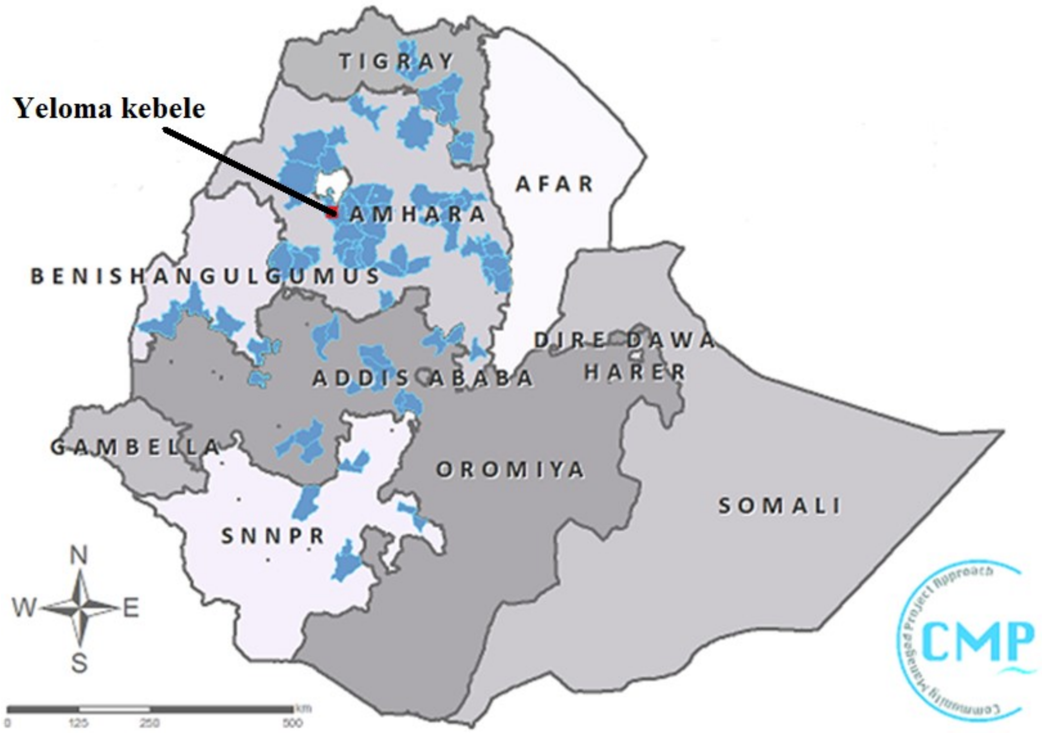

Figure 1. *Map of Ethiopia and the location of the study area, with all COWASH woredas in 2015 in darker blue (adapted from cmpethiopia.org 2018)*

COWASH applies the so-called Community Managed Project (CMP) approach, which puts communities in the center of development of water and sanitation projects. The CMP approach has been developed in earlier water projects supported (financed) by the Government of Finland. In the beginning it was called the CDF (Community Development Fund)

In the CMP approach local communities, schools or health centers apply for financial support for their own water supply or latrine construction. They receive the investment money, and manage the construction, acquisitions and governance themselves. Funds for the projects are routed through the Ethiopian government's finance bureau from the regional level to a Micro-Finance Institution (MFI). The money is distributed directly to the communities for construction by the MFI. The communities form a committee to be in charge of the project, called WASHCO (water, sanitation and hygiene committee).

Members for the WASHCO are elected by the community. They are responsible for the planning and implementation of the whole project, as well as for governing the scheme after completion. Money is only for up-front cash contribution which is meant for O&M (operation and maintenance). Communities also contribute to the infrastructure by providing labor and local materials (in-kind). Only in some projects cash for investments is required, if the in-kind contribution does not reach 15 % of the investment costs. (cmpethiopia.org 2018)

The CMP approach has received very positive international attention in Ethiopia and globally. (Behailu 2016) It is one of the implementation approaches in the OWNP (One WASH National Program), a sector-wide approach to harmonize the actions of different WASH stakeholders to achieve the country's goals in water, sanitation and hygiene. (OWNP 2010)

During the last seven years COWASH has implemented over 13 000 water supplies. Most of these systems are small water point supplies (hand-dug wells and on-spot spring protections) each serving a population of approximately 150 – 250 people and using the shallow aquifer as a water source. A limited number of piped water supplies have also been constructed (gravity and motorized). In 40 COWASH districts in Amhara region alone, altogether 2 151 080 people have gained access to an improved water supply between 2011 and 2017. (cmpethiopia.org 2018)

There have been several MSc and BSc studies (Mebrahtu 2012; Muhummed 2012; Tesfaye 2012; Mitiku 2013) on the CMP approach, and one PhD level research (Behailu 2016). They have studied the effectiveness, challenges and impacts of the CMP approach. Behailu (2016) found that the CMP approach had performed well in involving communities in water supply projects. Achievements were also found to be in creating ownership, training WASHCOs and caretakers, and involving users. Community management was found to be a favorable way to implement water supply projects in rural areas. Ownership is important for the success of the projects and user participation should not be forced. It is essential for the experts to understand the importance of community participation for community management to operate well. (Behailu 2016)

1.2 Research goals

The hand-dug wells with hand pumps and spring protections helped Ethiopia achieve the Millennium Development Goal by 2015. Thereafter Ethiopia has set a new standard for its Growth and Transformation Plan (GTP) for 2016 – 2020. The Sustainable Development Goals (SDG) standards for rural water supply are more demanding than the previous Millennium Development Goals (MDG). Many of the installed hand pumps by RWSEP and FinnWASH have come close to the end of their lifetime as they have been functional for more than 10 years. Very soon the oldest hand pumps and springs constructed by COWASH will be at the end of their lifetime as well.

Therefore, it is necessary for the sector and COWASH in particular to analyze whether the hand-dug well equipped with the hand pump is anymore the only option to continue in the achievement of the SDG and GTP-2 targets. Hand-dug wells with hand pumps and capped springs are still designed for the coming years. Piped water systems are given priority in the One WASH National Program. (OWNP II 2018) Thus, this research compares the three of the most prominent technology options for rural water supply, and it proposes how these options can be implemented to achieve the more specific SDG 6 and GTP-2 targets in comparison to the previous MDG targets. This analysis produces research-based knowledge for the water sector in Ethiopia and COWASH project for its future implementation.

1.3 Research outlines

The three technological solutions included in this research were:

a) Basic water point supply system (hand-dug well with hand pump)
b) Piped water supply system either by gravity or motorized scheme
c) Improved, innovative, and extended water point supply system (solar pumping to the distribution tank).

The piped scheme and solar pumping water supply systems were designed to the same areas to serve the same population which is now served with basic water point supply systems.

The selection criteria of the technology options were made based on the life-cycle costs of each option. Other characteristics that were analyzed include the following points:

- Water safety (potable)
- Water availability (available all the time)

- Water quantity (ensuring the resource i.e. catchment management)
- Functionality (maintenance and spare parts)
- Management of water supply system (voluntarily managed, professionally managed)
- Social issues (land use, accessibility, acceptability).

The selected area for the field research was Yeloma Kebele, located in Bahir Dar Zuria Woreda (district) (flat area with shallow ground water available) in Amhara region, Ethiopia. The study area was pre-selected by COWASH. The selection criteria were a flat area with a high groundwater level, high rainfall, high solar radiation, 100 % water coverage by hand pumps, a high population density and easy access to the area.

Social issues were also considered when designing the technical implementation, as the characteristics of each community effect how a water project can be implemented. For example in the case of accessibility, joined standposts (with taps) are more accessible to persons with disabilities than the traditional hand pumps that require manual labor and climbing onto the platform. And in the case of Walkie and Addis Alem (the two specific water points selected from the area), the special agreement that the two (Water and Sanitation Committee) WASHCO's have needs to be considered. The special agreement means that the two water points are used collectively by the community. It will be further explained in chapter 4.1.

2. THEORETICAL BACKGROUND

In this chapter the targets on drinking water in the Sustainable Development Goals are first compared to the previous Millennium Development Goals. Thereafter, they are compared to the goals set for rural water supply in the second Ethiopian Growth and Transformation Plan (GTP-2). The current situation of the rural water supply in Ethiopia is also discussed.

2.1 Rural water supply in Ethiopia

The rural population in Ethiopia was estimated to be approximately 75 million in 2017, with a rural population growth rate of 1,8 % per annum. The urban population was estimated to be approximately 19 million in 2017, growing at an estimated rate of 5,0 % every year. According to the Central Statistics Agency (CSA) estimation in 2013, the total population may surpass 130 million by 2030. There are new job opportunities in the services sector, construction, and industry, which are believed to accelerate the rural-urban migration. One effect of this is the number of villages increasing in size to the small towns category (with a population up to 50 000). There were 534 small towns in 1994 and around 973 in 2011. (OWNP 2018b)

The percentage of the rural population in Ethiopia is estimated to be 80 % (in 2018). Most of these people are farmers and pastoralists, that work and live often in harsh and quite variable climates in the highlands of Ethiopia. Towns can provide markets and support functions, including labor pools for agriculture. According to the Ministry of Water, Irrigation and Electricity (MoWIE) annual budget year performance report of 2009 EFY (2016), 68 % of the rural population and 55 % of the urban population had access to an improved water supply. The water supply non-functionality rate was 11 %, and 61 % of the total population had some kind of latrine facility. (OWNP 2018b)

The situation is more alarming in schools. According to the WASH (water, sanitation and hygiene) sector annual report (in 2016), only 38 % of primary schools had access to a water supply and only 12 % of these had an adequate water facility. Only 4% of primary schools had all WASH elements. WASH elements include a protected and functional water supply and an improved latrine facility with handwashing available. In secondary schools the situation was a bit better, as 63% had access to a water supply, 24% had an adequate water facility, and 10% had access to all WASH elements. (OWNP 2018a)

The annual review meeting of the Ministry of Water, Irrigation and Electricity (MoWIE) in August 2018 provided the following situation in Ethiopia by July 2018. The water supply coverage is presented in table 1 for each region in 2016 and 2017 (2009 EFY and 2010 EFY, respectively).

Table 1. *Water supply coverage and plans for each region in Ethiopia in 2016 and 2017. (MoWIE 2018)*

Region	Disaggregated Indicator	At end of 2009 EFY (%)	Plan for 2010 EFY (%)	At end of 2010 EFY (%)	Plan for 2011 EFY (%)
Tigray	Rural water supply coverage	59	67	61	80
	Urban water supply coverage	54	69	54	70
	Region (Rural +Urban)	57		59	77
	Non-functionality rate	3	2	4	2
Amhara	Rural water supply coverage	76	86	84	85
	Urban water supply coverage	69	79	74	79
	Region (Rural +Urban)	75	85	84	
	Non-functionality rate	9	8	8	
Oromia	Rural water supply coverage	61	70	64	
	Urban water supply coverage	51	68	62	69
	Region (Rural +Urban)	59	70	64	
	Non-functionality rate	11	9	10	8
SNNPR	Rural water supply coverage	51	63	55	70
	Urban water supply coverage	75	90	80	
	Region (Rural +Urban)			58	70
	Non-functionality rate	19	11	13	11
Gambella	Rural water supply coverage	74	89	75	
	Urban water supply coverage	40	69	43	
	Region (Rural +Urban)	64	68	66	
	Non-functionality rate	5	2	4	
BSG	Rural water supply coverage	60	70	66	78
	Urban water supply coverage	42	53	42	64
	Region (Rural +Urban)	58	66	61	75
	Non-functionality rate	8	6	8	4
Diredawa	Rural water supply coverage	82	86	84	89
	Urban water supply coverage	In 2010 EFY planned to produce 11,877,034 m^3 water but produced 10,930,237 m^3 water (92%).			
	Region (Rural +Urban)	-	-	-	-
	Non-functionality rate	2	0	1	0
Addis Ababa	Urban water supply coverage	Not reported			
	Non-revenue water	39		37	?
Total /Country	Rural water supply coverage	**69**		**74**	**80**
	Urban water supply coverage	**55**		**60**	**75**
	Region (Rural +Urban)	**66**		**71**	**77**

Table 1 shows how Ethiopia has high goals to improve the water supply coverage in the country. It also shows the actual development compared to the plans. Most plans for the 2010 EFY in water supply coverage were not fulfilled in 2010 EFY. However, in most regions the water supply coverage in both rural and urban areas increased. In the country as a total, the water supply coverage increased from 66 % to 71 % between 2009 EFY and 2010 EFY. In some regions, the non-functionality rate was reduced to the target or even more (for example Benishangul-Gumuz region).

2.2 Sustainable Development Goals

Goal 6 of the Sustainable Development Goals focuses on water and sanitation issues. This includes drinking water, sanitation, hygiene, wastewater treatment, water use efficiency, integrated water resources management and transboundary cooperation, water-related ecosystems, international cooperation, capacity-building, participation in water and sanitation management, and to enhance the monitoring of these targets. Target 6.1 is to achieve drinking-water access for all and to improve service levels. (UN-Water 2018) SDG 6.1 will be the focus of this research, as it applies to drinking-water.

For global monitoring, the WHO/UNICEF Joint Monitoring Program (JMP) has developed an interpretation for the SDG 6.1 target. "By 2030, achieve universal and equitable access to safe and affordable drinking water for all." (UN-Water 2018) The interpretation for the target is shown in table 2. All the elements of this normative interpretation are not yet covered by the indicators, but additional criteria have been added since the MDG period. (WHO 2017)

Table 2. *The JMP normative interpretation for SDG 6.1 (WHO 2017)*

Target language	Normative interpretation
By 2030, achieve	
universal	Implies all exposures and settings, including households, schools, health facilities, workplaces and public spaces
and ***equitable***	Implies progressive reduction and elimination of inequalities between population subgroups
access	Implies sufficient water to meet domestic needs is reliably available close to home
to ***safe***	Safe drinking water is free from pathogens and elevated levels of toxic substances at all times
and ***affordable***	Payment for services does not present a barrier to access or prevent people from meeting other basic human needs
drinking water	Water used for drinking, cooking, food preparation and personal hygiene
for all	Suitable for use by men, women, girls and boys of all ages, including people with disabilities

The Joint Monitoring Program was established in 1990 to continue the monitoring process made by WHO since the 1960's. The JMP tracks progress and provides global reports on drinking-water, sanitation, and hygiene, and establishes norms to benchmark progress and inform decision-making. In the MDG period the JMP had two indicators to measure progress on drinking water and sanitation (MDG 7 C). In the current SDG period JMP tracks the progress on targets 6.1 and 6.2. (UN-Water 2018; WHO 2017)

The JMP tracks progress based on a so-called service level ladder. An improved source is one that is capable to deliver safe water by design, including protected wells, protected springs, rainwater collection, boreholes or tubewells and piped water. (WHO 2017) Improved sources can provide a limited, basic or safely managed service level, depending on the collection time, availability, and water quality. Safely managed is the ultimate target that the 2030 Agenda aims for, even though reducing collection times and reaching improved services for everyone are the initial focus. (UN-Water 2018) Table 3 shows the criteria for the JMP service ladder.

Table 3. *The JMP drinking water service ladder. (WHO 2017)*

Service level	Definition
Safely managed	Drinking water from an improved water source which is located on premises, available when needed and free of faecal and priority chemical contamination
Basic	Drinking water from an improved source provided collection time is not more than 30 minutes for a roundtrip including queuing
Limited	Drinking water from an improved source where collection time exceeds over 30 minutes for a roundtrip to collect water, including queuing
Unimproved	Drinking water from an unprotected dug well or unprotected spring
No service	Drinking water collected directly from a river, dam, lake, pond, stream, canal or irrigation channel

The table above means that the water service level should meet three criteria to be considered as safely managed service. The criteria are access on premises, available when needed and free from contamination. Otherwise drinking water from an improved source is considered as a basic or limited service, depending on the collection time.

2.2.1 SDG 6.1 and MDG 7 C

Millennium Development Goal 7 C stated to “to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation”. (UNICEF & WHO 2015) In 2010 it was reported that at the global level the target had been achieved. However, this achievement was measured on the global scale while there were still many countries not meeting the target. (UNICEF & WHO 2015)

The current SDGs in general are more ambitious than the former MDGs. The SDGs have additional focus on the connection between targets and integration of goals. (UN-Water 2018; WHO 2017) SDG 6.1 shows this new ambition, not just aiming to extend services to the population that still lacks even a basic service level but enhancing the level of the service provided as safely managed for all. The main focus, however, is to secure access to an improved water source for everyone and to reduce time spent on collecting water. (UN-Water 2018)

The MDG 7 C target referred to sustainable and safe drinking water access. The only indicator measured the type of source used, considered improved or unimproved. In 2008 an additional category of piped water on premises was added. (UNICEF & WHO 2015) The indicators in the SDGs include the quality of the service provided (accessibility, availability, affordability) in the indicators, not just the type of source used. The SDGs contain a new JMP service ladder for drinking water in households, schools, and health care facilities. It contains additional criteria to mark the progress and define the service level in addition to the existing MDG indicators. SDG 6.1 is more specific than MDG 7 C, and contains higher requirements for achieving the target, including also the requirement for the affordability of the service. Accessibility, availability, and the quality of drinking water are included in the indicators. The new steps in the service level ladder are safely managed, basic, limited, unimproved and no service. (WHO 2017)

Figure 2 shows the situation of drinking water service levels in Ethiopia in 2017 according to the JMP monitoring. Only four percent of rural water supply is considered as safely managed. When the basic service level is added, the coverage only reaches 26 %. (JMP 2017)

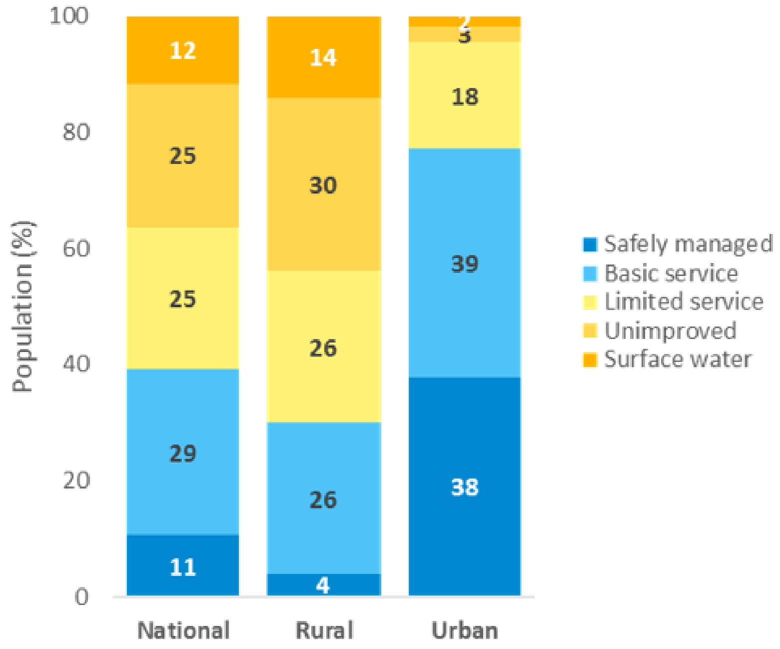

Figure 2. *The drinking water service levels in Ethiopia according to the JMP monitoring program. (JMP 2017)*

As can been from figure 2, there is still a long way for Ethiopia to achieve the SDG target. Technological solutions are needed to achieve the targets. The basic solutions that have been used so far (for example hand pumps, rope pumps and spring protections) are not enough to achieve the new SDG targets.

2.2.2 SDG 6.1 and GTP-2

In terms of water quantity SDG 6.1 does not define the sufficient amount of water necessary for domestic purposes. A sufficient amount of drinking water per capita per day is to be specified by each country. GTP-2 goal 1.2 aims to provide a minimum service of 25 liters per capita per day for the rural population. For the urban population, the minimum service level is based on the population of the town/city. (GTP 2015)

GTP-2 has defined a minimum service level for the rural population, the Ethiopian standard. According to goal 2.1 the service level should be 25 liters/capita/day of safe water at a maximum distance of 1 km from the home for 85 % of the rural population. Additionally, 20 % of this should be provided with RPS (rural piped scheme). (GTP 2015)

GTP-2 goal 2.6 states to "ensure rural safety through rural water supply water quality monitoring system and water safety planning and implementation". (GTP 2015) This goal has the same objective as SDG 6.1 in achieving safe (free from contamination) water. In GTP-2, the water quality is to be measured by the WHO standard (for safe drinking water), and "improved" is to be measured by the JMP definition. GTP-2 does not mention availability, but goal 2.1 is to reduce the amount of non-functioning water supply schemes down to 7 %. The GTP-2 target is set to be achieved by the year 2020, 10 years before the SDG targets at 2030. (GTP 2015; OWNP 2018b)

2.3 Water collection time

Water collection times have received a lot of attention. For example, it is included in the JMP service ladder as one of the criteria. In the SDG period reducing the time spent collecting water has been made a priority along with extending even a basic service level to all. (UN-Water 2018) Collection time has been added to the JMP monitoring of SDG target 6.1, whereas it was not considered in the MDGs. The household drinking water service ladder considers the time taken for a round trip (including queuing), defining whether the service level is safely managed, basic or limited. (WHO 2017)

In GTP-2 the time spent collecting water is not specified but is presented as distance to the source. In GTP-1 it was within 1,5 km for the rural population, and in GTP-2 the maximum distance is one kilometer. (GTP 2015) Therefore, the time spent on a round trip depends on the time spent queuing and the condition of the terrain. For example, in Yeloma kebele, during the rainy seasons the paths were very muddy, and walking was considerably slower than during the dry season.

In Ethiopia, generally women and children, especially girls are in charge of collecting water. The task can take up to several hours per day. Collecting water is an everyday task, and the time spent for water collection could be saved and used more productively for income generation or having more time for household chores etc. Collecting water also affects girls' school attendance negatively. (Abebaw et al. 2011) In the COWASH baseline survey, it was found that in almost 80 % of households the females are in charge of water collection. Of girls aged 14 and under 52,9 % were also responsible for the task. However, it is to be noted that there are also households with males in charge of water collection. (COWASH 2017)

Reducing the time spent collecting water allows time for other activities. It can allow for more time for social activities, such as spending with family or friends. In some cases, however, the time spent at the well with other women can be considered as a social activity. Although the economic benefits from saving time cannot directly be measured, it is generally accepted that it has a positive effect on the quality of life. Women can use the saved water collection time for more productive use, such as childcare and other domestic activities, or to pursue other means of income. (Abebaw et al. 2011)

Time spent collecting water is often a factor that affects the school attendance of girls (and sometimes boys), as they frequently have to skip school or come late to school. A study conducted in Ghana indicate that reducing the water collection time increases girls' school attendance, the effect being stronger in rural areas. The same effect was found also in boys' school attendance. (Abebaw et al. 2011; Nauges & Strand 2011)

Pickerings and Davis (2012) studied how water fetching distance affected children's health in Sub-Saharan Africa. They found out that reducing the time women spend collecting water reduced under-five child mortality and diarrhea prevalence, and positively affected children's nutritional status. There is some research suggesting that carrying heavy water containers for long distances can cause many physical health problems, such as spinal (back or neck) pain. (Geere et al. 2010; Geere et al. 2018) However, in all cases the water burden may not be the only factor in causing these problems.

Collecting water from longer distances increases vulnerability to violence for women and girls in some contexts. The risk of being harassed or attacked causes stress and anxiety. (Abasa et al. 2014; Thompson et al. 2011) A study in rural Ethiopia found that besides experiencing violence on the way to fetch water and while queuing, some women experience domestic violence over water or the amount they bring. (Stevenson et al. 2012) There are multiple studies on violence related to water, sanitation and hygiene (WASH) and water collection. Violence can be in multiple forms, physical, sexual, psychological or sociocultural. Violence related to water collection is mostly linked to women and girls, but even boys and men may face violence. (Sommer et al. 2015) Reducing time spent collecting water and bringing water closer to the households would thus reduce the risks of being attacked.

2.4 Hand pumps

In Ethiopia, the Afridev hand pump and India MKII are commonly used as community hand pumps. They are used in hand-dug wells and boreholes. These two types of pumps dominate the hand pump market in rural Ethiopia. The India MKII hand pumps are used in deeper schemes up to 70 meters. They are conventional lever action hand pumps for heavy-duty community use.

All of the Afridev hand pumps are manufactured in India, as in Ethiopia there is no hand pump manufacturing. The hand pumps in the study area are all Afridev hand pumps installed in hand-dug wells. Figure 3 shows an Afridev hand pump installed at the Walkie water point.

Figure 3. *Walkie water point with an Afridev hand pump. (Kaisa Kuismanen 2018)*

Afridev pumps are used from 10 m to 45 m in depth and is designed for community use for up to 300 persons. It is a conventional lever action hand pump. The approximate discharge at a 20 m head is 0,9 m^3/h. This means that it takes around 1,3 minutes to fill a 20 l jerrycan. (Erpf 2007)

A cross section of an Afridev hand pump is presented in figure 4. The pump is corrosion resistant and easy to install. (Erpf 2007)

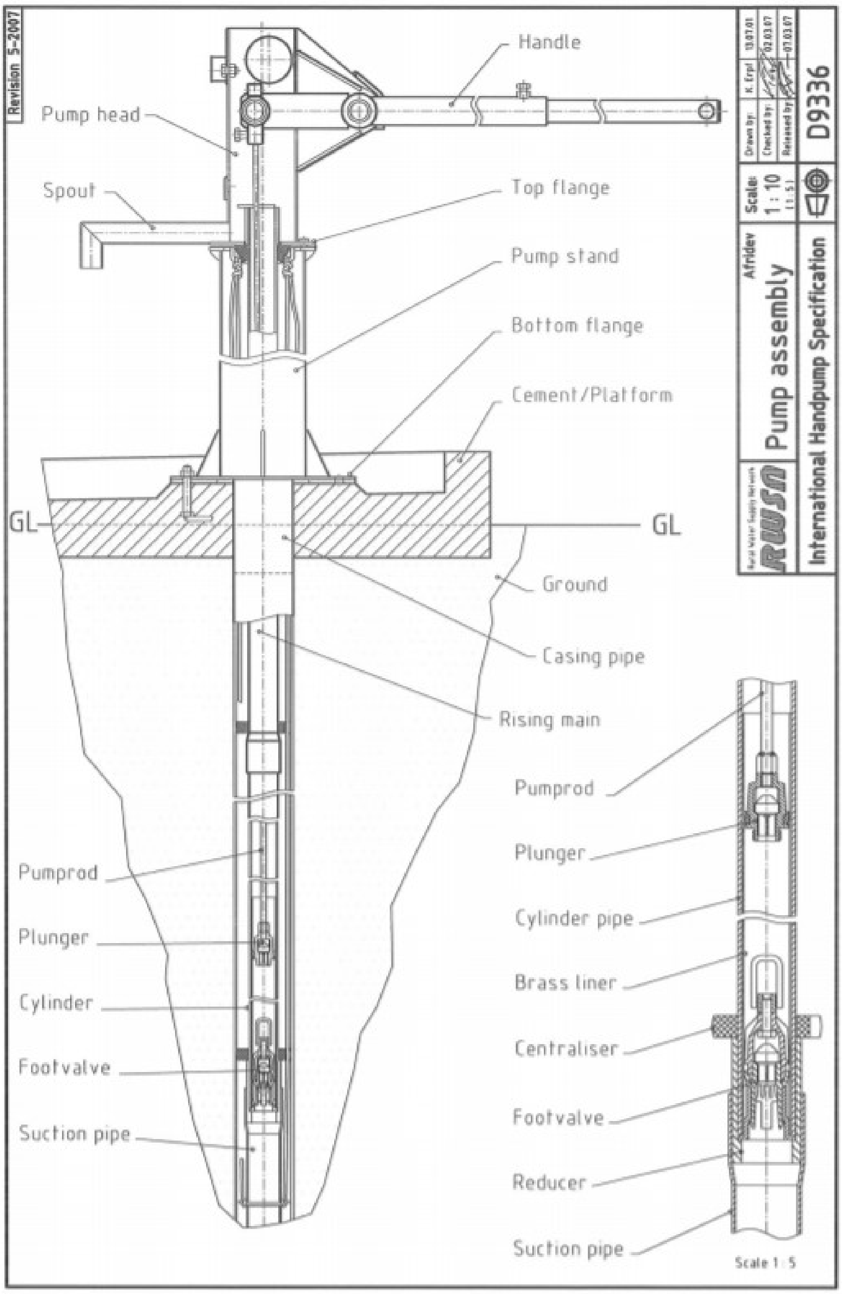

Figure 4. *Cross section of an Afridev hand pump used commonly in hand-dug wells up to 45 meters in depth. (Baumann & Keen 2007)*

The lifetime of the pump is around 10 years, depending on how well it is maintained during use. Hand pumps require regular maintenance to prevent frequent breakdowns. The non-functionality rates for hand pumps can be as high as 35 – 40 %. (Jiménez et al. 2017) Of the water points inspected by COWASH in 2017, the functionality rate was 83,2 % in total in Ethiopia. (COWASH 2017) In many cases, pumps break down long before the end of their expected lifetimes. The neglection of maintenance is one of the major reasons for non-functionality. (Butterworth & McNicholl 2018) Other reasons for non-functionality can be problems with management and limitation of funds (or money not collected regularly). (Jiménez & Pérez-Foguet 2011)

2.5 Solar pumping

Solar pumping is still relatively new in Ethiopian markets, but it is gaining ground and raising interest. In developing countries solar photovoltaic water pumping is mainly used for drinking water supplies and small-scale irrigation. Solar pumping is especially applicable in remote areas without access to grid power. It has the capability to produce a high level of service and it is an environmentally-friendly solution, as it produces no emissions. (Meah et al. 2006; Bamford & Zadi 2016) Solar pumping can make water supply more accessible to people with disabilities (installing taps), as it doesn't require the same manual labor as operating a hand pump. (Bamford & Zadi 2016)

Solar pumps use the sun as a power source and panels convert energy from sunlight directly to electrical energy. (World Bank 2018a) The photovoltaic potential for solar pumping is necessary to assess for each separate scheme. Solar potential can vary a lot even within a country or a district, and is the basis for a functioning solar pumping system. The map (figure 5) below shows the potential for photovoltaic power in Ethiopia. There is a lot of photovoltaic power potential in Ethiopia, as it is located near the equator. However, the solar potential is not constant within the country. Climate and weather conditions affect solar potential.

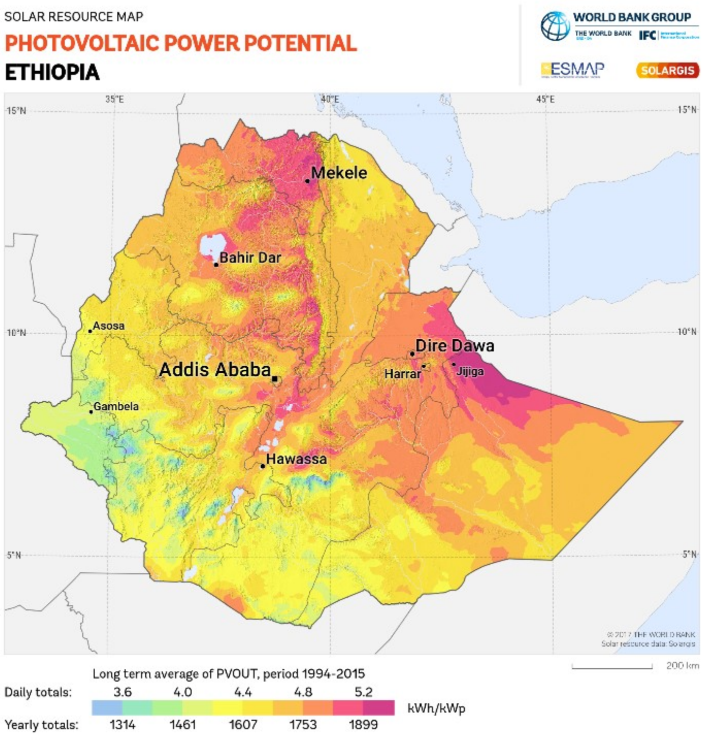

Figure 5. *Photovoltaic power potential in Ethiopia. (The World Bank 2018b)*

Solar panels are made from photovoltaic cells commonly made from silicon, grouped together and encased. They are either monocrystalline (silicon wafers cut from a single crystal of silicon), polycrystalline (casting molten silicon and crystallized into intergrown crystals) or amorphous (a thin layer of non-crystalline silicon) silicon PV cells. Solar panels are then grouped together, in series or parallel, to form solar arrays with the required voltage, current and power. (Chandel et al. 2015)

The solar panels are connected to a maximum power point tracker (MPPT), which controls the pump. The pump motor (AC or DC) converts electrical energy from the solar panels into mechanical energy, and then into hydraulic energy to lift water. (Chandel et al. 2015) The water then flows from the well into the storage tank through the riser pipe. The water thereafter can be distributed into communal taps, or further into households with pipe connections. Figure 6 shows the basic design of a solar powered pumping system.

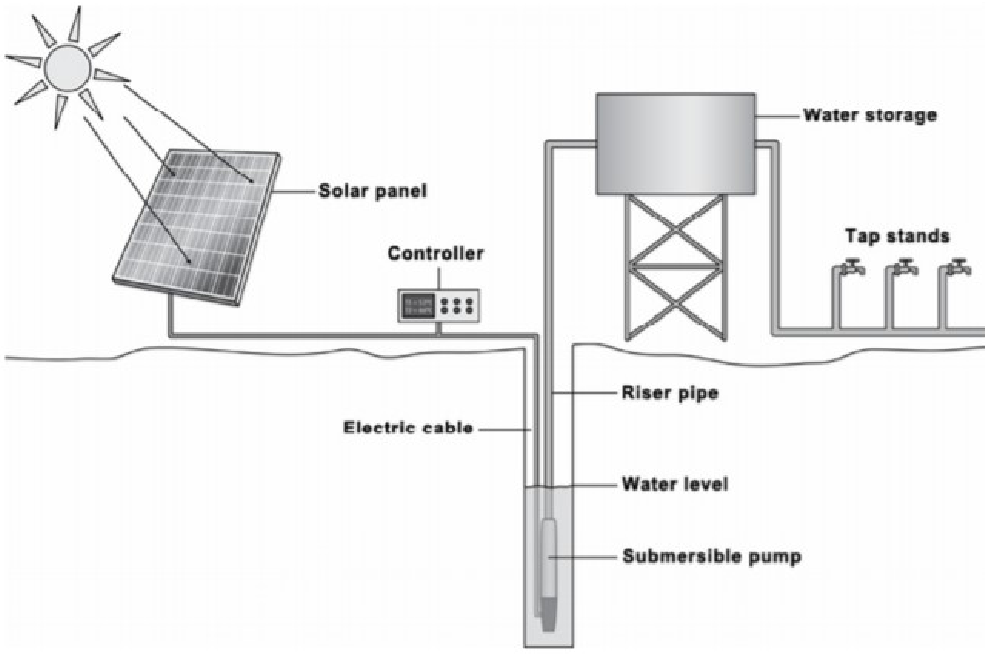

Figure 6. *Basic design of a solar powered pumping system (VNG & IRC 2014)*

Solar powered pumps can also be designed as a hybrid system, where grid electricity or more commonly a diesel generator can be used as a backup power source. Solar power would be designed to be the primary source of power. In case there is insufficient solar available, grid electricity or a generator would be used for additional pumping hours. Hybrid systems allow for longer pumping hours, and less storage space is needed as the water supply is more reliable. Hybrid systems with a diesel generator are typically used in off-grid areas where solar systems cannot produce enough water alone. The systems are more complex, and generators need to be replaced more often than the solar pumps and require more maintenance. The initial investment costs will be higher, as a generator will need to be purchased in addition to the solar equipment. (GSWI 2018; World Bank 2018a)

Batteries can be installed as a part of the system to store energy to be used during nights or low irradiation (bad weather conditions). However, batteries make the system more complex, and it will require more maintenance and they have a short lifespan of 1 – 2 years. Installing batteries also requires more solar array capacity, as the power losses in the system will be higher. Another more applied solution is to add a storage tank for water to be filled during the daytime. Stored water can then be used during peak times, nights, or days when the irradiation is not enough to pump sufficient amounts of water. (Bamford & Zadi 2016; UNDP 2015; World Bank 2018a) If the height of the storage tank is high, it will increase the need for solar panels and will then increase investment costs.

Operation of the solar pump can be either manual or automatic. Manual operation increases costs, as a pump operator is needed. This, however, leaves space for human error. An automatic system detects the level of water in the well and switches the pumps off when it reaches a certain level. There can also be a sensor in the tank to detect when it is full to stop the water flow. These sensors protect the pump from running dry, which could damage the pump and avoid unnecessary pumping when the tank is full. (Bamford & Zadi 2016; UNDP 2015) Manually operated systems are also found to malfunction more often compared to automatic systems.

Solar pumps can be divided by their applications into submersible, surface and floating pumps, or by their pumping principle into positive displacement pumps and centrifugal pumps. Positive displacement and centrifugal pumps are the two types of pumps most commonly in use globally. Solar pumps can pump water up to 200 – 250 meters, depending on the pump efficiency and number of solar panels. (The World Bank 2018a)

Proper installation and dimensioning of the system are key factors in the effectiveness of a solar powered pumping system. Underdimensioning of the system can lead to insufficient water to meet the demand or lead to longer queuing at the water point. Overdimensioning the pump can be a risk to the sustainability of the source. It can lead to source overexploitation, and also the initial investment costs will be higher. (GSWI 2018; Bamford & Zadi 2016)

Solar powered water pumping systems are considered as reliable, as they generally require little maintenance and rarely break down. They are also durable, as the lifespan of a solar panel can be up to 25 years. (Armstrong et al. 2017; GSWI 2018; World Bank 2018) The pump itself needs to be replaced every 7 – 10 years. It depends on how well they are maintained and the hours of pumping per day. The accessories for the pump have a typical lifetime of 10 years. (GSWI 2018)

More technical knowledge and expertise are required to design and implement a solar pumping scheme compared to a simple hand pump installation. Additionally, installing a solar pumping system is more complex than installing hand pumps. It requires qualified electricians for the job. Lack of knowledge and expertise are some of the challenges related to solar pumping. Other challenges include the availability of spare parts and technicians, theft and vandalism, improper management of the systems, badly done design and the higher initial investment costs for the pumping system. (GSWI 2018; The World Bank 2018a)

Theft and vandalism can be major risks for solar pumping systems. The PV panels are valuable, and even one missing panel from a solar array can stop the whole system from running. These risks can be reduced by for example properly mounting the panels, so they cannot be removed, using tamper-proof bolts and screws, fencing and locking the area, and hiring a security guard. Vandalism may not always be intentional. For example, children might throw stones on the panels to see what could happen or since they make a nice sound. The community needs to understand how valuable the panels are, and thereby community ownership is important. (GSWI 2018; World Bank 2018a)

Solar panels prices have significantly dropped in the past decade and there are more suppliers and manufacturers for the growing markets. Module costs have declined as production has increased and there has been considerable advancement in the pump and panel technologies as they have become more efficient and have larger capacities. (Armstrong et al. 2017; Bamford & Zadi 2016; Chandel et al 2015; World Bank 2018a)

The decline of the solar panel module costs can be seen in figure 7. The current prices are only a small fraction of the prices that were in 1977.

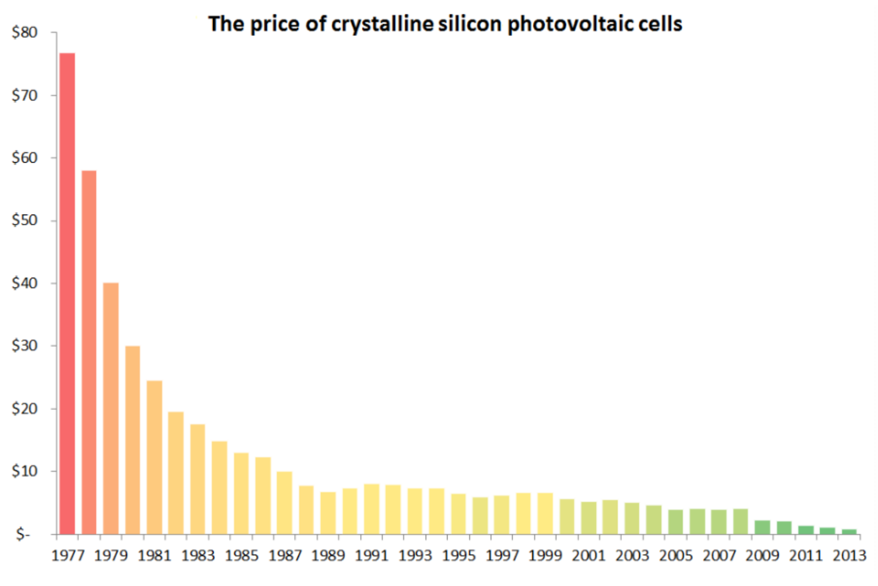

Figure 7. *How the price of photovoltaic cells has dropped since 1977. (Exeo Energy 2018)*

There are many studies that show how solar pumping is an economically more feasible solution compared to diesel powered pumps. (Bamford & Zadi 2016; Girma et al. 2015a; Hossain et al. 2015; Kabade et al. 2013; Meah et al. 2006) Although the initial investment costs of solar pumping are generally higher, they become more cost-effective when full life-cycle costs are considered. A diesel-powered system depends on imported fuel, and the supply chain can sometimes be unreliable. Fuel prices are escalating worldwide, as opposed to the free and continuous supply of energy for the solar pumping systems. (Bamford & Zadi 2016; Kabade et al. 2013)

If there is reliable grid electricity available solar pumping might not be the most feasible option. However, if grid electricity is often unreliable, then solar pumping should be considered. (GSWI 2018) Table 4 shows the estimation of the population with access to electricity in Ethiopia in 2016 for the rural, urban and total population.

Table 4. *Estimation of population with access to electricity in Ethiopia. (Trading Economics 2018)*

	2016 estimation (%)
Urban areas	86
Rural areas	27
Total population	43

Currently it is estimated that around 30 % of the rural population have access to electricity. This means that there are plenty of opportunities for solar pumping in rural Ethiopia. Even when there is grid electricity available, it can be very unreliable.

2.6 Other types of pumping systems

Another renewable source that can be used to pump water is wind energy, which has been used for centuries. Wind pumping systems are either mechanical or electric. They require an average wind velocity of 3 – 4 m/s to function properly, with mechanical pumps functioning better at lower wind velocities. Batteries can be used to store energy in the electric systems, but they lower the efficiency of the system. In most cases a storage tank would be a more feasible option. (Girma et al. 2015b; Gopal et al. 2013; Lara et al. 2011)

Wind power be paired with solar to make a solar-wind hybrid system. A hybrid system would be more flexible and reliable. According to some research, wind pumping would be a more economical option compared to diesel powered systems. (Girma et al. 2015b, Gopal et al. 2013; Hammad 1995) Even though there is potential and feasibility in Ethiopia for wind power (Girma et al. 2015b), the wind pump has not yet gained much foothold.

Rope pumps have been used in Ethiopia since 2004. They are mainly for household use and small scale irrigation. It is a low-cost technology, and part of the national policy guidelines for self-supply in Ethiopia. In self-supply the users make investments at a household or small community level for water supplies. Rope pumps are easy to use and require only little regular maintenance. However, neglecting simple maintenance is one of the major reasons for pump failure. Another major reason for pump failure is the use of poor quality materials. Spare parts are easily available as they are manufactured at a local level. Rope pumps are mainly installed in hand-dug wells up to 35 meters in depth, but in wells deeper than 25 meters the pump becomes quite heavy to operate. (van der Wal 2015)

Grid electricity is sometimes used to pump water, but in rural areas the electrification in Ethiopia is only 26,5 %. (Trading economics 2018) Diesel generators are commonly used for pumping water for both household use and irrigation, especially in off-grid rural areas. As discussed earlier in chapter 2.5, diesel generator systems require more maintenance. They also have higher life-cycle costs than solar pumping. The initial investment costs are lower, but operation costs largely rely on diesel prices that are constantly increasing. Diesel generators can be used as a backup for another power source to increase the reliability of the system. Motorized pumps are capable of pumping up to 600 meters, even deeper than solar pumps. (Bamford & Zadi 2016; Kabade et al. 2013)

3. RESEARCH METHODOLOGY

The research approach was mainly qualitative. Quantitative research was applied in household water consumption, but in this case the amount of collected water had a maximum.

Information was gathered from COWASH data, and literature was used for the background of this study. Basic information on the water points and community in the study area was gathered by conducting questionnaires. Additionally, some members of the community were interviewed to clarify some points and gather some additional information. Water quality was tested in a few of the water points in the area by professionals from the local water bureau. The water points and study area were personally observed during a four-month field work phase in Ethiopia.

3.1 Literature review

Background information on the CMP approach, the selected technologies, water supply management, SDGs, etc. and COWASH project has been collected from literature and from research available on the project as well as current project documents. These are mainly presented in the background area of this research (chapter 2). The literature review was done before the field work phase, during the field work phase as well as in the finishing process.

3.2 Data collection methods

The different types of data collection methods in this study are surveys by questionnaire, field observation, literature overview and water quality testing. Surveys were conducted at the levels of households and WASHCOs. A four month field work was done in Ethiopia as part of this study.

3.2.1 Household questionnaire

A household survey was conducted in the research area by a questionnaire to evaluate how the people’s daily water use compared to the SDG 6 targets and GTP-2 goals. The questions were also designed to provide information on the water consumption as a basis for the design of the solar schemes. It contained basic questions on the members of the household (age, gender, possible disabilities) water consumption and use, the different types of water sources, differences between the dry and wet seasons, the water points and willingness to pay for water supplied closer to their homes. The questions were closed-end questions, and can be seen in appendix A.

The survey was conducted by four enumerators (2 men and 2 women), that were selected from the local water office in Bahir Dar. They were chosen based on their experience in the water sector, knowledge of the local language (Amharic) and that they were familiar with the area and people there. They all had previous experience in conducting surveys.

3.2.2 WASHCO questionnaire and additional interviews

WASHCO members were questioned for the basic information on the water points in the study area. The questionnaire was done in groups for each WASHCO. Altogether seven WASHCOs were questioned with the questionnaire (appendix B). The questions were also on functionality, water shortages, tariffs and funds. As many WASHCO members as were available at the time were gathered form each water point. The WASHCO interviews were conducted by two of the same enumerators that conducted the household questionnaire.

Additional information was gathered from the WASHCOs by interviews. These questions were asked to clarify some points that were unclear from the questionnaire.

3.2.3 Site observations

Site observations were done during visits to the study area before and after the questionnaires were conducted. The water points were each personally observed, and both the school and health post were visited.

3.2.4 Water quality testing

Water quality testing was conducted to get an understanding of the current water quality in the study area, and to assess possible needs for water treatment. The tests were conducted by two professionals from the local Bahir Dar water bureau (The ARNS Water, Irrigation & Energy Development Bureau of Bahir Dar).

Water quality was tested in five water points (out of the total 14) which were Walkie, Addis Alem, Gult-1 (also referred to as Gult Addis Alem in the community), Gult-5 and Mehal Yeloma. Walkie and Addis Alem are situated in the north part of the road where the household questionnaires were also conducted. The three other water points were selected in different parts along the road to get a better view of the water quality in the whole area. Tests were made both on site (pH, conductivity, turbidity) and in the laboratory. Basic chemical, physical and bacteriological properties were analyzed.

3.3 Life-cycle cost analysis

In the life-cycle costs approach, all aspects of the service are considered from initial planning to the replacement of the infrastructure. Both hardware and software are to be considered (Fonseca et al. 2011; WASHCost 2012)

Life-cycle costs were calculated for each of the three technical options included in this research (hand pump, smaller solar scheme and larger solar scheme). The costs were calculated as total costs for 10 years, taking into account the expected (or estimated) lifetimes of each system element. The components of the life-cycle costs comparison that are included as a part of this research are capital expenditure, operating and minor maintenance expenditure, and capital maintenance expenditure. The hardware and software elements considered for each category are specified in the results of this study.

Capital expenditure (CapEx) costs are the initial investment costs for the scheme. It includes the purchase of fixed assets, the construction costs of the scheme, costs related to stakeholder involvement and coordination before construction, planning and training. This also covers the costs involving transportation of materials. (Fonseca et al. 2011)

Operating and minor maintenance expenditure (OpEx) includes the operation and minor maintenance costs of all the system elements. Minor maintenance does not include major repairs or replacement of components, but is the basic maintenance needed to keep the system running. Water treatment costs, possible monitoring of the water quality and administration related costs are all part of OpEx. OpEx expenditures are recurring, regular costs. In case of a diesel generator or hybrid system, fuel costs would be included. (Fonseca et al. 2011)

Capital maintenance expenditure (CapManEx) costs replacement of the system elements (as well as installation and procurement costs), ongoing repairs and rehabilitation. (Fonseca et al. 2011)

Expenditure on direct support, expenditure on indirect support and cost of capital are other cost components included in the life-cycle costs approach. These were not included in this study. Expenditure on direct support (ExpDS) includes all supervision costs related to the project, both before and after construction. Expenditure on indirect support (ExpIDS) costs are not specific to a single project. It includes for example regional level annual planning, capacity building, monitoring and federal technical assistance team costs. The cost of capital (CoC) includes the interest on loans and the return required. (Fonseca et al. 2011) In this case, there is no interest expected as there is no loan involved.

4. STUDY AREA

In this chapter general information on the study area and the results from the conducted questionnaires (for households and WASHCOs) will be presented. The results for the water quality tests in the study area are shown also in this chapter.

4.1 Demographic description

The total population of Ethiopia is over 100 million with a 2,46 % population growth rate. (World Population Review 2018) The rural population in Ethiopia is 80 %. (The World Bank Group 2018) There are two city administrations and nine regional states (regions) in Ethiopia. The city administrations and regions are divided further into districts called woredas and villages called kebeles. Amhara is one of the regions and it is divided into 151 administrative zones (woredas). (COWASH 2017)

Bahir Dar Zuria woreda (district) is one of the administrative zones in Amhara. It is located south of lake Tana and can be seen in figure 8. It has a population of 220 410, including 32 kebeles (villages). One of the villages is Yeloma kebele. A part of Yeloma kebele was selected for this research.

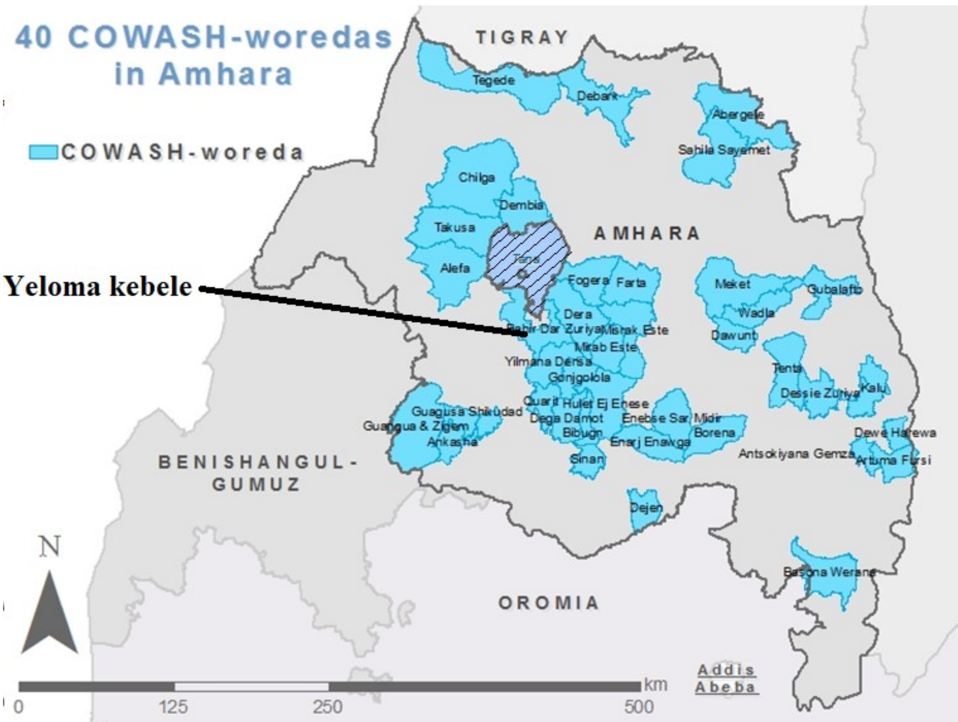

__Figure 8.__ The COWASH woredas in Amhara region are in blue, and Yeloma kebele south of Lake Tana. (adapted from cmpethiopia.org 2018)

Yeloma kebele is located in Bahir Dar Zuria woreda, 30 kilometers southwest from Bahir Dar. There are over 1 200 households in Yeloma Kebele with a total population of around 5 800. There were altogether 14 water points in the selected study area, all of which are located along the road on communal land, east of the houses. Agriculture was the main source of income, and the main produced fruits were mango and avocado. In 2018 there was no electricity in the kebele, but there will be in the near future. Connecting lines had just been constructed, but there was no information to be found on when it would actually happen. Yeloma could be accessed by a dirt road in poor condition through Meshenti town located by the main road leading from Bahir Dar to the capital Addis Ababa.

There was a school located in the north of the study area with over 1000 students (985 students in 2016). The school had a water point located 250 meters from the school (Worke school). Access to a safe water source (free from bacterial, physical or chemical contamination) should be within 100 m or 10 minutes round-trip from the school and accessible to all students including those with disabilities. There should be one tap for every 100 students and provide a minimum of five liters per student and staff member. (Ministry of Education 2017) The school water point was functional at the time of the study, but had cracks and was vulnerable to contamination (figure 9).

Figure 9. *The school water point in Yeloma kebele, with large cracks around the base of the pump stand. (Kaisa Kuismanen 2018)*

The area surrounding the water point was grazing land for the community’s animals. The well was 11,2 meters deep and the water column 2,8 meters during the wet season, but according to the villagers the water point runs dry around November each year. For the remaining dry season the school has no access to water.

There were four latrines for the students, two for the female and two for the male students. They were not built considering students with disabilities, and there was no place to wash hands. There were 250 students to every latrine cubicle in this school, when the national standard is one stand/cubicle for every 50 female students and one stand and urinal for every 75 male students. Menstrual hygiene management should be considered in the sanitation facilities and there should be hand-washing facilities located next to the latrines. (Ministry of Education 2017) Neither sanitation facilities nor the school water supply fulfill the national requirements.

Along the road there was one health post which has two health workers. Additionally, there were two health extension workers who go around the village visiting each house. The health post had its own unprotected well which has collapsed. The closest water source was a communal water point 50 meters from the health post along the road. There were two latrines in the yard. However, the health post had no medicine and the closest health service was in Meshenti town (4 km from the community).

The selected research area is outlined in figure 10, and it includes 14 improved water points altogether. All of the water points were located along the road on communal land. The ground level is slightly lower on the road and communal land than in the residential area. All the water points were hand-dug wells with by Afridev hand pumps. One of the water points (number 13) was not functional during the time of the study, as it was constructed earlier that year and had not yet been taken into use. All of the other water points were found to be functional.

Figure 10. *Map of the study area, which shows the location of all water points (numbered 1-14) in Yeloma kebele. (adapted from Amhara National Regional State Rural Land Administration and Use 2018)*

Two water points were selected for the study for the application of the smaller solar systems. These water points were Walkie and Addis Alem (numbers 1 and 3, respectively). Walkie was constructed before Addis Alem eight years ago. However, the water in Walkie water point was not enough for the whole community and the Addis Alem water point was constructed to ease the demand. Both water points had their own WASHCO and bank account. Each had 40 households using the water point and paying a user's fee of 20 ETB per year (63 Euro cents). Walkie and Addis Alem water points had a special agreement, where the users from both water points share the two points. They use one water point in the morning and the other in the evening for collecting water. Because of this agreement, both water points have a total of 80 households as users. The reason behind the agreement could not be clarified, but it was a joint social agreement. The caretaker for the schemes and other possible payments were paid together by the two WASHCO's, explaining why they have almost the exact same amount of money in their accounts (1320 and 1350 ETB).

4.2 Household questionnaire

The majority of the respondents in the household questionnaire were male (in 33 of 40 households), even though the objective of the questionnaire was to ask those in charge of collecting water (generally the women in rural Ethiopia). In many of the cases, however, both male and female members of the family were present, while the questions were mainly answered by the male. This shows the male focused culture of the village.

Even though the objective to interview the person in charge of collecting water (in most cases the women) was clearly stated in the questionnaire, there could have been a misunderstanding with the enumerators. Or the women were not available at the time to answer the questions.

Altogether eight of 40 (20 %) were female headed households, which is quite high for rural areas. The percentage is generally less, but the result is not abnormal, as the number can vary from place to place. According to the enumerators, it is a normal amount for this area. The average household size was 5,2 members, ranging from 1 – 13 members per household.

In four households there was one member with a disability, two of them with a hearing impairment, one with a physical impairment and one unspecified disability. The percentage of persons with disabilities in the community was 1,9 %. The average for the total population of persons with disabilities in Ethiopia is 17,6 % according to the World Report on Disability. (WHO & The World Bank 2011) The result is considerably lower than the average, which shows that there might have been some kind of misunderstanding on what disability actually means. Three of the households with a person with a disability were collected by the same enumerator. It is possible that there are more persons with disabilities in the community, but the community did not feel comfortable to provide the information, or there was a problem with the setting of the question by the other enumerators, even though according to them the disability question was asked the same way by each enumerator. In 2017 COWASH conducted a baseline survey and found the disability prevalence to be on average 3,9 % of the household members in COWASH woredas. It was noted that there may be differences in data collection methods, level of understanding by the enumerators, invisibility of impairments and willingness of the people to provide the information. (COWASH 2017)

All 40 households reported that they were collecting water from the Walkie water point both during the dry and wet seasons. Out of those 32 households also had access to an unprotected household well. These wells are generally shallow (8 – 15 meters) hand-dug wells with buckets. Only one family reported that they collected rainwater during the rainy season.

The main uses of water collected from the water point were for drinking, and all but one for cooking. Six households also reported that they used the collected water for washing and cleaning. Five out of six of these households did not have access to any other water source, which is probably the reason for using the collected protected water for all household needs. Only the main uses of the water collected from the water point were asked in the questionnaire, so the results do not imply that all the water was used solely for the mentioned purposes.

In the dry season 38 households collected four jerrycans per day from the Walkie water point and the remaining two households collected 2 – 3 jerrycans per day. Possible explanations for collecting less water than the majority could be that one of the two households had only three members, a 55-minute collection time and access to an unprotected well. In the other case it was the only household to report using the collected water for drinking only, so there less need to collect water if they in fact do not use it for other purposes.

Nine households collected four jerrycans per day in the wet season and the rest collected 2 – 3 jerrycans per day. Seven out of the nine reported that the collected water was not adequate for their household. The average family size for the households which collected four jerrycans even in the wet season was 7,14 (with 4–10 members). It was higher than the total average household size (5,2 members of 40 households). The household with only four members had a person with a physical impairment, and four out of nine households only had access to one water source. Figure 11 shows the number of jerrycans collected per household during the wet and dry seasons.

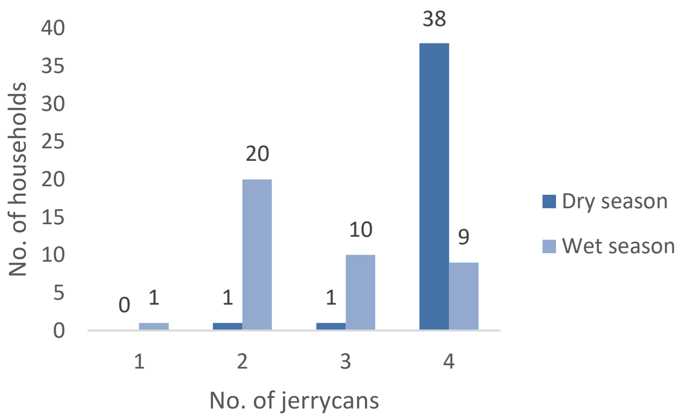

Figure 11. *Number of jerrycans collected during the wet and dry seasons.*

In the wet season the average amount of collected water was less than during the dry season (2,675 and 3,925 jerrycans per day, respectively). This is due to less need for water during the wet season, because of the climate and availability of water from other sources in the wet season.

The GTP-2 goal is to provide safe water 25 liters per capita per day in rural areas. The maximum amount of water that can be collected per household is four jerrycans from both water points, altogether eight jerrycans per day (one jerrycan is approximately 20 liters). This means that for households with seven members or more the GTP-2 standard is not met. The largest household in the study area had 13 members, which would require 325 liters (approximately 16 jerrycans) of water per day for the household. In reality they can only collect up to eight jerrycans per day. There are eight households with seven members or more (20 % of the households), which all cannot collect the amount of water as per the Ethiopian standard. In other words, the higher the number of members in the household, the smaller the per capita use of drinking water.

Figure 12 shows the views of the respondents, whether the water they collect was adequate or not during the dry season. Out of the 40 households 28 (70 %) reported the collected water from the water point to be adequate even in the dry season. Ten households (25 %) reported water not being adequate during the dry season and two did not reply to the question.

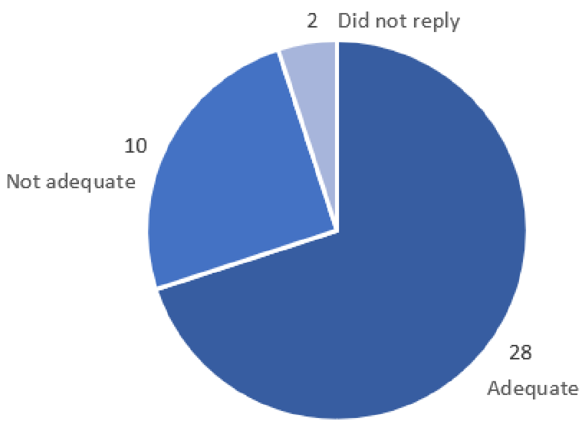

Figure 12. *The views of the respondents on drinking water adequacy during the dry season (out of 40 respondents).*

During the wet season the collected water was generally adequate, due to the increased availability of water (rainwater). Many (31 households) do not collect the maximum amount of four jerrycans in the wet season, which shows that they have enough water for domestic use. The households that collect the maximum amount of water even in the wet season, all had either only one water source available, or seven or more household members. Of these households, only two reported the collected water to be adequate (one had only one member, the other seven members but had access to an unprotected source).

Seven out of 40 households reported the collection time for a round trip (including queuing) to be 30 minutes or less. This means that only these seven (17,5 %) households can be considered as having a basic service level, as per the JMP drinking water service ladder. The average time taken to collect water was 42 minutes, ranging from 25 to 60 minutes per household. The average queuing time was 22 minutes. For the remaining 33 households the collection time was over 30 minutes, so the service level is considered as a limited service (figure 13). None of the households in the area had a safely managed service level, as it would require drinking water to be available on premises.

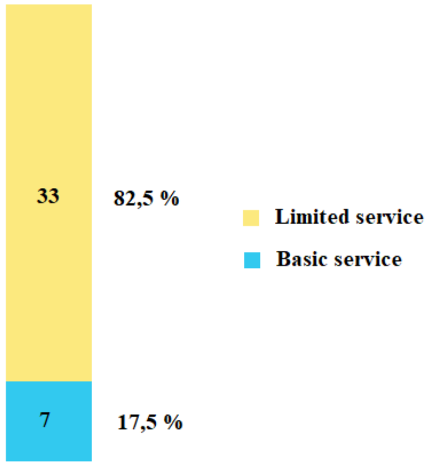

Figure 13. *The drinking water service levels in the study area according to the JMP drinking water service ladder.*

The households were asked about their views on the water quality in Walkie water point was. The majority of households (27) reported the water to be very clean in their opinion. 10 said the water to be fairly clean in their opinion and three said it varied from time to time but did not specify what they meant (varies between dry and wet seasons, varies between time of the day or other reason).

All households reported that they also used another protected source, with an average of 3,2 jerrycans of water collected per day. The other protected source was Addis Alem for all of the households, as according to the agreement between the Walkie and Addis Alem water points. 33 households had an unprotected well available for other domestic use than drinking and cooking, with an average of 4,99 jerrycans of water collected by them per day. The varying amounts collected in the dry and wet seasons were not specified in the questionnaire for the other protected source.

All households reported that they pay a user's fee of 20 ETB per year, paying 10 ETB biannually. This is equivalent to the amount reported by the WASHCO.

All households reported that they would be willing to pay more for clean drinking water if it was supplied closer to their house. In one question it was asked how much they would be willing to pay per jerrycan in this situation, and the reported average amount was 0,98 ETB. Assuming that they collect altogether eight jerrycans per day from both protected sources in the dry season, this means that the payment per week would be more than what they pay now per year. This amount on a yearly basis would be completely unaffordable for these households (over 1400 ETB per year, if the payment was 1 ETB per jerrycan and 4 jerrycans were collected per day). It can be assumed that they misunderstood the question that the additional payment would be per biannual tariff i.e. 21 ETB per six months instead of the current 20 ETB per six months. Or they did understand the question but did not realize how much the increase would be. This was discussed with the enumerators later on to clarify the question of how much more the households could pay per year for it to be affordable for the households. The conclusion was that a 30–50 % increase in the user's fee per year would be an affordable amount. This means that for Walkie and Addis Alem the payment made per household per year could be raised to 30 ETB.

The number of cattle/sheep/goats/equines in total per household ranged from 1 – 24, with an average of 8,2 per household. Questions on the amount of these animals were asked to get some understanding of the wealth of the households, and to assess if there were differences in their willingness to pay based on their wealth. The amount of these animals was not found to be a factor in how much they were willing to pay more for better access.

Out of 40 households nine were identified as the most vulnerable based on the questionnaire answers. The factors that considered a household as vulnerable included female headed households, households with disabled members, households with the fewest cattle/sheep/goats/equines (considered possibly to be the poorest households) and households with the longest collection times from the Walkie water point. Most of the selected households had more than one of these qualities. Two of the most vulnerable households selected had the longest collecting times (60 minutes) out of all the households (40) surveyed. One of the technical solutions for the solar powered option would be to place some of the joined standposts as close as possible to these vulnerable households to ensure more equitable access for all, if found to be a technically feasible option.

There were 40 users (households) for the Walkie water point and 40 for the Addis Alem water point. However, they use the two water points collectively (80 households altogether) collecting the same amounts from each water point every day. Addis Alem was constructed later in 2001 EFY due to Walkie not providing a sufficient amount of water for all the households.

4.3 WASHCO questionnaire and additional interviews

Members of altogether seven WASHCOs in the study area were interviewed. Each WASHCO had five members. In six WASHCOs out of seven there were three male and two female members. In one WASHCO there was only one female member, who held the position of chairperson. In the other cases, the positions varied among the female members. Each WASHCO had caretakers to maintain the scheme.

The number of households using the water points varied from 30 to 40, with an average of 36 households per water point. Three of the water points had the same number of users as when it was constructed, the other four had more users (5 – 10, or unspecified).

All the water points were functional during the questionnaire. None reported that there had been any shortages of water in the water point. However, at least in the Addis Alem and Walkie water points there is an agreement for the maximum amount of water each household can collect per day, so that the water points do not run dry.

All the WASHCOs reported that the water points had not been non-functional at any point. The Gult-1 water point broke down during the measuring of the well depth and water column and was non-functional for almost a week before it was fixed. This was not reported in the survey, and when asked they said that they did not regard it as a break-down, as it did not break during the use but was a special case.

The COWASH Baseline survey found by inspection that 83,2 % of the water schemes were functional at the time of the survey. According to the household survey 95,3 % of schemes were thought to be functional. This is likely to be due to a different understanding of the concept of functionality. (COWASH 2017)

The user's fee (tariff) ranged from 10 – 30 ETB per year per household, in each case paid biannually. Three of the WASHCOs reported that some households were exempted from payment but did not specify the number of households. Exemption is usually for the poorest households, who cannot afford paying. Three WASHCOs had provisions for exemption in case such a need would rise, one did not and the other three did not reply to the question.

Each WASHCO had their own bank account for the water point. According to the WASHCO interviews there was almost the same amount of money (1350 or 1320 ETB) in four of the bank accounts. In the case of Walkie and Addis Alem, as they collectively used the water points and they also paid the caretakers (and other possible costs) the same amounts from each bank account. This explains how they could have had the same amounts of money in the bank, as the costs were paid equally between the two WASHCOs.

4.4 Water quality test results

Altogether 25 parameters of water quality were tested. All of the five water points tested could be considered as having acceptable values for the physical and chemical properties tested according to the Ethiopian water quality standards. Only the pH of Gult-5 was slightly lower (pH 6,1) than the standard value (pH 6,5 – 8,5), the magnesium level was 89 µg/l in Gult-1 compared to the standard maximum of 50 µg/l, and the turbidity of Gult-

1 was 6 (Ethiopian standard value is 5). Apart from these all values were within the standard ranges.

All the sampled water points had fecal coliforms. The amounts can be seen in table 5. According to the standard fecal coliforms should not be detectable at all. This shows that there is a need for quality improvement, as all the selected water points were contaminated.

Table 5. *Test results for fecal coliforms.*

	Fecal coliforms (CFU/100ml)
Addis Alem	34
Walkie	86
Gult-5	103
Gult-1 (Gult Addis Alem)	10
Mehal Yeloma	19

The catchment area was not protected in any way nor was there any sort of water safety planning. The contamination can be partly due to the animals grazing near the water point. The chlorination of the water pumped from the hand pump can currently only be done by chlorinating the water in each jerrycan separately. This is cumbersome and requires high discipline from the users.

Both the solar pumping and piped scheme solutions would include the chlorination of the water, in which case it could be considered as free from contamination. A solar system would also prevent humans from stepping on the water point as the hand pump would not be there anymore and the area would be properly fenced to prevent anyone from entering.

5. RESULTS AND ANALYSIS

In the first part of this chapter the parameters used for the pump design and details of the selected pumps are presented. Each technical option is described in more detail, explaining how the distribution points and distribution network (for the larger solar scheme) were designed and how the solutions were selected.

The second part of the chapter contains the life-cycle costs for each technical option. They are divided into capital expenditure, operation and minor maintenance expenditure and capital maintenance expenditure. The total life-cycle costs are then compared as costs in ten years. All costs are in Ethiopian Birr (ETB). The applicability of solar pumping is assessed in the last subchapter.

5.1 Pump selection and design

The dimensioning for both solar pumping systems (for the two water points Addis Alem and Walkie, and the larger piped scheme) was done by a company that can locally provide the whole system. Other possible solar pump options were also investigated, but the information available for others was not found reliable and proper test results were not available. Other cheap models that were found were mainly meant for household use and their lifting heads were not adequate for these hand-dug wells.

Design was done based on water demand, borehole specifics and location of the scheme. Below are the parameters used for the design of the pumps and more details on the selected pumps.

5.1.1 Smaller solar schemes

The smaller solar schemes were designed for the Addis Alem and Walkie water points. These wells were chosen because they had the highest water columns, and thus were more promising options compared to the other wells in the area.

In the case of Walkie and Addis Alem, the two water points were collectively used but had separate WASHCOs. The people saw the two water points as communal, so solar pumping would have to be installed for both water points. If solar would be only installed in one well, the community would not approve it. The benefits would decrease as the users would still collect water from one hand pump, having to walk the same as now and the water quality improvement would not be of much use. For this case, two solar pumps (one for each well) are necessary to actually make an improvement.

As the water points had the same well specifics and water demand, the solar pumping system was be designed for one scheme only. The same design was then used for both schemes.

The technical solution chosen for the scheme was to install a solar panel and pump and pump the water from the well into one slightly elevated tank. The water would then be distributed by gravity to the joined standpost located next to the tank. To install more than one tap at the joined standpost would reduce the time spent collecting water, as more than one person could fill their containers at the same time. According to the household questionnaire, the average collection time was 42 minutes and the average time spent queuing was 22 minutes. Reducing the queuing time by 10 – 15 minutes would bring the average collection time under 30 minutes, which is considered as a basic service level in the SDGs. The water in the tank could be chlorinated as it was contaminated by faecal coliforms.

The drainage systems at the water points were often found not to function properly. There was trash and dirty water stagnant around the water point, and then a risk to well contamination. Two examples of this can be seen in figure 14.

Figure 14. *Left: drain with trash and stagnant water in Walkie water point. Right: drainage not working properly at Mehal Yeloma water point. (Kaisa Kuismanen 2018)*

If a solar pumping system would be installed, the area directly around the water point could be isolated. This would have a positive effect on water quality as there would be even a small protected area around the well.

The data in table 6 was used for the solar pump dimensioning for Addis Alem and Walkie water points. The safe yield was based on the experience of the community. The average daily demand was based on the consumption of the users, and the well depth and static head were measured on site. The static head was measured from the top of the well to the water level. The total dynamic head (TDH) consists of the depth of the water level to the ground (dynamic water level), the elevation difference between the top of the well and top of the distribution tank, and pipe friction losses.

Table 6. Parameters used for pump selection and design for the smaller solar schemes.

Average daily demand	3,2 m3/d
Static head	8 m
Safe yield	3,2 m3/d
Well depth	16 m
Total dynamic head (TDH)	18 m

The solar pumps selected for Walkie and Addis Alem water points were the same model, and the well specifics and water demands were the same for both water points. The selected pump was a Lorentz solar helical rotor pump (PS2-200 HR-04-3), which can be seen in figure 15.

Figure 15. *The Lorentz PS2-200 HR-04-3 pump selected for the smaller solar schemes. (Lorentz pumps 2018)*

The operation of the pump would be automatic. There would be a sensor in the tank to detect when it is full, and then automatically stop the pump. An overflow pipe is necessary for the tank just in case. There would also be a sensor in the well to detect the level of the water, to protect the pump from running dry.

In this case the pump can be operated by a single 300 W solar panel. With the required head of 18 m, the daily output during the average month was 5,6 m^3, which is the maximum capacity that can be pumped with the one solar panel of 300 W (watts). The hourly maximum was 0,51 m^3 pumped from 7 am to 5 pm (11 hours of pumping time per day). By adding solar panels (increasing the power) the pump is capable of pumping up to 50 meters with an output of up to 0,6 m^3/h.

Figure 16 shows the performance curve for the selected pump. The 18 meter pumping head can be seen as the darker curve. From this the power required to pump water up to a certain head can be seen.

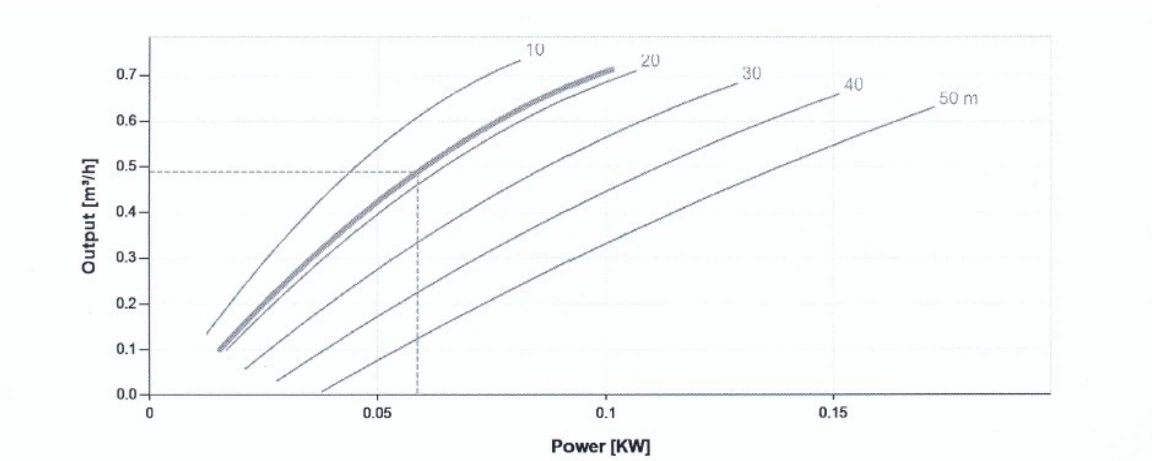

Figure 16. *The performance curve for the Lorentz PS2-200 HR-04-3 solar pump. The darker line is the 18 m head. (Lorentz pumps 2018)*

With a 50 m total dynamic head, the pump is capable of pumping the water higher or a longer distance. This means that the water source does not need to be located next to the point where the water is used. It would especially be a good application for schools, when the well could be situated further from the compound in a better location, and the pump would still have the capacity to pump to the school. Increasing the pumping head requires more power, and additional solar panels would be needed in that case.

5.1.2 Larger solar scheme

The third technical solution examined in this study was a larger piped scheme for the community. It would not be economically feasible to design a larger piped scheme just for the users of Addis Alem and Walkie water points. Thus, the piped scheme was designed to serve a total of 2 400 people. This was the estimated number of people living in the area, including water for the health post and school. The school had over 1 000 students and staff at the time of the study. The water demand was calculated for 1200 students and staff members, allowing for the school to have access to safe water throughout the year. The school would then be able to have hand-washing facilities for improved sanitation. Five liters per student and staff member per day of water was estimated according to the Ethiopian National School WASH Implementation Guideline. (Ministry of Education 2017) This amounts to 6 m^3 of water per day for the school. This amount can be supplied for the school from a hand-dug well daily, and can be an option to solve the school water problem.

For a larger piped scheme, the yield of the hand-dug wells would not be enough. Also, the water demand will rise as people get access to safe drinking water straight to their homes. A borehole is needed to supply the whole area with adequate water. The amount by the Ethiopian GTP-2 standard is defined as 25 liters per capita per day for a rural setting. This means that the required amount of water for the day in this case is 65 m^3. The borehole would be fitted with a solar pumping system.

Grid electricity in Ethiopia, and especially in the rural areas can be very unreliable. Therefore, eight out of 10 Ethiopians have to use unhealthy lighting, such as kerosene lamps and wood fires, for daily activities. (IFC 2018) Solar pumping is a feasible option in cases where there is no grid electricity available or it is unreliable (GSWI 2018). Therefore, solar pumping was chosen for this study. There is enough solar potential in the study area for solar pumping to be an economical solution.

As referred to earlier in this study (chapter 2.5), compared to diesel powered pumps solar pumping has been found to be more cost-effective in the long term. (Bamford & Zadi 2016; Girma et al. 2015; Meah et al. 2006) Therefore, diesel powered pumps will not be considered for this scheme.

The location for the borehole was chosen based on the catchment area. The most potential and appropriate area for the borehole was selected slightly downhill from the residential area. The elevation difference between the top of the borehole and the furthest point was five meters. This location was chosen because it is on communal land and is, therefore, a potential site for the borehole.

Because of the location of the borehole, a single large reservoir for the pumped water would not be constructed. It would either require additional pumping to distribute the water uphill and 1,7 km to the furthest point. Otherwise, an elevated reservoir would be necessary to distribute water by gravity. However, the reservoir would have to be significantly elevated and would be an expensive option. In this case, the chosen method was to pump the water straight from the borehole into the pipes. The water would then be distributed into smaller tanks (5 – 6 m^3 each, depending on the number of users at each point) along the road. The water could then be chlorinated separately in each tank. The tanks would be slightly elevated and a joined standposts can be placed either next to the tank or brought closer to the households. Household connections can be designed directly from the main pipeline.

Figure 17 shows the selected location for the borehole as the white square. The white line in the figure is the distribution line to the public standposts (white circles).

Figure 17. *The potential borehole location, distribution line and standposts for the larger solar scheme. (Adapted from Amhara National Regional State Rural Land Administration and Use 2018)*

The distribution points would be similar to those in the smaller solar schemes. The water points all in the area serve 30 – 40 households (with an average of 36) according to the

WASHCO interviews. The tanks would be designed to all be the same size as those designed for the smaller solar schemes (5 m^3). The tanks should also be elevated each one meter from the ground, to allow for the water to flow by gravity to the joined standpost, with several taps installed. The joined standpost would also be the same as for the smaller solar schemes, with two taps at each standpost.

The quality of water can then become acceptable in the whole area. Also, queuing times can be reduced by installing several taps at each water point. The collection time can further be reduced by locating the taps even closer to the households by connecting pipes from the tank. However, the tanks would have to be significantly higher and this would be a costly option. If the water consumption would rise in the future, the pump could be replaced with a more efficient one, more solar panels could be added or even another deeper or additional borehole could be drilled.

In this case the elevation difference was three meters and the height of the tanks was 5 meters. As there was no existing larger borehole in the area, data (presented in table 7) was used from an existing borehole which was drilled in a nearby area.

Table 7. *Parameters used for the pump selection and design for the large solar scheme.*

Average daily demand	65 m3/d
Static head	30 m
Dynamic head	50 m
Safe yield	8 l/s
Well depth	74 m
Total dynamic head (TDH)	82 m

The pump selected for the larger piped scheme was a centrifugal Lorentz solar pump (PS-2-4000 C-SJ5-25). The pump can be seen in figure 18.

Figure 18. *The Lorentz PS-2-4000 C-SJ5-25 pump selected for the larger solar scheme (Lorentz pumps 2018).*

Altogether 28 solar panels of 300 W were required for the larger solar pumping system, a total of 8400 W. The pump had a maximum pumping head of 140 m and maximum flow rate of 7,0 m^3/h. The average flow rate was 5,8 m^3/h, and average daily pumping rate 63 – 70 m^3/h depending on the month (different amounts of solar radiation between months).

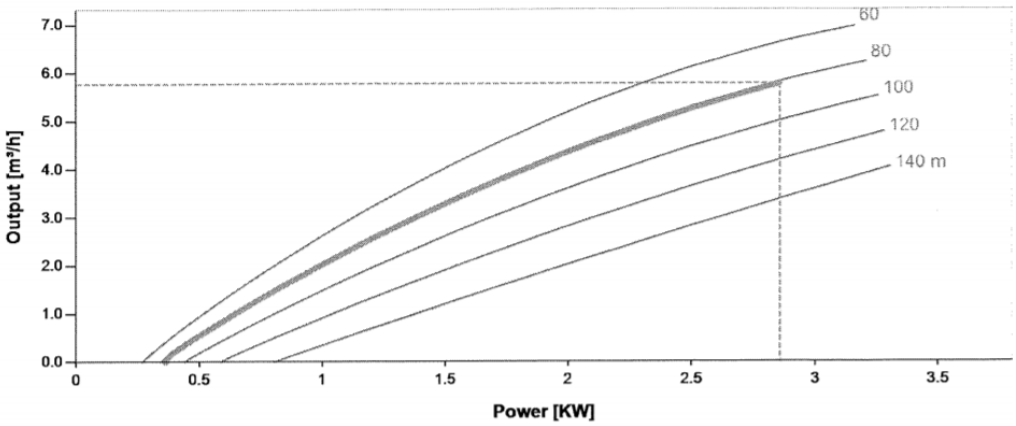

Figure 19. *Performance curve of the Lorentz PS-2-400 C-SJ5-25 pump. (Lorentz pumps 2018)*

The performance curve for the larger solar pump is presented in figure 19. The total dynamic head is 82 m. The system would also be operated automatically, with sensors in the borehole and tanks to stop the pump when necessary.

5.1.3 Drinking water on premises and joined standposts

To install joint standposts on premises for a few households could give up to 3 – 5 households in the same courtyard a water service level up to safely managed. To achieve a safely managed service level, water would also have to be free from contamination (pumping to tank allows for chlorination) and available when needed. This option would, however, cost more, as the tank may have to be elevated higher and more pipes would have to be installed. The water could also be pumped straight to the households, but then the households would only have water when the pump is on. In that case household level water tanks would be required.

Another option would be to pump water directly to the homes with taps in each household. There could also be one tap in each courtyard, as often there are several households in one compound. This would also qualify as "on premises", fulfilling the criterion for safely managed drinking water.

However, it is necessary to consider how water consumption would change when water is made accessible on premises. The Walkie and Addis Alem water points had a maximum amount of water that can be collected per household to ensure that there is water available for everyone. If water consumption increases as water becomes more easily available, the two water points cannot provide enough water. In this case the water consumption still would have to be regulated, either by water meters or by installing individual tanks for each household. It can be assumed that in the future the population of the area will grow, as the population growth in Ethiopia is currently around 2,4 %. (World Population Review 2018) Even now there is not enough water for every household when compared to the GTP-2 standard of 25 l/c/d. (See chapter 4.2)

5.2 Capital expenditure costs

The capital expenditure costs are presented here for the three technical options, which are a hand pump, two smaller solar schemes and a larger solar scheme. Costs were also calculated for the construction of a hand-dug well, where either a smaller solar pumping system or a hand pump can be installed. This was included to be able to compare the costs in a case there is no existing well at the scheme. The costs for the hand-dug well are presented in chapter 5.2.3. All costs are current market costs during the time of this study, or estimations based on existing COWASH data and professionals.

5.2.1 Hand pump

The first technical option in this study would be to replace the current hand pumps with new hand pumps when they come to the end of their lifetime. The hand pumps would be replaced with the same hand pumps currently in use (Afridev). The hand pumps could be completely replaced or just the parts that have worn out, depending on the condition they are in. For the purpose of this comparison the costs will be calculated assuming that the whole pump needs to be replaced (including rods and pipe). This way the calculated costs will be the maximum amount.

If the hand pump is maintained properly, the average lifetime of an Afridev hand pump is 10 years. The initial investment costs (CapEx) are the costs for a new Afridev hand pump and installation costs, as in the study case the hand-dug well exists. Table 8 shows these costs.

Table 8. *Costs for the replacement of an Afridev hand pump.*

	Costs
Afridev hand pump	12 000
Pump installation	300
4 % commission for MFI	492
Total (ETB)	**12 792**

The initial investment costs also include a 4 % payment for micro finance institutions (out of the total scheme construction costs), which is 492 ETB for this option. Other non-recurring capital expenditure costs include training costs for the site management and costs related to construction supervision and site selection. These can be seen in table 9.

Table 9. *Non-recurring costs for the hand pump, excluding the costs for installing the hand pump.*

Description	**Costs**	**Cost calculation and comments**
Training costs		
WASHCO CMP management training	7 784	1 112 ETB/person x 7 (average WASHCO members) = 7 784
WASHCO in O&M management training	6 342	906 ETB/person x 7 (average WASHCO members) = 6 342
Training pump attendants/caretakers	3 534	1 767 ETB/person x 2 = 3 524
Site selection and supervision costs		
Site selection & appraisal	1 800	
Construction supervision	1 800	

WASHCO CMP management training would be done as this would be a COWASH project. Training the WASHCOs would be necessary, as a review and there might be new members. These amounts are from existing COWASH projects.

5.2.2 Smaller solar schemes

The investment costs of the solar pump equipment and installation, distribution point and tank for the smaller schemes (Addis Alem and Walkie water points) are shown in table 10. The costs are for one smaller solar pumping system.

Table 10. *Actual investment costs for solar equipment, installation and distribution point for smaller solar schemes. Distribution point and tank costs are estimations.*

	Unit	Quantity	Unit Price	Total price
Solar pump, controller and accessories				
Lorentz pump (x)	Set	1	50 993	50 993
Lorentz controller (x)	Pcs	1	27 830	27 830
Lorentz surge protector (x)	Pcs	1	1 254	1 254
Lorentz PV disconnect (x)	Set	1	14 851	14 851
Lorentz Well probe sensor (x)	Pcs	1	3 611	3 611
300 W Solar module 18 V DC	Pcs	1	8 165	8 165
Cables and electrical accessories				
3x4mm2 Submersible power cable (x)	m	25	173	4 313
2x1,5mm2 Single core control cable (x)	m	25	47	1 173
6mm2 Single core cable for DC line (x)	m	10	63	633
16mm2 Single core cable for earth line (x)	m	15	163	2 450
Cable splicing Kit-DAB (x)	Set	1	2 300	2 300
Earthing rod c/w clamp (x)	Set	1	748	748
Structure, fitting, transportation and installation				
Panel support steel structure	Set	1	4 485	4 485
Riser pipe with heavy duty socket	Pcs	3	2 639	7 916
Other installation materials	Set	1	13 179	13 179
Transportation of materials	Ls	1	11 500	11 500
Installation, testing, commissioning	Ls	1	40 250	40 250
Subtotal for solar pump and equipment (including VAT 15 %)				**195 649**
Distribution point and tank				
1m high masonry tank stand	Pcs	1	2 000	2 000
5000 l capacity fiberglass	Pcs	1	17 500	17 500
HDP pipe from hand-dug well to tank	m	12	100	1 200
2 taps for joined dtandpost	Pcs	1	13 000	13 000
1" and 6 meters long HDP pipe from the tank to joined standpost	m	6	90	540
Subtotal for distribution point and tank				**34 240**
Total cost (ETB)				**229 889**

The (x) in table 10 shows the components of the solar pumping system that need to be replaced within 10 years. The are the components calculated for table 16 (chapter 5.4).

The costs for the distribution point and tank include the pipe line from the top of the well to the distribution tank, a one meter elevated tank including the tank stand, pipeline from the tank to the joined standposts and the construction and materials for the joined standpost with two taps. A fiberglass tank was chosen as it was seen as a better option compared to a plastic tank.

The total capital expenditure costs also include the 4 % commission for the MFI's (out of the construction costs), which is 0,04 * 229 889 ETB = 9 196 ETB.

The training costs and operational costs have been estimated to be the same for the smaller solar schemes and the replacement of the hand pump. The schemes are the same size, and therefore, the WASHCOs would be the same size as well (5 – 7 members). The non-recurring costs are presented in table 9 in chapter 5.2.1, as they would be the same amount for the hand pump and a smaller solar scheme.

5.2.3 Costs for a new hand-dug well

In the case of Walkie and Addis Alem water points, there was an existing water source (hand-dug well). Therefore, the costs for constructing the well were not included in the above estimations for the smaller solar scheme and hand pump. The costs for a hand-dug well are also presented here in table 11. This was to compare the costs of an existing well that needs a pump replacement to a completely new scheme.

Table 11. *Cost estimation summary for a hand-dug well of target depth of 20 meters in Ethiopian Birr (ETB).*

	CMP contribution	Community contribution	Total costs
Labor costs	6060	17100	23160
Materials costs	23940	3970	27910
Equipment and tools costs	2932		2932
Administration related costs (5%)	2247		2247
Total (ETB)	**35179**	**21070**	**56249**

These costs are based on COWASH data on projects that have been implemented. The costs for constructing a new well and installing a solar pumping system (including distribution point) would then be 307 398 ETB (table 12). These are the total capital expenditure costs.

Table 12. *Costs for the new hand-dug well, solar pumping system and distribution point (including tank).*

Solar system and distribution point costs	229 889
Costs for hand-dug well	56 249
Training costs	17 660
Site selection and supervision costs	3 600
Total (ETB)	**307 398**

The costs for management training and operational costs are the same as for the replacement of the hand pump. Details can be seen table 9 (chapter 5.2.1).

5.2.4 Larger solar scheme

The capital expenditure costs for the larger scheme also included the borehole drilling costs, as the borehole did not exist. The costs related to well drilling were based on projects implemented by COWASH in Amhara region, and was the approximate price calculated as per meter of drilling in depth. This includes all costs related to borehole drilling and the installation of casing. However, the actual costs can vary depending on how successful the drilling process is and how deep the actual drilling is done. Therefore, the amount presented here in table 13 is only an estimation.

In the pipe laying work there are excavation and pipe backfilling works, which are mostly done as a community contribution. Even though communities may do the work and there will be no actual costs, it is part of the investment and have been included in CapEx. The excavation and pipe backfilling costs are estimations. As in table 10, the (x) shows the solar pumping system components to be replaced in 10 years.

Table 13. *Investment costs for solar equipment, installation and distribution point for the larger solar scheme.*

	Unit	Quantity	Unit Price	Total price
Solar pump, controller and accessories				
Lorentz pump (x)	Set	1	132 888	132 888
Lorentz controller (x)	Pcs	1	83 375	83 375
Lorentz surge protector (x)	Pcs	1	1 254	1 254
Lorentz PV disconnect (x)	Set	1	14 851	14 851
Lorentz Well probe sensor (x)	Pcs	1	3 611	3 611
150 W Solar module 24 V DC	Pcs	70	5 796	405 720
Cables and electrical accessories				
3x10mm2 Submersible power cable (x)	m	80	429	34 334
2x1,5mm2 Single core control cable (x)	m	80	47	3 754
6mm2 Single core cable for DC line (x)	m	150	63	9 488
16mm2 Single core cable for earth (x)	m	15	163	2 450
Cable splicing kit (x)	Set	1	2 300	2 300
Earthing rod c/w clamp (x)	Set	1	748	748
Structure, fittings, transportation and installation				
Panel support steel structure	Set	1	183 138	183 138
Riser pipe with heavy duty socket	Pcs	13	2 639	34 303
Other installation materials	Set	1	13 179	13 179
Transportation of materials	Ls	1	27 945	27 945
Installation, testing, commissioning	Ls	1	177 100	177 100
Subtotal for solar pump and equipment (including VAT 15 %)				**1 130 436**
Well drilling				
Well drilling and casing installation	m	74	3 500	259 000
Pipework				
Supply and lay 2000 m long 2"GI pipe	m	2000	300	600 000
Fittings work (20% of sum pipe cost)	Ls	1		120 000
Trench excavation for pipe laying (0,6mx0,8mx2000m)	m3	960	60	57 600
Backfilling of soil above the laid pipes	m3	768	60	46 080
Distribution point and tank				
1m high masonry tank stand	Pcs	14	2 000	28 000
5000 l capacity fiberglass tank	Pcs	14	17 500	245 000
2 taps for joined standpost	Pcs	14	13 000	182 000
1" and 6 meters long HDP pipe from the tank to joined standpost	m	84	90	7 560
Subtotal for distribution point, drilling and tank				**1 545 240**
Total cost (ETB)				2 675 676

Based on recent information, the maximum size of the HDP pipe imported into the country is too small for this scheme, so the 2’’GI pipe was chosen for the 2000 m distribution line from the borehole to the tanks, even though it is more expensive than the HDP pipe.

Materials and construction for a fence around the joined standposts and/or the solar panels, were estimated to be 3000 ETB. The materials are however usually contributed by the community, so the actual costs are considerably less or none at all.

Other costs for the capital expenditure of the larger solar scheme are training costs, operational costs and construction supervision. They are presented in table 14.

Table 14. *Other capital non-recurring expenditure costs for the larger solar scheme.*

Description	Costs	Cost calculation and comments
Training costs		
WASHCO CMP management training	16 680	We have 14 public tapstands. So, we will have 15 members for the main WASHCO (1 representative from each fountain) to be trained in CMP management. Cost = 1 112 ETB/person * 15 = 16 680 ETB
WASHCO in O&M management training	38 052	We will have WASHCO's with 3 members for each fountain to be trained in O&M. Cost = 906 ETB/person * 14 fountains x 3 people/fountain = 38 052 ETB
Scheme operators training (technicians, tariff collectors, plumbers, etc.)	5 361	1 787 ETB/person x 3 = 5 361 ETB
Site selection design costs		
Well site selection & appraisal	3 590	1 800 ETB for woreda experts and 1 790 ETB for zonal experts assisting woredas.
Rural piped schemes design	22 300	4 400 ETB for woreda experts and 17 900 ETB for zonal experts assisting woredas.
Construction supervision costs		
Well drilling supervision	3 590	1 800 ETB for woreda experts and 1 790 ETB for zonal experts assisting woredas.
Construction supervision for rural piped schemes (RPS)	12 760	5 600 ETB for woreda experts and 7 160 ETB for zonal experts assisting woredas.

As there are more WASHCO members planned for the larger scheme, the training costs are also higher than for the hand pump and smaller solar schemes. In addition to the site selection and appraisal costs for woreda and zonal experts, there are the costs for designing the piped scheme and construction supervision. This includes the technical details for the distribution system, starting from the top of the borehole (pipe dimensioning, pipe layouts, etc.) As there was no existing water source, the well drilling supervision costs have also been included.

5.3 Operation and minor maintenance costs

For the solar pumping schemes there are basically no operational costs, as the system is fully automatic and runs on solar energy. Maintenance costs are small as well, mainly the cleaning of the solar panels. As the operation and maintenance costs are very low, the collected user's fee from the community can be saved and used in case of a breakdown. However, solar pumping generally is very reliable, and most malfunctions are minor. (Bamford & Zadi 2016) In another study, it was found that most malfunctions happened within the manufacturer's warranty period, which is usually 1 – 2 years. Often the reason for malfunction is also mishandling of the equipment by the user's or improper installation. (Armstrong et al. 2017) The saved money can then be used for the replacement of the controller and pump, as they have the shortest lifetimes (7 – 10 years).

Table 15 shows the estimated yearly costs for operation and minor maintenance for all of the three technical options. The chlorination costs for the smaller solar schemes and hand pump are the same, as the water volume is the same. The guard salary for the smaller solar scheme, however, is higher, as the solar pumping system is more valuable. Also, theft can be an issue.

Table 15. *Estimated yearly operation and minor maintenance costs for the three technical options.*

Description	Total yearly costs	Cost calculation
Hand-dug well with hand pump		
Operation costs		
Guard for the pump	600	50 ETB x 12 months = 600 ETB
Chlorination	200	
Maintenance costs		
For civil works (0,6 % of the investment cost of civil works)	-	For hand-dug well with hand pump the major portion of the maintenance costs is for the hand pump as estimated in F.2.2 below
Hand pump maintenance costs (slow & fast wearing spare parts and maintenance services costs).	1 200	10 % of the cost of the pump, which is 0,1 x 12 000 ETB = 1 200 ETB
Smaller solar schemes		
Operation costs		
Guard of the solar pump	1 200	100 ETB x 12 months = 1 200 ETB
Chlorination	200	
Maintenance costs		
For civil works (0,6% of the investment cost of civil works)	670	Although the total construction cost of the system is 229 889 ETB the cost of the civil works & pipes is 111 570 ETB (excluding the cost & installation of solar pump). So, the maintenance cost is 0,006 x 111 570 = 670 ETB
For electrical and electro mechanical works	-	Solar pump does not need such costs.
Larger solar scheme		
Operation costs		
Accountant	9 600	800 ETB x 12 months = 10 800 ETB
Plumber	7 200	600 ETB x 12 months = 8 400 ETB
Guards of the solar pump	2 400	200 ETB x 12 months = 2 400 ETB
Other operation costs such as chlorine procurement, stationeries, per-diem etc.	4 000	
Maintenance costs		
For civil works and pipes (0,8 % of the investment cost of civil works & pipes)	15 847	Although the total construction cost of the system is 2 675 676 ETB the cost of the civil work & pipes is 1 980 905 ETB (excluding the cost & installation of solar pump). So, the maintenance cost is 0,008 x 1 980 905 ETB = 15 847 ETB
For electrical and electro mechanical works		Solar pump does not need such costs.

The larger solar scheme has so many users, that an accountant is necessary to handle all the payments. There are many solar panels, which are very valuable, so two guards are necessary for the scheme. Also, a plumber is required as there is more than two kilometers of pipeline altogether in the scheme (even more if separate household connections could be made).

5.4 Capital maintenance expenditure

The capital maintenance expenditure costs for each of the three technical options are presented in table 16.

Table 16. *CapManEx for the three technical options.*

Description	Total costs	Cost calculation
Hand-dug well with hand pump	12 300	The hand pump is to be replaced in 10 years.
Smaller solar scheme	111 154	Out of the total cost of the solar pump 118 319 ETB, the parts costing 110 154 ETB need to be replaced after 10 years as per the manufacturer's recommendation.
Larger solar scheme	289 051	Out of the total cost of the solar pump 694 771 ETB, the parts costing 289 051 ETB need to be replaced after 10 years as per the manufacturer's recommendation.

The lifetimes of each component were taken into account when calculating the capital maintenance expenditure. The parts that need to be replaced after 10 years include the pump, controller and accessories. The solar pump and support structures have a longer lifetime of around 25 years. (GSWI 2018; The World Bank 2018) So, the replacement costs are the costs related to all the parts that need to be replaced, including installation and transportation of the materials. The system components that need to be replaced in 10 years and were included in this table can be seen in tables 10 and 13, marked with an (x).

5.5 Summary of life-cycle costs

Table 17 summarizes the total life-cycle costs for each technical option for 10 years. The population growth was taken into account, and the projected population was calculated for each option. According to the World Population Review, the population growth rate for Ethiopia in 2018 was 2,46 %. (World Population Review 2018) For the small schemes currently serving 200 people, the projected population in 10 years would be 256 people. For the larger scheme the population in 10 years would then be 3069 people.

Table 17. *Summary of costs calculated for 10 years for each technical option including the replacement costs. (HDW = hand-dug well and HP = hand pump)*

Cost components	Amount for new HDW with HP (ETB)	Amount for existing HDW with HP (ETB)	Amount for new HDW, smaller solar scheme (ETB)	Amount for existing HDW, smaller solar scheme (ETB)	Amount for larger solar scheme (ETB)
Capital expenditure					
Site selection, study and design	1 800		1 800	1 800	25 890
Construction of scheme components	68 249	12 300	286 138	229 889	2 675 676
4% commission for Micro Finance Institutions (out of the construction cost	2 730	492	11 446	9 196	107 027
Construction supervision cost	1 800		1 800	1 800	12 760
Total cost of trainings given to WASHCOs and pump attendants	17 660		17 660	17 660	60 090
Total capital expenditure cost	**92 239**	**12 792**	**318 844**	**260 345**	**2 881 443**
Operation and minor maintenance expenditure					
Operation cost	8 000	8 000	12 000	12 000	232 000
Maintenance cost	12 000	12 000	6 700	6 700	158 470
Total operation & minor maintenance cost	**20 000**	**20 000**	**18 700**	**18 700**	**390 470**
Capital maintenance expenditure					
Replacement cost of pump parts (after 10 years)	12 300	12 300	111 154	111 154	289 051
Total capital maintenance cost	**12 300**	**12 300**	**111 154**	**111 154**	**289 051**
Total life-cycle cost (in 10 years)	**124 539**	**45 092**	**448 698**	**390 199**	**3 560 964**
Present project users	200	200	200	200	2 400
Project users in 10 years	256	256	256	256	3069
Per capita life-cycle cost in 10 years (ETB)	**486**	**176**	**1754**	**1526**	**1160**

The first column shows the costs for a hand pump including the costs for a new hand-dug well (for cases where there is no existing water source). In the second column is the amount for a new hand pump to be replaced with an existing hand-dug well (as in the case of Walkie and Addis Alem water points). The third column shows the amount in the case there is no existing hand-dug well and the installation of a smaller solar scheme. The fourth column shows the amount for the smaller solar scheme with an existing hand-dug well (as in the study area). The last column shows the total life-cycle costs for the larger solar scheme, as presented in chapters 5.2.4, 5.3 and 5.4.

Table 17 shows that hand-dug wells fitted with hand pumps would be the cheapest option out of the three options investigated in this study. In the case of Yeloma kebele, the life-cycle costs in 10 years for the first technical option (to replace the existing hand pumps with new hand pumps) would be 176 ETB per capita. This means that the costs would be 176 ETB / 10 years = 17,6 ETB per capita per year.

The smaller solar scheme would be more expensive than the larger solar scheme per capita in 10 years. In the larger solar scheme, there were altogether 70 solar panels costing 405 720 ETB. This is 36 % of the total costs for the solar pump (including equipment and installation costs). For the smaller solar scheme, the cost of the solar panels is only 3,5 % of the total costs for the solar pump (including equipment and installation). The lifetime of solar panels is 25 years, which is why they are not calculated in the replacement costs of the solar pumps as the calculations are for 10 years. So, it would be more cost-effective to construct larger solar schemes when possible.

The costs for the solar pumping equipment are based on the offer made by one local company. There are many other solar pumps and panels on the market, but it is important to choose one that will be reliable, as there are many bad products in the market. The Lorentz pumps were chosen because they are suitable for the specific needs in this case, and Lorentz is one of the most reliable manufacturers on the solar pump market according to many professional's experiences. Other cheaper products could also be tested.

The transportation and installation costs are included in the capital expenditure costs for the solar pumping system. However, these costs could be reduced at least a bit if COWASH were to train their own professionals for installation and transport the parts themselves. The option of purchasing cheaper solar panels could also be investigated, as it could cut down the initial investment costs.

Hand pumps are easier to install than solar pumps, and spare parts are easy to find. The joined standposts can be a risk, as the taps can be vulnerable and break down easily if mishandled. The community is not used to taps, and the current hand pumps are designed for heavy duty use. Therefore, they must be trained to properly handle the taps.

There are some advantages for changing to solar in the study area. Water quality improvement, reducing queuing times and better accessibility for persons with disabilities. For the larger solar scheme, there is the option of piped connections to each household, if the borehole yield would be sufficient. For the smaller solar schemes, household connections would not be feasible, so a safely managed service level could not be achieved.

It is to be expected that the population in the area will continue to grow. In 10 or 20 years, the yield in the Walkie and Addis Alem water points might not be enough for the population in the area, and an additional water source would be necessary. Therefore, it would be a risk to install the smaller solar pumps in the wells, if they could only function for up to 10 years. Solar pumping becomes more cost-effective in the long term, so solutions that only last 10 years cannot reach all the advantages financially.

Compared to diesel powered pumping, solar has many more advantages than compared to hand pumps. Solar pumping and hand pumps both produce no pollution and are not dependent on a fuel supply chain.

5.6 Applicability of solar pumping

Even though solar pumping has many advantages, it is not the right technology for every situation. It is necessary to determine each case separately, whether solar is the best option. System design must also be done carefully for each individual scheme, as badly done design is one of the main problems for malfunctions. Technical knowledge in both design and implementation are important.

The solar pumping system is more complex than hand pumps. Therefore, they require skilled technicians and electricians to install and repair the solar pumps and pumping system. Solar is discouraged, if there is no good supply of spare parts.

For solar pumping to be feasible, there needs to be enough solar potential. This should be analyzed for each specific location, as the solar radiation levels can vary even within a country. The average solar radiation should be able to provide the amount of water required.

If there is reliable grid electricity available, it should be considered as an alternative to solar. Solar becomes a more feasible option if grid electricity is unreliable or there is no grid in the area. It has been shown that solar pumping systems become cheaper than diesel powered pumping in the long term. Also, if the fuel supply chain is unreliable, solar can provide a better solution not being dependent on fuel supply or increasing prices.

It was also shown in this study, that solar pumping will have higher costs in 10 years than the hand pump systems currently in use. Therefore, if the community contribution is raised, the willingness to pay more for a better service level needs to be assessed for each community. The life-cycle costs for solar pumping will be lower for a larger scheme.

Site specific issues are important for the designing the system and determining if solar pumping can provide better technical or economic advantages than the existing scheme. These include social issues such as land use and ownership. In the case of Walkie and Addis Alem water points, the land in the residential area was used to a maximum and there was no extra space for a public water fountain. The location of the pumping system (panels and pump) was on communal land, where there is space and it is accepted by the community. But the best advantages cannot be achieved in this case as none of the residents would want the joint standposts to be on their own land. In this case the only option would be to construct connections to each household. However, because of the limited quantity of water it is not feasible for this site. Land use and ownership are important to acknowledge, and they need to be discussed and agreed with by the community.

Another social issue is acceptability, as the community has to be interested in developing the scheme (existing or not) the same as for any other water scheme. The social characteristics and most vulnerable households are important to investigate if joined standposts are to be constructed. The locations of these standposts can then be chosen to best serve the community.

The site selected for the solar panels should not have any shade for the panels to receive as much sun as possible. Solar panels are valuable, and thus theft an issue. If solar is installed in areas where theft is a high risk, extra measures should be taken to protect the panels.

Solar pumping allows for water to be pumped to a distribution point from further away, depending on the pump capability. The water can be pumped closer to where the users are, and thus reduce collection times. For example, if the well in downhill from the users, it can be pumped instead of having to walk uphill carrying water. This would be a good application for schools and health posts, many of which do not have their own water source (as in Yeloma kebele).

All in all, solar pumping should only be used when there are significant advantages compared to existing solutions.

6. CONCLUSIONS, RECOMMENDATIONS AND ASSESSMENT

In this study the characteristics of the community were explored in terms of water supply, availability, water consumption and basic information on the household members. This was done by conducting household and WASHCO (water, sanitation and hygiene committee) questionnaires and interviews. The site was personally observed to get a better view of the area.

Solar pumping has many advantages compared to other solutions, such as hand pumps. They require very little maintenance and operation can be totally automatic. Site selection for a solar pumping scheme plays an important role in the success of the project. It is important to implement solar pumping in areas where it can provide clear advantages. Advantages include improving the service level, quality improvement, accessibility (for persons with disabilities), reduced operating costs (compared to fuel generators) and bringing water closer to households.

Life-cycle costs were calculated as total costs for 10 years. The costs considered in this study were capital expenditure, operation and minor maintenance expenditure, and capital maintenance expenditure. Compared to hand pumps solar pumps were found to have higher life-cycle costs. The larger solar pumping scheme had lower life-cycle costs than a smaller scheme.

Social issues are significant to consider when planning a solar scheme. Social issues to be considered are land use and ownership, acceptance of the community and the willingness to pay. These issues were found to affect the design for Yeloma Kebele, by restricting the technical solutions that could be implemented.

One of the problems in this area was water quantity. The Walkie and Addis Alem water points had a limit on the amount each household could collect water per day. If the water was pumped from the two water points straight to each household on premises, household water consumption would likely increase. At this point Walkie and Addis Alem water points could not provide enough water for the whole community. To fulfill the criteria for a safely managed service level, a new water source is needed. Bringing water closer to the households and to construct joined standposts (three or more in the residential area) would not work in this case as none of the households would be willing to give up a part of their land for this purpose.

In Yeloma kebele, solar pumping would bring some advantages. These include reducing time spent queuing (and total time spent collecting water as a round trip), improving accessibility for persons with physical disabilities and improving the quality of water (by chlorination). A smaller solar scheme could not bring water closer to the households. They would not be able to provide a higher quantity of water either. The larger solar scheme on the other hand would require quite a large initial investment. Also, the borehole location would need to be examined further. The costs will get higher if several boreholes need to be drilled to find enough water.

The management of the scheme is most simple for the hand pumps, as the WASHCO's are already in place and have received training. With a smaller solar scheme, some extra training would be required, but the management could still be done by a WASHCO the same size as for hand pumps. The larger solar scheme would need a professional accountant, as the number of user's is much higher and there is a lot more money moving around.

To achieve the JMP (WHO & UNICEF Joint Monitoring Program) definition of safely managed services, water from an improved source should be free from contamination, available when needed and located on premises. A basic service level requires drinking water to be from an improved source with less than a 30-minute collection time (round-trip, including queuing). The solutions discussed in this research could reduce the queuing time and achieve a basic service level for more households. The criteria for a safely managed service would not be met for the hand pumps or the smaller solar schemes. The larger solar scheme could have potential to provide enough water for household connections (piped on premises) and then to achieve the safely managed service level.

The Ethiopian GTP-2 has a goal for rural water supply to be 25 liters per capita per day within one kilometer, and to reduce the non-functionality of schemes. The Walkie and Addis Alem water points were both within 1 km of the users. They could not, however, supply enough water for all households. This is because of the agreement to collect four jerrycans per household per day from each water point (not enough for households with 7 members or more).

With the hand pumps the SDGs do not come any closer. To improve the level of service and quality of the water, there needs to be some change. Hand pumps have been a significant improvement from using unimproved sources of water such as surface water or unprotected wells for drinking water. Solar pumping is one feasible option to come closer to the SDGs, but it is necessary to determine for each scheme individually whether solar pumping is the right solution. The costs for solar pumping become lower with a larger scheme.

Table 18 presents a summary of the selection criteria for the three technical options. The points were given based on the findings of this study. The three technical option were ranked on based on which option had the best outcome. The darkest green is for the highest points (3) and the lightest green for the lowest points (1) for each criterion.

Table 18. *Summary of the selection criteria ranked from 1 – 3 for the three options. Dark green for the best points, light green for the middle points and very light green for the poorest points.*

	Hand pumps	Smaller solar scheme	Larger solar scheme
Life-cycle costs	3	1	2
Water safety	1	3	3
Water availability	1	2	3
Water quantity	1	1	3
Functionality	1	2	3
Management of the system	3	2	1
Social issues (land use, accessibility, acceptability).	3	2	1
TOTAL	**13**	**13**	**16**

In this table the larger solar scheme is getting the highest score. All options have received the highest score in some category. The hand pumps and smaller solar scheme receive the same score, a few points behind the larger solar scheme. However, moving straight to the larger solar scheme from the current situation is a big step, as the planning and implementation are much more complex compared to the other two options.

Both solar schemes were given the highest points for water safety, as they both have a good opportunity to improve water quality. The water quantity is the same for the smaller solar scheme and hand pump, as they use the same source. Therefore, they receive the lowest points as the water quantity is not enough. The larger solar scheme has potential for enough water to be supplied to households.

The management of the system gives the highest points to hand pumps. This is because the hand pumps already have functioning management by WASHCO's, and they have been trained to manage a scheme with a hand pump. Installing solar would require more training, and with the larger scheme an accountant would be necessary as the number of users is much higher than with the smaller solar scheme and hand pump. Hand pumps also receive highest points for life-cycle costs (were the cheapest option) and social issues (they are already fully accepted by the community).

The smaller solar system would improve the situation for the water point. In an institutional water supply a smaller solar scheme could become the best option if a similar table was done for the school. The smaller solar scheme for the school would receive highest points for at least for water quantity and water availability. This would change the scores to favor the smaller solar scheme.

6.1 Recommendations

It is important for the community also to be part of the solar pumping project, as they are already in the CMP approach. With a solar pumping system, the community needs to properly understand the worth of the system and take ownership. For example, it includes training children not to throw stones at the panels. When the community understands the worth of the system, the risk of vandalism and theft will also go down as they would all protect the panels.

It is also recommended that solar pumping schemes should be implemented in nearby areas or each other if possible. It would be better for the spare parts supply, as solar pumping equipment cannot be purchased everywhere in the country yet. Maintenance and servicing of the pumps would then also have lower costs as there would be less need to travel between the schemes.

In the study area, a smaller solar scheme would not be the best option for Walkie and Addis Alem water points, one reason being the problem with water quantity. The water quality for the water points could be improved by chlorination of each jerrycan separately for example. Taking better care of the water point area, by cleaning the trash and making sure the drainage system works, could also improve the water quality. Installing a gate could prevent animals from entering the water point area. The land around the point is grazing land for animals, so there is an extra risk for contamination.

The best opportunity to try out a smaller solar pumping scheme in the area would be for the school. The school water point was not included in this study, but based on these results and observations on site, it is recommended to test the smaller solar system for the school only. This would bring an immediate solution for the school water crisis. It was calculated that 6 m^3 of water would be enough for the school per day for drinking water, sanitation and hygiene purposes. With solar pumping, the water could be pumped from further away to the school and be stored in a tank. The school water point in Yeloma was far and ran out of water early in the dry season each year, so a new well would be needed. There was a great need for drinking water for the students and staff, as well as water for hand washing. Additionally, it would be recommended to construct more latrines. There are currently too few and they are not accessible for persons with disabilities.

6.2 Self-assessment

In this study, the costs of only three technical options were considered. A more comprehensive study could cover more technologies as well. Also, there are other solar products that would be good to investigate. The ones chosen are considered very reliable and durable, and they can be purchased locally, which is not the case for all solar products in Ethiopia. Many of the products on the market are only designed for small-scale household use and could not be applicable for this case study. Therefore, only the selected ones were included in the study.

In the household and WASHCO questionnaires there were some questions that were found to be difficult. The results of the survey depend a lot on the enumerators and how they understood and presented the questions. The questionnaires were gone through with the enumerators before they conducted them, but in this case, it was not possible to be present with them during the surveys. Some results (as the questions on disabilities and how much more the respondents would be willing to pay) showed that there probably was some misunderstanding either with the enumerator of the respondents. Test surveys were not conducted before the actual questionnaires. A test survey could have shown some of the possible misunderstandings and problems with the questionnaire beforehand, and the questions could have been edited for better results.

This study can be used as a guideline in estimating the total life-cycle costs for a solar pumping system. The applicability of solar pumping was also discussed in this study, and it is relevant when solar pumping is considered as an option for rural water supply. This study also showed how important the social aspects are in the implementation of a solar pumping scheme.

Some of the costs in this study were estimations. The next step would be to test these solar pumping systems to determine the actual costs and to see if solar pumping should be considered in a larger scale.

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APPENDIX A: HOUSEHOLD QUESTIONNAIRE

Name of the family head ____________________________

1. Sex of the respondent 1. Male 2. Female
2. Sex of the household head 1. Male 2. Female
3. How many members are in the family (including household head)?
   Total _____________ Male ___________ Female _______

4. Does someone in your household have any of the following health problem(s)?
   1. Yes ______ 2. No __________ 3. I don't know __________

   4.1 If yes to Q4, specify how many members have each problem

It. No.	Type of health problem	No of Household members with the problem
1	A lot of difficulties in seeing even with eye glasses	
2	A lot of difficulties in hearing	
3	A lot of difficulties in walking or climbing steps	
4	A lot of difficulties in washing or getting dressed by themselves	
5	A lot of difficulties in remembering	
6	A lot of difficulties in understanding or talking/speaking with others	
7	Use any assistive devices (crutch, wheelchair/artificial limb)	
8	Others (epilepsy, paralysis or leprosy)	

5. What different water sources are available for you? (circle all water sources)
   1. Protected source (hand-dug well/spring) 2. River(s)
   3. Pond(s) 4. Unprotected well 5. Rain water harvesting
   6. Other source (specify)…..
6. If you collect water from a protected source (handpump), do you collect water from this nearby water point? 1. Yes
   2. No (if no, move to Q14)
7. If yes to Q6, when do you collect water from this water point?
   1. Dry season 2. Wet season 3. Both dry and wet seasons
8. If yes to Q6, for what purpose you <u>mainly</u> use the water you collect from this water point? 1. Drinking 2. Cooking 3. Washing
   4. Cleaning 5. Other (specify) ……
9. If yes to Q6, how much water do you collect a day (or how many jerrycans)? Insert amounts 1. Dry season _____________ 2. Wet season ______________

10. If yes to Q6, is the water you collect from this water point adequate for your household?
    1. Yes 2. No
11. If yes to Q6, how much time does it take to collect water from this water point (round trip, in minutes, including time spent queuing)? ___________
12. If yes to Q6, do you have to queue at the water point?
    1. Yes (specify how long) ___________ 2. No
13. If yes to Q6, what do you think about the quality of the water in the water point?
    1. Very clean 2. Fairly clean 3. Not very clean 4. Dirty 5. It varies from time to time (specify when) ……
14. If you also collect water from another source for domestic purposes such as cooking, washing, drinking, cleaning, which sources do you use and how much do you collect <u>per week in Jerrycans</u>? (insert amounts for each source separately)
    1. River ____________
    2. Pond ______________
    3. Unprotected spring ______________
    4. Unprotected well(s) _______________
    5. Rainwater harvesting _______________
    6. Other protected sources/water points (specify which one and amount) _____________
15. If no to Q6, what is the main reason for not using the water point?
    1. Not enough water 2. I don't like to queue 3. It is too far
    4. I don't like the water smell/color/taste 5. Other (specify) …..
16. If no to Q6, from which source do you mostly collect your drinking water?
    1. River 2. Pond 3. Unprotected well(s)
    4. Rainwater harvesting 5. Other water points 6. Other source (specify)
17. Do you pay a user's fee for water?
    1. Yes 2. No
18. If yes to Q17, how much? __________________ in Birr

    18.1 If Yes to Q17, how often do you pay?

    1. Monthly 2. Biannually 3. Annually 4. Other (specify) ……
19. Are you willing to pay <u>more</u> for clean drinking water if the water is supplied closer to your house? 1. Yes
    2. No (specify why not)…..
20. If yes to Q19, how much would you be willing to pay for 20 liters (jerrycan) of drinking water supplied to your house? ___________ Birr
21. How many cattle (ox/cow/heifer/bull) do you have in total? __________
22. How many sheep/goats do you have in total? __________
23. How many horse/mule/donkeys do you have in total? __________

APPENDIX B: WASCHO QUESTIONNAIRE

1. What is the name of the water point? _________________
2. WASHCO members (gender and position)
3. Are there caretakers to maintain scheme?
   1. Yes (If yes, insert number and gender) _______________
   2. No
4. How many households are using the water point? _______________
5. Is this the same number than when the water point was constructed or has the number changed?
   1. Same number
   2. It has changed (specify how much more/less for both options)
      a. More people are using it _________ b. Less people are using it _________
6. Is the water point currently functional?
   1. Yes 2. No
7. If not, why? 1. Not enough water 2. Pump is broken 3. Other (specify) .....
8. Have there been shortages of water? 1. Yes 2. No
9. If yes to Q8, when have there been shortages of water?
   1. In the rainy season 2. In the dry season 3. Both dry and rainy seasons 4. Sometimes in the dry season 5. Sometimes in the wet season
   6. There is always a shortage of water
10. If yes to Q8, how long did they last on average? 1. A week or less 2. 1 week – 1 month 3. 1 – 6 months 4. More than 6 months
11. Has the water point been non-functional at some point?
    1. Yes 2. No
12. If yes to Q11, what were the reasons? (circle all that apply and insert number of times) 1. Mechanical 2. Water quality 3. Management problem 4. Other (specify)…..
13. If the pump has been broken, what is the average time to get pump fixed after breakdown? 1. Less than 1 week 2. 1 – 2 weeks 3. 2 – 4 weeks
    4. More than 1 month
14. Is tariff/users fee payed? (Does not mean the upfront cash contribution payed to construct water point)
    1. Yes 2. No
15. If yes to Q14, how much is the payment per household? _________________ Birr
16. How often is the tariff payed? 1. Monthly
    2. Biannually 3. Annually 4. Other (specify) ……
17. Are there any households who are exempted from payment?
    1. Yes 2. No

18. If not, is there this kind of provision in case the need arises?
    1. Yes 2. No
19. Is they have a bank account and what is the amount in bank?
    1. Yes (specify how much) ____________ 2. No
20. How much money is there in cash? ____________
21. How deep is the well? ________________
22. How high is the water column? ________________