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Rachel Jackson Winters Date

Levels of Self-supply for Water Delivery in Rural Ethiopia:

What different scenarios for supplementary self-supply in three *woredas* of Amhara, Ethiopia can be used to reach the SDG water-related goals of 2030 and how much will the different scenarios cost?

By

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Abstract

A considerable proportion of the world lacks access to a basic water supply. According to recent data gathered by the Joint Monitoring Programme for Water Supply and Sanitation, nearly 70 percent of people living in rural Ethiopia lack a basic water supply, defined as an improved source where water can be collected within 30 minutes. Due to variable hydrogeology and difficult terrain, there is added difficulty in providing access to microbiologically safe drinking water. The goal of this study was to estimate water procurement costs in Ethiopia and to explore different water supply strategies that would aid in achieving the SDG goals by 2030.

We used population density mapping and cost prediction models to quantify implementation costs for several different hypothetical water service levels in Ethiopia. This method of model building allows for the comparison of three different water systems: traditional community water supply (CWS), self-supply, and piped water. We were also able to compare these systems at different hypothetical levels of installation. We used Google Earth® to draw buffers around clusters of houses to estimate population density and ran cost equations in Excel®. Estimating the approximate number of water points needed for each cluster of houses was also included as part of the model to establish the total costs for each *woreda* (district). Estimating population density was critical for this study as the further spread apart houses are, the costs to serve water to those homes would vary depending on the type of service. This is illustrated in the variation of costs between the three *woredas* we studied.

Our results indicate that the most cost-effective option was using 50% piped supply, 20% self-supply, and 30% CWS. These results suggest the notion that a low-level of self-supply can be used to supplement already existing water service delivery options. An additional result indicated that one *woreda* in particular, North Mecha, had homes closer together so this might have been a factor for the lower average costs, due to the increased population density and cost sharing savings. Additional research should collect more cost data on self-supply and other water infrastructure in rural Ethiopia to improve water service cost estimates. These methods have the potential to strengthen efforts for water coverage improvements in rural Ethiopia.

Table of Contents

Acronyms

CARE: Cooperative for Assistance and Relief Everywhere
CSA: Central Statistical Agency
CWS: Community Water Supply
JMP: Joint Monitoring Program
MWA: Millennium Water Alliance
NGO: Non-Governmental Organization
SDG: Sustainable Development Goals
SSA: Self-supply Acceleration
WASH: Water Sanitation and Hygiene
WIF: WASH Implementation Framework

Some Key Definitions

Water point a man-made structure where water is assessed by the end user, could be any well types including a self-supply well.

A conventional community well (referred to as CWS) is a large well usually greater than 1.2 meters, is lined with concrete rings and has an apron for drainage and protection and has a handpump.

A family well or **self-supply well** is any well type that was built mainly for the family but also is shared with other neighbors but is paid for and owned by the family. Family wells usually are built by traditional standards but may have a mechanized pump.

A traditional well refers to the 'traditional' technology used and is usually partially or unlined and has low levels of protection.

A *woreda* is synonymous with 'district' and is the lowest level that the Bureau of Water and Energy (BWE) has offices. The *woreda* is split into smaller kebeles, and this is equivalent to a neighborhood and is the smallest section of local government.

Safely-managed having a water point on the premises, available when needed and free from contamination

At least basic meaning having a water point that is roundtrip, less than 30 minutes from the home.

Direct costs are the support activities of local-level stakeholders and users.

Indirect costs are the macro-level support, such as planning and policy making costs.

Opex (operating expenses) are the regular expenditure of the day-to-day function of a water point, such as cleaning products.

Capex (Capital expenditure) is the initial building cost, the costs of providing a water service where none existed before.

Note: Definitions derived from (Sutton, 2012, Fonseca et. al., 2011 and JMP, 2015).

Chapter 1: Introduction

The UN Sustainable Development Goal (SDG) 6 calls for universal water access for all, which will require dramatic improvements in availability of water and sustainability of water services. Though the world “met” the 2015 Millennium Development Goal for water, hundreds of millions of people, especially those living in rural and hard to reach areas remain without access to reliable, safe and affordable water. To fill this gap, policy makers and global stakeholders are trying to estimate what costs and resources are needed to reach the current populations without water. Access to reliable, sustainable, potable drinking water remains a major concern across the globe. An estimated 844 million people around the world lack access to a basic water supply (WHO & UNICEF, 2017). According to the JMP about 80 percent of Ethiopian people live in rural areas and 70% of the population is without access to basic water. It is important for policy makers to know how much it will cost to achieve water targets, so decisions can be made about how to use existing funds. Using models, we can explore different service delivery strategies and project costs associated. Understanding what resources and funds are needed is important in moving the world toward more universal and sustainable services.

In Ethiopia, approximately 61 million people lack access to basic water, and in rural areas some Ethiopians are walking more than 3 hours from their homes to collect unsafe water from open sources, such as streams and hand dug wells (Water.org, 2017). Unsafe water that is contaminated drives health risks for families who don’t have access to safer water sources. Besides obvious health risks, contamination is also associated with time burden and this holds families back from progressing financially (Sutton, 2016). Many countries in Africa, including Ethiopia, did not reach the benchmark for the Millennium Development Goals (MDGs), and due to population growth, are off-track to reach the SDG targets unless appropriate changes are made to their water systems (Sutton, 2016).

Traditional self-supply, where families construct and fund their own source of water collection, has been a way that people procured water in Ethiopia for many years. Another method traditionally used is rainwater harvesting (Workneh et al., 2009). However, traditional self-supply has proven to be unsafe and unsustainable, and a formalized approach to self-supply is needed. In the last decade, governments and non-governmental organizations in Ethiopia considered improving self-supply as a way for low-income countries to fill gaps in water coverage. Self-supply increases water access to people with limited local water sources or those who are living in areas without a water source at all. A low-cost method such as self-supply is a more feasible option when compared to other water service delivery models (SSAP, 2014).

The goal of this study is to offer a method that can be used to identify the most cost-efficient path to take and to estimate the cost that it would take to get there by 2030. In order to reach SDG water-related targets by 2030, there is a need to improve water services. Costs and resources remain one of the largest barriers to making changes to the water service delivery in Ethiopia (Sutton, 2016). In resource-limited settings, maximizing the sustainability and durability of water infrastructure is critical to save costs and resources. This study focuses on estimating population density as a key determinant that drives cost differences between various water service delivery methods in Farta, North Mecha, and Dera *woredas* -- the administrative unit responsible for water through decentralization, similar to a district (OECD, 2016) in Ethiopia. Population density is used to predict how much it would cost to reach each region with these different methods, including self-supply.

Our study area was chosen for this study based on previous self-supply research performed by IRC WASH (Mekonta et. al., 2016). The *woredas* selected from the baseline were - Farta, Dera, and North Mecha – that are located in the Amhara Region. Amhara is located in the North Western/Central part of the country, and it is a vastly rural population with nearly 90% living in these sparsely populated areas (Ethiopia.gov, 2018). The study done by IRC WASH had the goal to accelerate self-supply in Ethiopia. Beginning in 2014, the Millennium Water Alliance (MWA) partnering with IRC WASH began a collaborative pilot for self-supply in five *woreda*s in Ethiopia and worked with *woreda* government officials to drive further progress with self-supply (Mekonta, 2017). This was a test to see how self-supply could be accelerated by NGOs supporting the private sector. While mixed, the results were mainly positive, suggesting more than 730 wells were either built or improved, and more than 18,270 people were served in the program. But one of the most important challenges they identified was that while more people gained easier access to water, the quality of the water provided with self-supply could not be guaranteed and showed to be sub-standard in most water quality testing (Mekonta, 2017). This limitation of water quality is discussed further in the limitations section.

The cost of delivering water with a given service delivery model is not fixed across contexts. In setting targets for reaching SDGs, governments and financiers often think in cost-per beneficiary (Bexell, et. al., 2017). The same infrastructure may have varying costs in the *woreda*, depending on geography of the land, accessibility of parts, and distance from major transit centers. The terrain and geography also influence what technologies would be available in rural verses urban areas (Hutton & Bartram, 2008). Central to this calculation is population density, which is needed to determine the cost-per-beneficiary and to understanding the approximate number of facilities required to insure all residents of the *woreda* have access to a water source within a reasonable distance from their home.

The goal of this work was to illustrate the costs of using self-supply along with other water service methods on a larger scale and to see how much it would cost to build new infrastructure in areas that are predominantly rural. Data show that rural areas in Ethiopia are where there is most need for a supplementary source of water in addition to existing community sources, due to the number of homes that are not currently reached. Rural communities are especially vulnerable, as not only do they often lack sources of clean water, but people have to travel great distances to get it. There is a clear need for improved water service delivery in rural areas of Ethiopia and using self-supply as a component could be a way to reduce costs of such efforts.

Chapter 2:

Comprehensive Review of the Literature

Self-supply in this study refers to an approach to gaining water access in which families dig their own wells or hire a local contractor to build them (Workneh et. al., 2008). Self-supply is especially important in rural areas where there is low rainfall or mountainous regions that are beyond formal water infrastructure, such as parts of Ethiopia. Even though self-supply is a critical part of water access in environments like Ethiopia, supplementing self-supply with other sources of water is critical for financial sustainability and equitable access. This literature review will explore existing research on self-supply, and its utility in Ethiopia, as well as, other alternative water source options for resource sparse areas.

Methods and technologies for self-supply vary significantly, as do quality and safety of the water accessed (Workneh et. al., 2008). In order for self-supply to be a safe method there is generally a need for formal support to ensure that standards are upheld throughout the entire process. This support includes access to a quality artisan builder to build the well, access to functioning hardware (such as pumps and covers) and training about how to use it, and routine and consistent upkeep such as maintenance of the moving parts.

In Ethiopia, wells owned by families are already being used in many parts of the country in both urban and rural areas, but there is still a large portion of the groundwater that is underutilized, as the family wells aren't usually dug deep enough (Butterworth, et al. 2013). Due to the low cost to the government, self-supply is viewed as a possible complementary approach to the traditional water service models supported by the government such as communitymanaged handpumps that are already in place. Furthermore, there is also the ability for self-supply to reach many people, especially those in rural and hard to reach areas, as it does not require large upfront capital costs by the government and does not necessarily require government intervention at all (Mekonta et al., 2015).

What is Self-supply
• Water supply financed by families in the form of loans, labor, and shared knowledge. • Usually shared by neighbors but have one private owner. • Hand-dug wells that access shallow groundwater, natural springs, or rainwater. • Mainly used for drinking but also for sanitary purposes, farming or livestock. • Usually the sole source for most houses, while CWS are partial sources for homes. • Traditionally developed by people out of necessity. • NGO and local governments working together to conduct self-supply pilots for increased water supply efficiency and safety.

Table 1: Definition of self-supply, derived from (Terefe & Butterworth, 2016).

Self-supply allows for families to slowly invest in their own water source in order to reach a fully-protected well. This ‘path’ is called the self-supply ladder and was developed by MWA during the 2014-2017 self-supply pilot. The ladder consists of 6 levels: Unprotected well I, Unprotected well II, Semi protected well III, Semi protected well IV, Protected well V, and Protected well VI (MWA, 2017). The highest rung on the ladder is a fully-lined well, with a hand pump, and a sealed well mouth to reduce contamination.

The Ethiopian government has implemented improved self-supply as a way to cover hard to reach areas that are not receiving adequate water through community supply (IRC, 2017). It was through this development that self-supply was also recognized as a formal water service delivery model in 2012 by the Ethiopian government (SSAP, 2014). However, there was a realization during the pilot by IRC in 2015, that there isn't a strong foundation of knowledge on how to gain support from the government and other actors in the sector (IRC, 2017).

In 2011, Government policy in Ethiopia was expanded to include self-supply as a service delivery model, which is part of the WASH Implementation Framework (WIF), and the National Policy Guideline for self-supply in Ethiopia was developed in 2012 (SSAP, 2014). In this household initiative, self-supply is considered complementary to community water supply (CWS). It is also a part of the One WASH National Program (OWNP). In all of these ways self-supply is being supported in the government to build an enabling environment for this delivery model grow and be promoted on the community level (SSAP, 2014).

In the 2014-2017 self-supply acceleration pilot by MWA – Ethiopia Program (MWA – EP), performed in five *woredas*, a new process to supplement self-supply into the rural water strategy was introduced. This effort was a collaboration of the regional and *woreda* levels of government, CARE, World Vision, Catholic Relief Services/Meki Catholic Secretariat, Aqua 4 All, Water.Org, IRC WASH and others. The goal was to perform activities that focus on developing and offering the support needed to create demand for self-supply (IRC, 2017). Approximately 18,000 people were served with new or improved water structures in the implementation of this pilot, and 731 wells were improved upon or newly constructed. This success illustrated the need for further acceleration of self-supply, as it showed that there is a demand for more affordable, safe water sources.

Even though the method used in the MWA- EP is recognized now by the government, it still lacks recognition as compared to other service delivery models (IRC, 2017). Creating demand within the community for Ethiopian people remains one of the biggest challenges for the local government and the private sector. Typically, past efforts of NGOs that fund initial installation and then fail to monitor the maintenance and sustainability of the water points, causes many of the existing structures to fail (IRC, 2017). This grassroots effort of using self-supply, might not seem as visible to the community and needs promotion of new concepts to existing partners in the community.

An additional challenge in scaling up MWA-EP model is that the education program is too brief and will not lead to sustainable changes in community behavior over time (Mekonta et al., 2015). There is also a concern that not enough funding will be allocated for how much is needed to implement such a large national effort. (Mekonta et al., 2015). Without effective community education and adequate funding, some self-supply programs could run the risk of damaging human health specifically through contamination.

In rural areas, there is a shortage of necessary education that is needed in order to reach improved self-supply for well construction. This leads to a lack of protection when individual families are funding the water supply, due to little opportunity to get help with proper building. Consequently, this has caused an overall disdain of self-supply, looked at in the sector as more quantity but lower quality (Sutton, 2016). The solution should be to focus on improving the existing self-supply in order to reach the government standards.

The MWA-EP pilot, which took place in 2015, attempted to address the risk of contamination in self supply programs. The MWA-EP program was able to improve 43% of all of the wells that were installed during the time frame. The issue of contamination was found with not properly cleaning the pit after installation and/or not providing the needed chlorine treatment to ensure clean water. This is partly due to the location of the latrines being fairly close to the wells (usually 30 meters) and there is an issue with unclean standing water near the wells (IRC, 2016). The reason for the unclean water often had to do with running out of chlorine to treat the wells on the inside and surrounding areas. Additionally, there was a gap of time between when the well was drilled and when the lining was built, causing the wells to collapse due to the low-quality install. Throughout the pilot, 49 % of the wells built were missing this physical barrier, and without the lining on the outside, there was often unsafe contamination from animals or livestock. A small number of samples were taken from the water from the MWA-EP wells that were built, and they all met the requirements of being well-protected from contaminants. However, 71.4% (5/7) of the samples had unacceptable levels of fecal coliforms. The high rates of fecal matter in the water was often the case in other tests done in other areas of self-supply intervention. The researchers found that the wells were not being properly disinfected after the upgrades were made (Mekonta et. al., 2017). Building the well the correct way, and then making sure home treatment of the water is maintained, is the best way to ensure the quality of the water. (Usman, et. al., 2018).

Given the potential risks of relying only on self-supply sources, alternative approaches must also be explored. One alternative is to construct a larger well that can be owned by the community, and harvesting rainwater is another alternative in areas where the groundwater is hard to reach (Sutton, 2016). However, rainwater is an issue with self-supply as well. The amount of groundwater is very dependent on the amount of rain that falls during the season. If there is not enough rain, then the shallow wells will be dry, but the CWS will remain functioning as they are usually much deeper (KII, 2018). Lack of rainwater due to climate fluctuation has proven to be a problem as well, with more shallow wells, the source can potentially dry up when there is a lack of rain (Mekonta, 2017). The end line study from MWA and IRC showed that around 12 % of self-supply wells experienced these shortages, leaving 78% functioning all year (Mekonta, 2017).

Water quality remains one of the largest challenges in self supply programs. If installed correctly and disinfected properly, self-supply could benefit the quality of the water that is ultimately consumed, as it brings the water access closer to the household. A microbiology study in rural Ethiopia found that 58% of water that is stored in the house is contaminated with Escherichia coli (E. coli) in contrast to only 38% in protected community supplies (Usman, et. al., 2018). One solution could be to target water storage in the home and ensure that water is not contaminated after collection. Using Self-supply to move the water closer to the homes can also assist with this issue. A study done by IRC Wash indicated that the closer people lived to the water source, the lower the contamination was (Mekonta et. al., 2017).

The literature reviewed here showed a lack of research on costs and financial promotion projects for families through self-supply. Limited published papers on this topic demonstrate that self-supply wells are more cost effective than community water sources. The initial capital investment ranges from 10-40 USD (for rudimentary hand-dug wells) to 750 USD (with the higher-end mechanized pump) (Sutton, 2012). This is where the self-supply/traditional costs in Table 2 were derived. As mentioned in the Table, the data were gathered from 1990, so the new costs include a 20-year inflation estimate. The goal of our study was to identify large scale costs of self-supply, and to estimate scenarios of self-supply that would result in each household per *woreda* receiving safe water.

Chapter 3: Methods

In order to estimate the costing scenarios shown in Table 3, we needed to initially determine the population distribution in the region, and then develop the costing model using these population distribution data. The population distribution was determined using Google Earth. The population distribution data were then applied to the costing model to calculate the costs in Excel. Together, this approach combining the population distribution and cost analysis allowed us to see hypothetical costs projected from now until 2030 and to estimate how much investment will be needed for the different scenarios.

Determining population Distribution

To estimate population distribution, we first drew *woreda* boundaries using Google Earth for three *woredas* (Dera, North Mecha, and Farta [Image 1]) based on maps provided by the IRC water supply specialist in Ethiopia, Lemessa Mekonta. In the drawing of the boundaries, we estimated that approximately 5% of households were incorrectly situated and were excluded from the boundary when they should have been included. This deviation was characterized as a +/- boundary error estimation. This population distribution method allowed for some estimation of water points based on the terrain. For instance, there was no water point estimated in mountainous regions that had no housing structures in Google Earth. A 30-meter radius buffer was chosen for this study. According to JMP, if a household has a water source within a 30-minute roundtrip distance, then it qualifies as an at least basic water source (WHO & UNICEF, 2017). For the purpose of this study, one assumption made was if several houses were all in the 30-meter radius then these houses would “share” the hypothetical water point. The average number of houses that share water points was approximately 8 houses. This was based on the population distribution data we calculated in this study. However, real-world numbers tend to be substantially higher; a recent study found that the average number of households that share a self-supply well is approximately 11 households, and for CWS the average is 21 (Hutton, 2016).

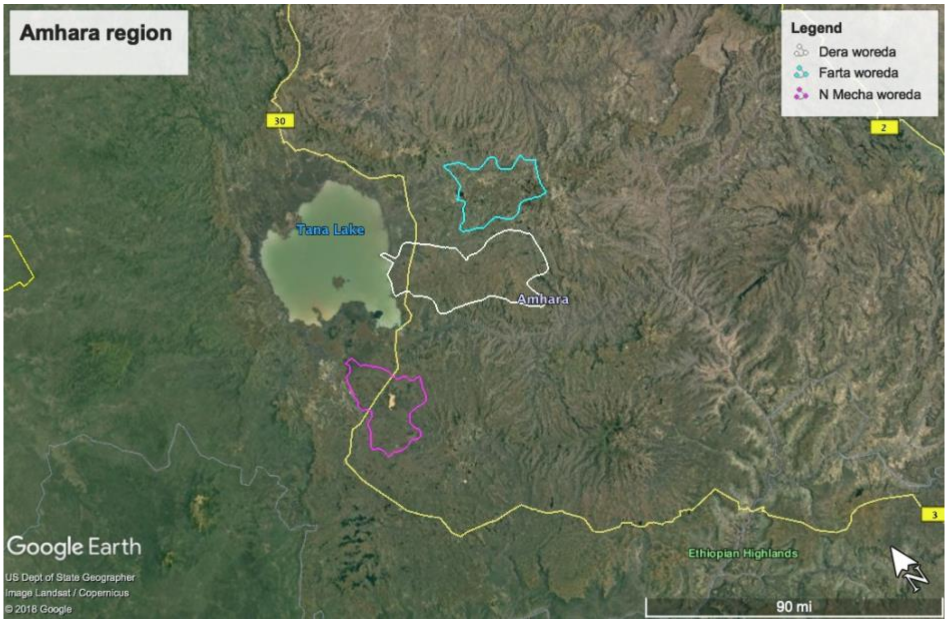


Image 1: Map of three woredas: Dera, Farta, and North Mecha, provided by Lemessa Mekonta IRC Ethiopia.

The next step in the population density process was to approximate the number of houses that were located in each *woreda*. This was done by creating buffer circles around approximately 200 houses and using three standard sizes of circles to cover areas of varying sizes. From the varying density, the buffers were categorized into 3 "levels" of different sized circles. The following index was used: buffers containing 200 households that were smaller than 1 km in circumference were considered a "small town" (shown in Image 5). Buffers greater than 1 km in circumference, but smaller than 6 km were considered a "village cluster" (shown in Image 3), and for the circles drawn larger than 6 km were called, "sparse or remote households." These were the very rural areas in each of the *woreda*s (Image 3), which illustrates the distance between houses for a "sparse or remote households" buffer). This process allowed for the estimation of distance between households in each *woreda*.

In order to check the accuracy of the population density that was calculated in this study, the population was crossed-referenced against the Census data from Ethiopia (CSA & World Bank, 2013). Briefly, census data were collected, and these were compared to the density derived in this study by converting individuals per house to population per region. Our data were approximately 14 percent above and below the census population data; therefore, we conclude that our estimates are reasonable. The population for this study was calculated using the census data for the number of people who live in each house. The most recent census data for Ethiopia indicates that there are approximately 5.1 people per household (Bigsten, et. al., 2003). Finally, an index was created and assigned to each circle based on circumference size (Table 3).

Developing costing model

Quantifying the approximate distance between households allowed us to estimate costs. Clusters of homes that were further apart are harder to reach with the same water source while maintaining the basic-level service standard (water source less than 30 minutes from the house). We assumed that all land is viable for construction of a water source, therefore ignoring current existing infrastructure which can be calculated out of the model if needed for future studies. Knowing the distance between clusters is crucial; if houses are further spread apart, the cost to serve water to those homes could be expensive depending on the type of water point.

To estimate the approximate number of water points needed for each population cluster, three sample buffers for each of the three levels were taken and smaller circles were drawn (with a 30-meter radius) inside it and around each house (illustrated in Image 5). The sample circle or buffer allowed us to calculate the average number of houses that were sharing one water point for each population density level. On a larger scale, this method was then used to estimate the average number of water points needed for a “small town”, a “village cluster”, and “sparse households”. JMP defines a “basic drinking water service” as less than 30 minutes to walk to a water point, collect water, and return home (JMP, 2017). For this study, this was converted from time to distance, in that a radius of 30 meters or less was chosen for this study based on the most recent JMP definition.

The final step was to identify the approximate number of houses that would be sharing water points for each of the distribution buffers. From the sample circles, the number of water points was then multiplied by the number of circles of that same size, resulting in the number of people served in each woreda (method shown in table 2 below). These data were then applied to a cost per person for each water point using Equation 1.

Equation 1:
Cost per head = standard cost of infrastructure / (# of households# of people per household)*

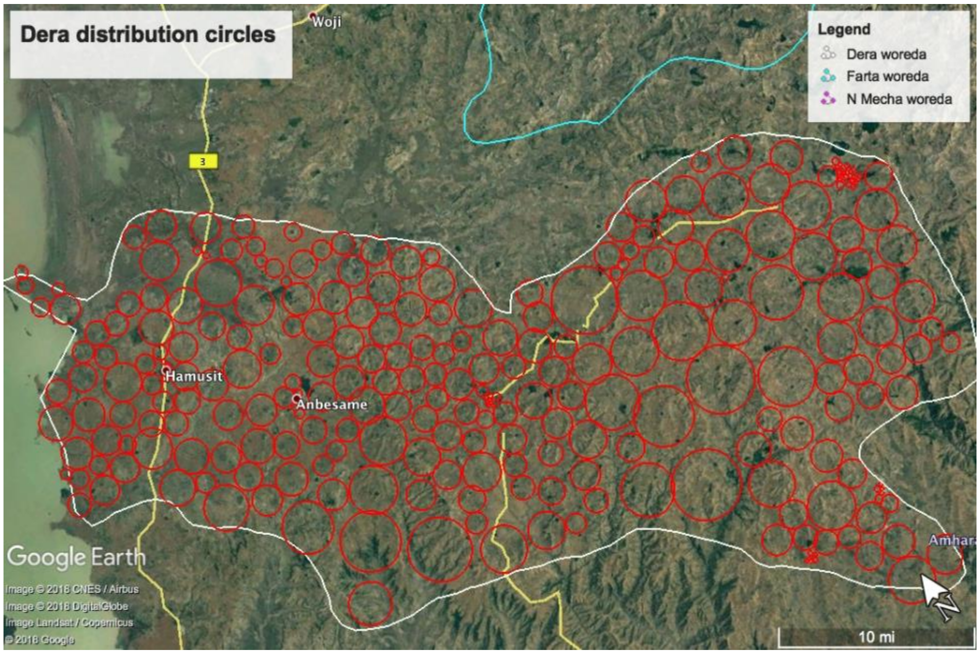


Image 2: Map of Dera woreda with circles surrounding 200 households; illustrating different population densities.

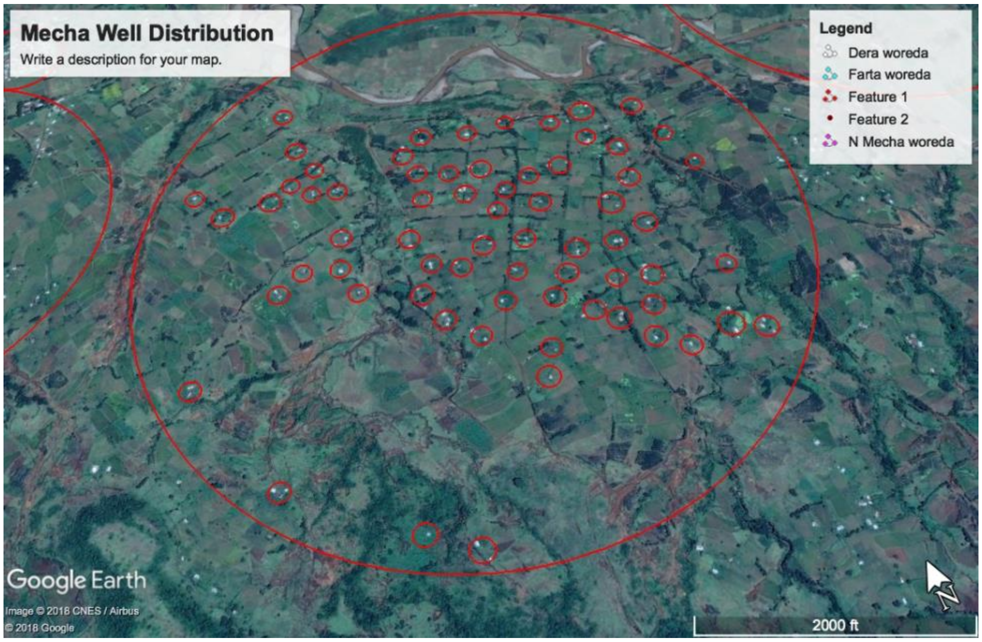


Image 3: A distribution circle in North Mecha woreda; illustrating the size of a "village cluster" and where the water-points would be placed.

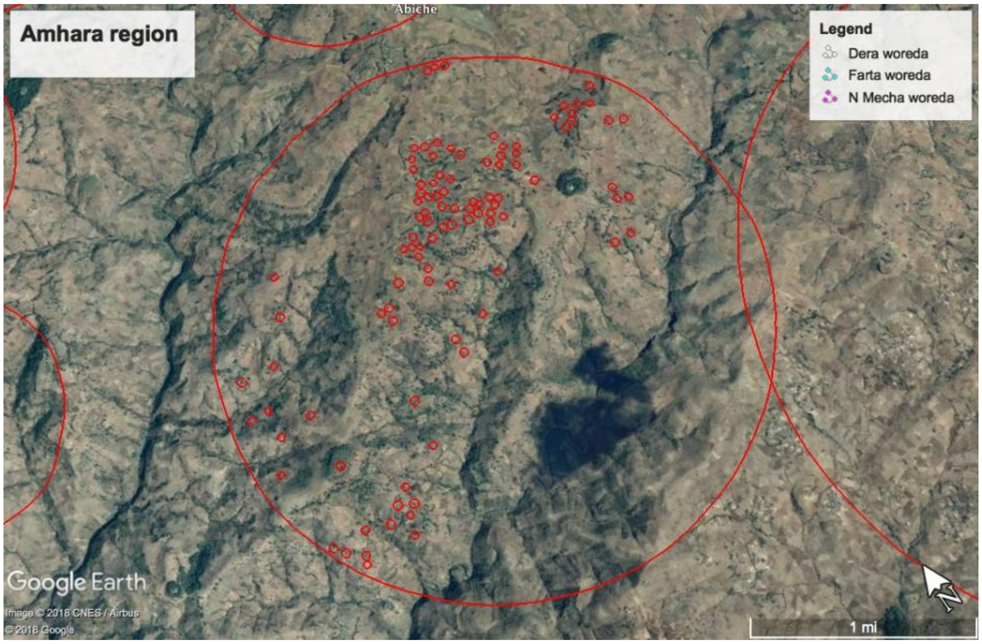


Image 4: Showing remote/sparse size population density in Farta woreda and where the water points would be placed.

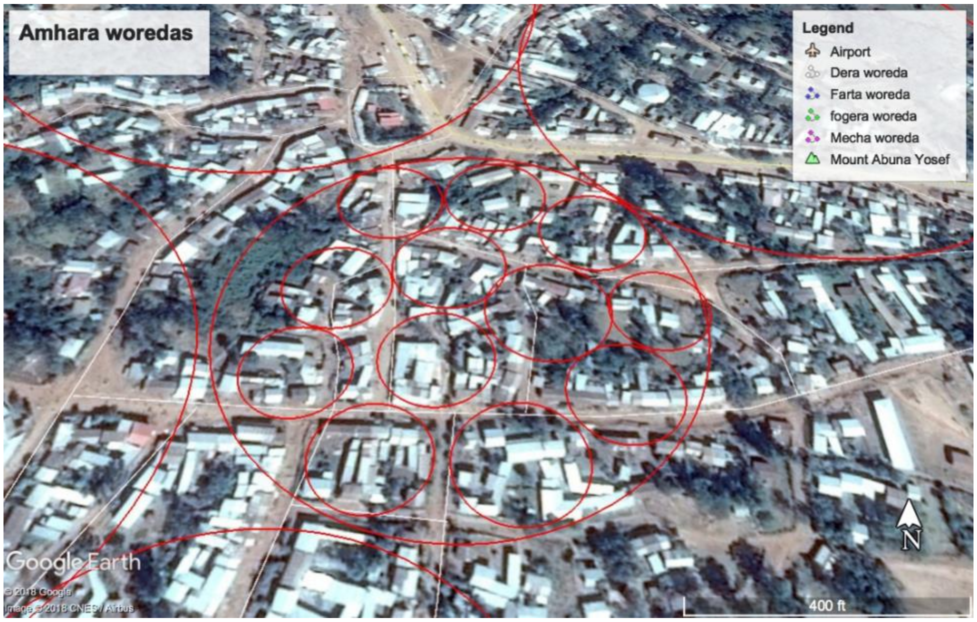
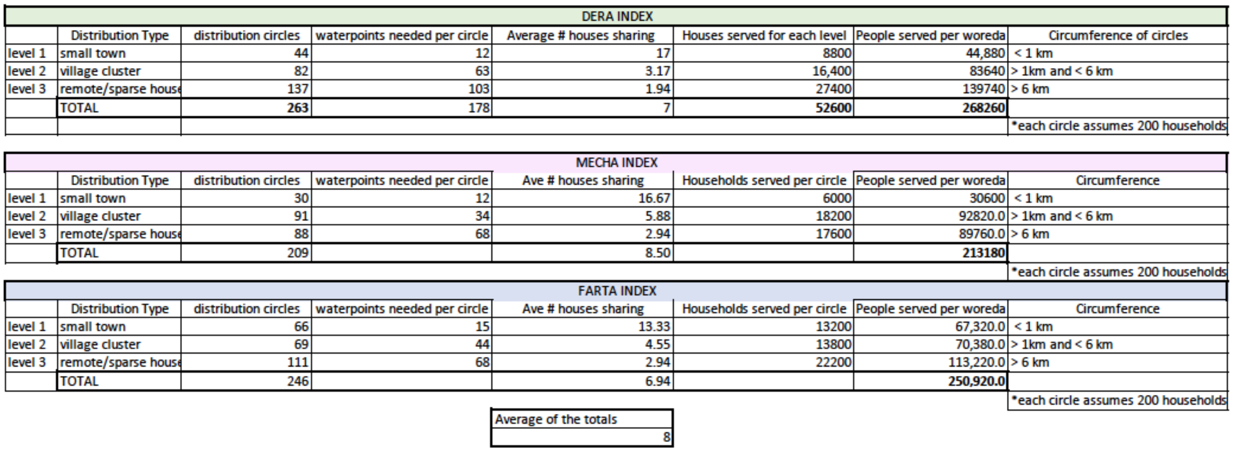


Image 5: Close-up of Mecha woreda water-point circles in an urban area referred to as "small town"; illustrating where one shared water system would be placed and shared among houses.

Population Distribution Table



DERA INDEX

	Distribution Type	distribution circles	waterpoints needed per circle	Average # houses sharing	Houses served for each level	People served per woreda	Circumference of circles
level 1	small town	44	12	17	8800	44,880	< 1 km
level 2	village cluster	82	63	3.17	16,400	83640	> 1km and < 6 km
level 3	remote/sparse hous	137	103	1.94	27400	139740	> 6 km
	TOTAL	**263**	178	7	**52600**	**268260**	
							*each circle assumes 200 households

MECHA INDEX

	Distribution Type	distribution circles	waterpoints needed per circle	Ave # houses sharing	Households served per circle	People served per woreda	Circumference
level 1	small town	30	12	16.67	6000	30600	< 1 km
level 2	village cluster	91	34	5.88	18200	92820.0	> 1km and < 6 km
level 3	remote/sparse hous	88	68	2.94	17600	89760.0	> 6 km
	TOTAL	209		8.50		**213180**	
							*each circle assumes 200 households

FARTA INDEX

	Distribution Type	distribution circles	waterpoints needed per circle	Ave # houses sharing	Households served per circle	People served per woreda	Circumference
level 1	small town	66	15	13.33	13200	67,320.0	< 1 km
level 2	village cluster	69	44	4.55	13800	70,380.0	> 1km and < 6 km
level 3	remote/sparse hous	111	68	2.94	22200	113,220.0	> 6 km
	TOTAL	246		6.94		**250,920.0**	
							*each circle assumes 200 households

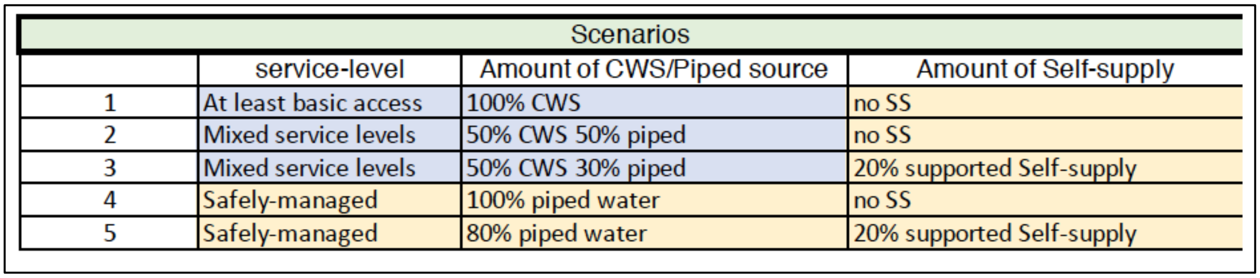
Average of the totals
8

***Table 2**: Indicating the indices for population distribution & how many each woreda had. Level 1 were < 1km; Level 2 were between > 1km and < 6km; and level 3 was > 6 km. This allowed to estimate population and the population density for each buffer.*

The method of cost model building used in this study allows for the comparison between three different systems: traditional community water supply (CWS), self-supply, and piped water to every household. Population density mapping, and estimation of the number of water points needed for each cluster of houses were two key steps in developing the model. Cost model building was conducted in Microsoft Excel (Redmond, WA).

The cost model compared the five scenarios by using self-supply at different supplementation levels (Table 3). The total cost for each scenario was then calculated for each *woreda* and used to predict total cost by 2030 based on current population growth projections.

There were five scenarios (Table 3) used to illustrate the SDG goals indicated by JMP, and the costs were applied to these scenarios using the population distribution data. The first scenario uses 100 percent CWS. The second uses 50 percent CWS and 50 percent piped supply. The third scenario uses 50 percent CWS, 30 percent piped, and 20 percent self-supply. The fourth uses 100 percent piped supply. Finally, the fifth scenario uses 80 percent piped and 20 percent self-supply. The scenarios are broken down into at least basic (meaning having a water point that is less than 30 minutes from the home) and safely-managed (having a water point on the premises, available when needed and free from contamination) (Table 3).



Scenarios			
	service-level	Amount of CWS/Piped source	Amount of Self-supply
1	At least basic access	100% CWS	no SS
2	Mixed service levels	50% CWS 50% piped	no SS
3	Mixed service levels	50% CWS 30% piped	20% supported Self-supply
4	Safely-managed	100% piped water	no SS
5	Safely-managed	80% piped water	20% supported Self-supply

Table 3: Scenarios with various levels of self-supply, created to compare costs and identify the most cost-effective scenario.

Chapter 4: Results

The results from this study were the population distribution and costing predictions of five water supply scenarios. The lowest cost option was the third scenario with 50% piped supply, 20% self-supply, and 30% CWS. There were five scenarios with varying costs ranging from 8 million USD to 12 billion USD depending on the *woreda* and the type of water point. We estimated that it would take approximately 8 million USD to supply North Mecha *woreda* with partial piped supply, CWS, and self-supply. This option was the most feasible scenario when compared to a fully piped supply and can have considerable cost savings by utilizing the CWS that is already in place. In this same *woreda*, it would cost around 12 billion dollars to build piped sources to each house. Our cost analysis method can be an effective technique to illustrate the costs associated with increasing piped supply to this area, and aid in making goals to meet these costs.

Population distribution

The pie charts for the population distribution data illustrate the following distribution information based on the different sized buffer index created in this study. The main difference between these charts was that Dera *woreda* is less densely populated than the other two *woredas,* meaning there was a higher percentage of people living in rural areas. In terms of water point costs, it would make logical sense that based on these charts Farta would be the less-expensive *woreda* to fulfill water coverage as it had a highest score for “small town”. However, this was not the case. The mid-range score of 44% for North Mecha made a greater difference in terms of cost and made the overall costs significantly lower. In this *woreda* the houses overall were closer together across the whole area and North Mecha has a higher population than the other two *woredas* due to of sharing of water points that caused the costs to drop considerably.

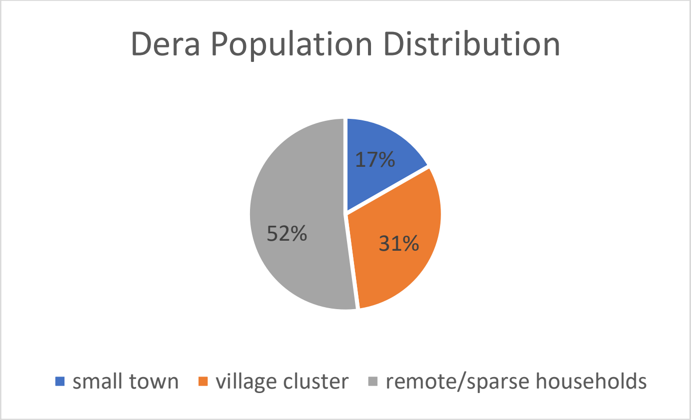


Chart 1

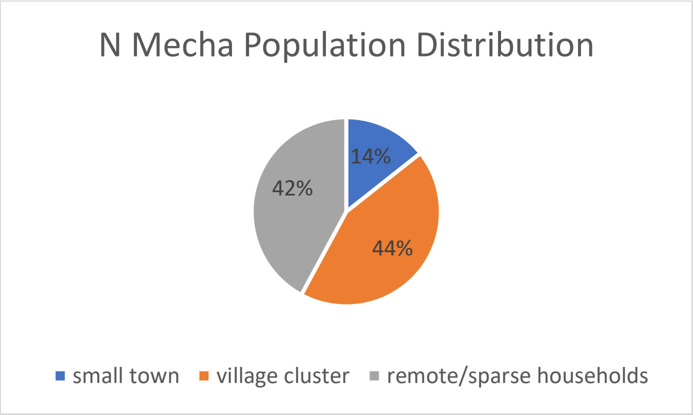


Chart 2

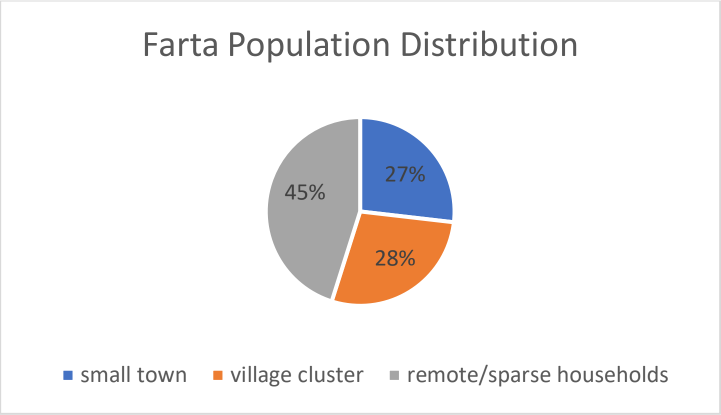


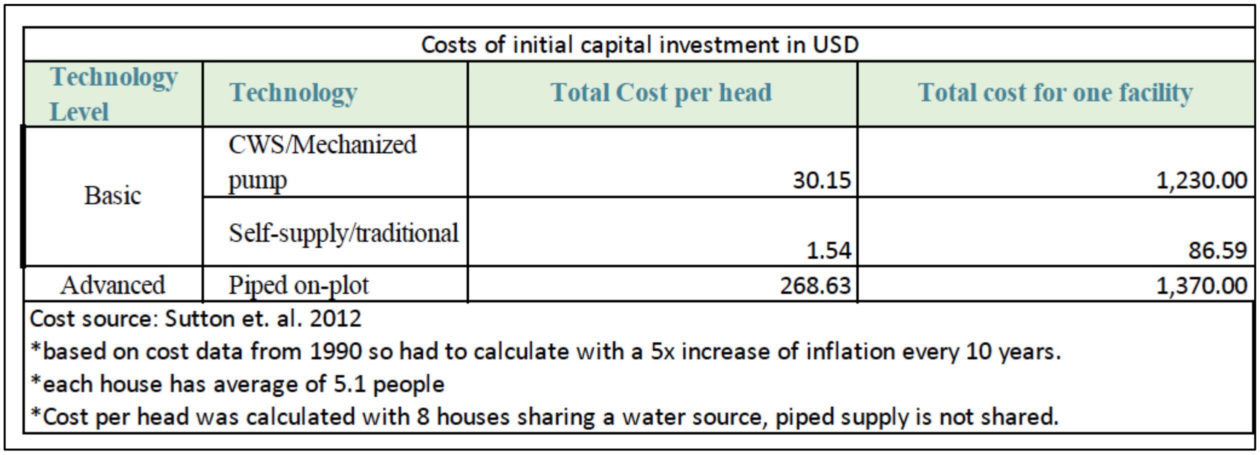
Chart 3

Costing predictions

Table 4 shows the initial capital investments based on the technology level. For instance, among the Basic level, the costs per head ranged from $1.54 (USD) to $30.15 and the total costs for one facility was $86.59 for self-supply and $1,230 for CWS. These were considerably less than the Advanced category, which had $268.63 cost per head and $1,370 for one structure.

Table 5 indicates the total calculated cost for each *woreda* needed by 2030. For example, with scenario 1 it would cost 24 million for Dera, 11 million for Mecha, and 14 million to supply Farta. The difference in costs are an indication of the distance between homes, based on the population distribution calculation. The scenarios that included piped supply were the highest costs, because of the lack of sharing between households with this system and the higher initial investment capital requirements. For instance, it would cost an estimated 27 billion dollars to install a piped system in every home in the Dera woreda by 2030.

The *woreda* North Mecha had the lowest estimated costs needed to reach every person with a water source. The lower costs were due to household being placed closer together than the other *woredas*. In terms of the lowest cost scenario to reach full water coverage, this was scenario 3, (50% piped, 30% CWS & 20% self-supply). The next cost-effective option was to use exclusively 100% CWS, these lower costs are due to the sharing between several households.

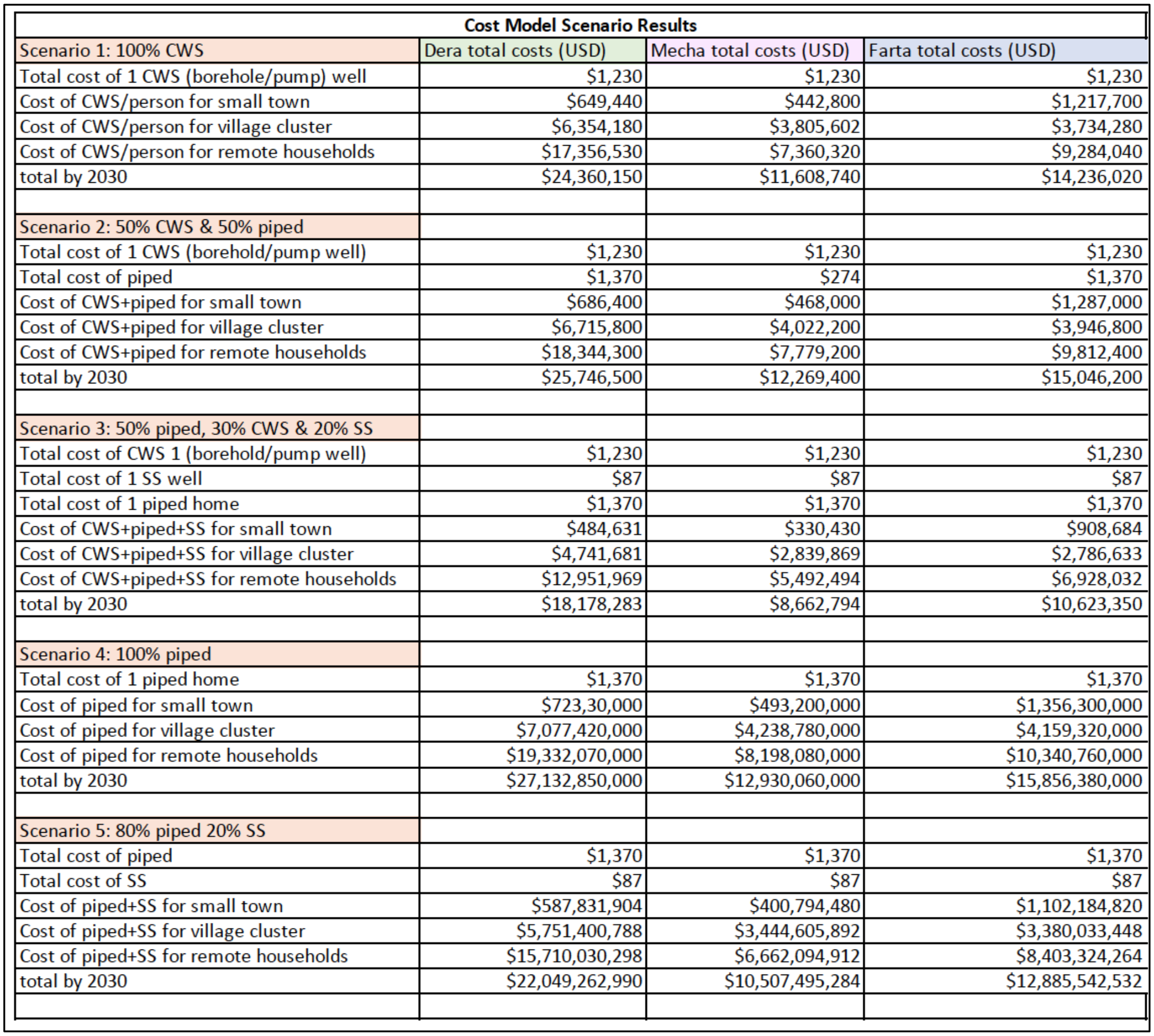


Costs of initial capital investment in USD

Technology Level	Technology	Total Cost per head	Total cost for one facility
Basic	CWS/Mechanized pump	30.15	1,230.00
	Self-supply/traditional	1.54	86.59
Advanced	Piped on-plot	268.63	1,370.00

Cost source: Sutton et. al. 2012
*based on cost data from 1990 so had to calculate with a 5x increase of inflation every 10 years.
*each house has average of 5.1 people
*Cost per head was calculated with 8 houses sharing a water source, piped supply is not shared.

Table 4: The cost for "One facility" is derived from Sutton et. al. 2012. The costs per head for CWS/mechanized pump versus a self-supply or traditional water service was calculated using "Equation 1" listed in the methods.



Cost Model Scenario Results

Scenario 1: 100% CWS	Dera total costs (USD)	Mecha total costs (USD)	Farta total costs (USD)
Total cost of 1 CWS (borehole/pump) well	$1,230	$1,230	$1,230
Cost of CWS/person for small town	$649,440	$442,800	$1,217,700
Cost of CWS/person for village cluster	$6,354,180	$3,805,602	$3,734,280
Cost of CWS/person for remote households	$17,356,530	$7,360,320	$9,284,040
total by 2030	$24,360,150	$11,608,740	$14,236,020
Scenario 2: 50% CWS & 50% piped			
Total cost of 1 CWS (borehold/pump well)	$1,230	$1,230	$1,230
Total cost of piped	$1,370	$274	$1,370
Cost of CWS+piped for small town	$686,400	$468,000	$1,287,000
Cost of CWS+piped for village cluster	$6,715,800	$4,022,200	$3,946,800
Cost of CWS+piped for remote households	$18,344,300	$7,779,200	$9,812,400
total by 2030	$25,746,500	$12,269,400	$15,046,200
Scenario 3: 50% piped, 30% CWS & 20% SS			
Total cost of CWS 1 (borehold/pump well)	$1,230	$1,230	$1,230
Total cost of 1 SS well	$87	$87	$87
Total cost of 1 piped home	$1,370	$1,370	$1,370
Cost of CWS+piped+SS for small town	$484,631	$330,430	$908,684
Cost of CWS+piped+SS for village cluster	$4,741,681	$2,839,869	$2,786,633
Cost of CWS+piped+SS for remote households	$12,951,969	$5,492,494	$6,928,032
total by 2030	$18,178,283	$8,662,794	$10,623,350
Scenario 4: 100% piped			
Total cost of 1 piped home	$1,370	$1,370	$1,370
Cost of piped for small town	$723,30,000	$493,200,000	$1,356,300,000
Cost of piped for village cluster	$7,077,420,000	$4,238,780,000	$4,159,320,000
Cost of piped for remote households	$19,332,070,000	$8,198,080,000	$10,340,760,000
total by 2030	$27,132,850,000	$12,930,060,000	$15,856,380,000
Scenario 5: 80% piped 20% SS			
Total cost of piped	$1,370	$1,370	$1,370
Total cost of SS	$87	$87	$87
Cost of piped+SS for small town	$587,831,904	$400,794,480	$1,102,184,820
Cost of piped+SS for village cluster	$5,751,400,788	$3,444,605,892	$3,380,033,448
Cost of piped+SS for remote households	$15,710,030,298	$6,662,094,912	$8,403,324,264
total by 2030	$22,049,262,990	$10,507,495,284	$12,885,542,532

Table5: Results of cost analysis: Costs would be spread over the years from 2019 until 2030 and do not account for existing infrastructure.

Chapter 5: Discussion

The goal of this study was to identify the most cost-effective scenario for self-supply in rural Ethiopian regions that would help achieve the SDGs by 2030. To best calculate the water supply costs, we determined the population distribution for Farta, Dera, and Mecha *woredas* in rural Ethiopia. We developed several scenarios of self-supply delivery to be used with existing water points to estimate costs. The main findings from this study were estimating the population distributions for the rural *woredas* and the costs associated with a range of self-supply delivery options.

Population Distribution

The findings from this study provide information on how self-supply can achieve the SDGs through sharing of water points. In Ethiopia, approximately 61 million people lack access to basic water, and in rural areas some Ethiopians are walking more than 3 hours from their homes to collect unsafe water from open sources, such as streams and hand dug wells (Water.org, 2017). Self-supply offers the possibility for services that are financially in-reach for most families in this area. The results from this study show that approximately 8 households can share a water point. Through self-supply, several households can invest in a shared water point making this a very cost-efficient water delivery method.

Another finding from this study was that North Mecha is the most densely populated *woreda* out of the three considered in this project. This means that North Mecha had the highest number of homes that shared a water source out of the three. This information could be used to further study appropriate methods to improve water service delivery for this region.

Model Improvement

We found that the most cost-effective option was the third scenario: using 50% piped supply, 20% self-supply, and 30% CWS. Our results suggest that a low-level of self-supply can be used to supplement already existing water service delivery options. The ability to avoid building all new structures is what makes this option the most feasible and sustainable.

There is need for further development on the model used in this study. Potentially this model could be used in the future as a planning tool for communities to understand funding requirements necessary to reach their country's safe water goals. Key improvements to the model would include: making the direct costs for self-supply more accurate, including inflation into the model, and adding more detailed cost breakdown of the different water facility types.

Assumptions & Limitations

There were several assumptions that had to be made during the methods process to derive the cost calculations. The first was that according to a survey done by CSA and The World Bank, the average household size in rural Ethiopia is 5.1, so this was the number used to estimate the number of people that lived in each house. This information allowed for an estimation of not just households per buffer (circle), but the approximate number of people that lived in each region. Based on this calculation it was assumed there were 1,000 people per buffer.

A second crucial assumption is related to cost. The costs per person for water supply calculated in the study by Sutton (2012) did not include indirect or direct support (costs associated with policy, planning, and stakeholder assistance), and this same assumption was made with these data in our study. Sutton only included the initial capital expenditure for building costs and the operational expenditure costs. Therefore, the projected costs for self-supply in this study are anticipated to be lower than they were be in reality as they have not accounted for these indirect and direct support costs.

Another assumption is that each water point was assumed to be shared among eight households for both CWS and self-supply, except a piped water method. Piped supply is the only water delivery method that typically goes directly to the house and is therefore not considered shared. However, in Ethiopia typically 21 houses share CWS and approximately 11 houses share a self-supply well (Sutton, 2012). Family self-supply wells are usually on the property of the owner or near the premise, but often shared among a group of houses (IRC, 2017). Nearly 58% of people who owned their own well shared with their neighbors, the majority shared with less than 5 houses, but 35% shared with less than 10 other houses (IRC, 2017). Sharing of water supplies and household wells is a considerable benefit to families as this provides increased access to safe water for more people and at the same time reduces the water supply costs per person. Future work should focus on sharing practices among families to further promote these cost saving. The sharing of household wells can increase water access and help reduce water access overhead costs.

Additionally, we assumed that there were no preexisting water systems in the woredas. While likely people living in these woredas already have some type of existing water source, there were limited data on these potential water sources and our estimates represent the more extreme situation. The accuracy of these cost estimates could be improved with future work to determine the number of functioning CWS wells in each woreda. Also, collecting data on the approximate number of self-supply wells that are currently in each woreda would also make the total cost decrease; instead of building brand new self-supply wells there would just need to be the added cost of improving the wells instead. This would also bring the total cost down.

However, due to the limitations of this study, these costs are more of an approximation and to be used as a comparison to the different delivery methods, and not necessarily to be used as a real-world budget plan. As mentioned above, further work could be done to build on this model to develop it into a cost planning tool for community use.

One limitation of this study was the selected location of water points across the *woredas*. In particular, it was assumed that all locations on the map were equally feasible for placing water points regardless of terrain or groundwater accessibility. In order for a well to be hand-dug or hand-drilled it would need to have access to groundwater that is less than 15 meters deep While outside the scope of this study, future work should use hydrological and topographical maps to refine which locations based on terrain would be ideal for self-supply.

Another limitation to this study was that little was known on the actual costs that families pay to build self-supply wells. We know from the literature that the government pays very little when self-supply wells are built, but the amount contributed in these specific regions is unknown. For this reason, many of the costs in this study were estimations from the literature and could benefit from future work in this area of specific costs in this region for self-supply development.

A final limitation was that our study did not address the issue of variable water quality across self-supply wells. The self-supply pilot done by IRC WASH and MWA found that many of the self-supply wells built during the pilot were not properly disinfected. Samples were taken from the wells that were built and 71.4% (5/7) had fecal contamination in the water. Work conducted by IRC suggests that group-led self-supply pilots may be able to address this issue in water quality. When built in a group-led setting, these wells were more likely to be properly installed and disinfected, which decreased the overall contamination rates (Terefe & Butterworth, 2016).

Future Implications

Further work and research are needed on cost predictions before 2030, both on the local government level and the private sector. However, this work illustrates the possibility that some of these development goals are attainable with self-supply supplementation. This study provides evidence of the need to consider different scenarios for service provision that account for the reality of limited resources. Future work can identify how much sharing is beneficial for families from both financial and health standpoints. In addition, future work on self-supply should include: physical evaluation of terrain, investigation on group-led self-supply, improvements to water quality, and a pilot to investigate a further cost evaluation. In regard to topography and hydrological mapping, future work is recommended to collect data that could be used to develop a cost index on building boreholes based on hydrological data. This work is the first step of many to bring forward more information in this area of water supply sourcing, and provides suggestions for improvements to low-income, rural areas with better water sources.

Chapter 6: Conclusion

Self-supply will play a crucial role in meeting SDG targets and provide a way to reach more people in rural Ethiopia (Holtslag & McGill, 2015, Mekonta, et. al., 2015). The models built in this study show that supplementing with self-supply can bring more people water and make water coverage for all more affordable. The approach used to accelerate self-supply needs to be adjusted, and more planning and promotion should be carried out in order to improve its effectiveness and safety. Based on our analyses, the lowest cost option is the third scenario; using 50% piped supply, 20% self-supply, and 30% CWS.

One future solution is to put more effort towards group-led self-supply. A case-study done by IRC showed that a group-led approach method was the most effective way to deliver safer water to families even with a shared service. Using group-led self-supply could possibly address the issue of contamination that previous self-supply pilots were not able to address. Group-led self-supply pilots could ensure the proper sanitation needed and make this option more sustainable long-term. The downside is this method turned out to be even more expensive than the traditional community water system (CWS) when looking at cost per well, due to the labor costs and the planning needed to execute such a large project (Terefe & Butterworth, 2016).

In terms of this costing study, if further research is done on the approximate number of functioning CWS wells that are in each *woreda*, the costs found in this study could be adjusted and therefore more useful for a practical budget. Further research and planning on self-supply should be done in order to help discover more cost-efficient ways to implement group-led approaches in the future.

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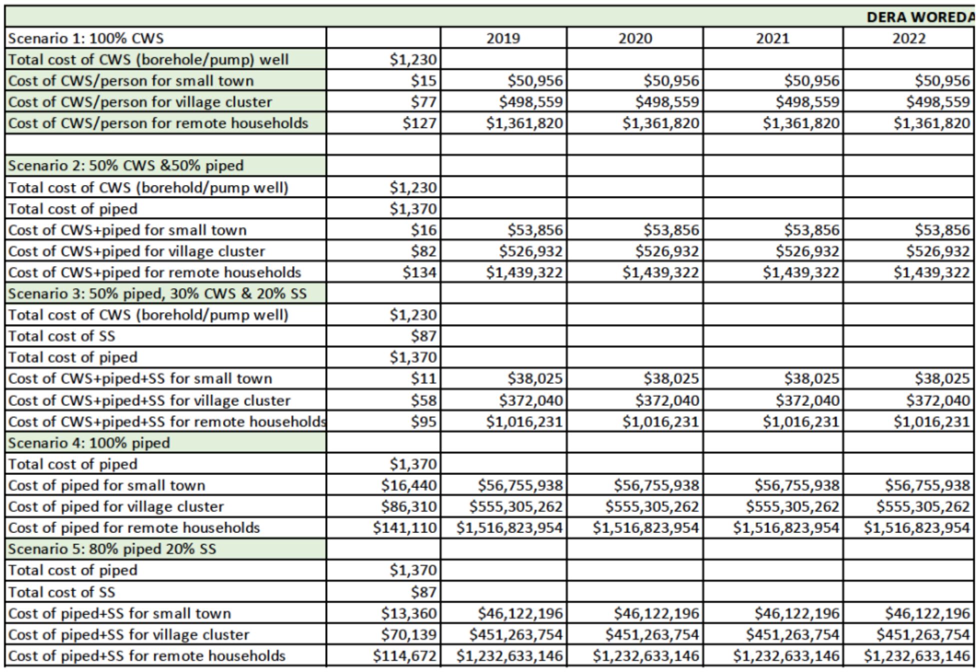
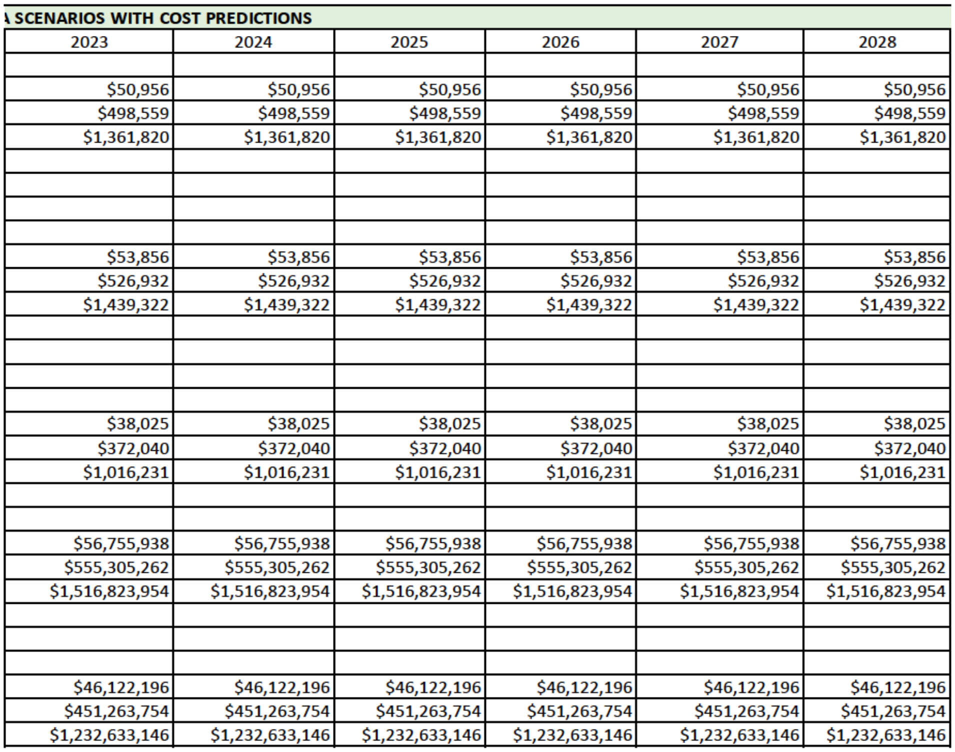
Finally, I would like to thank my mentor, Dr. James Hughes, who provided me with wonderful support and guidance through my entire time at Rollins School of Public Health.

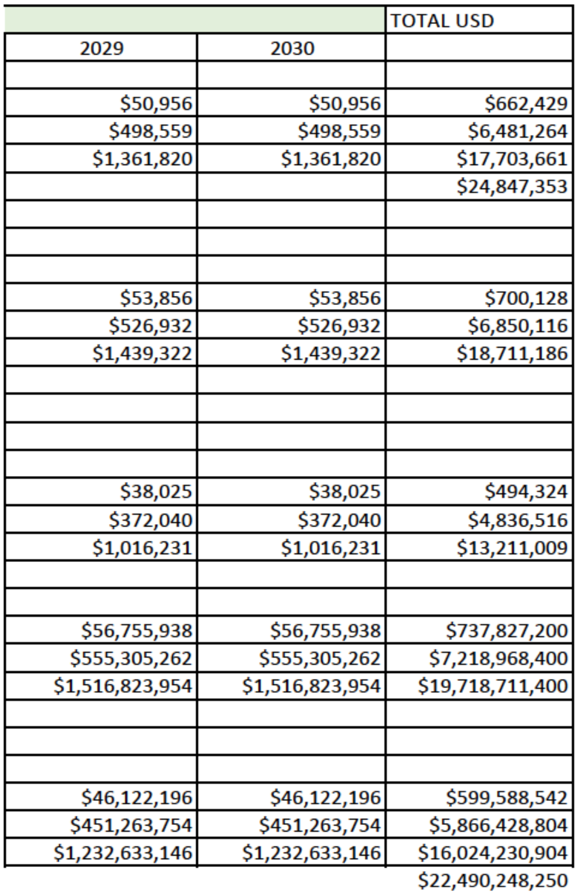
Appendix – Full Costing Model



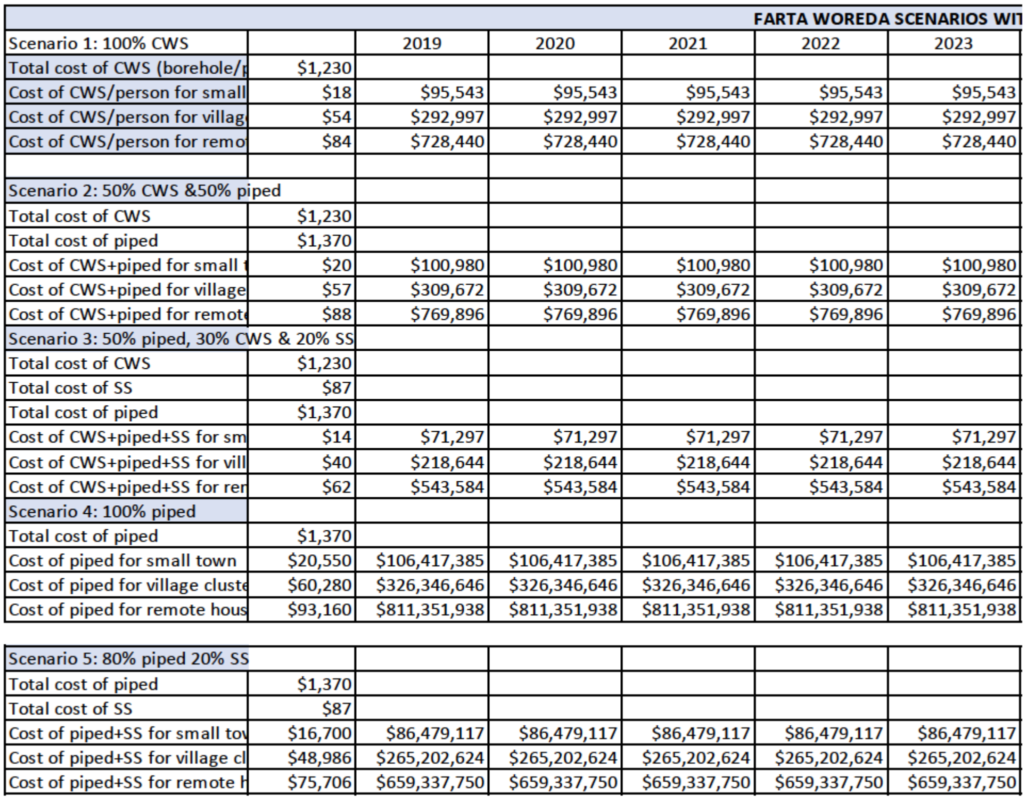


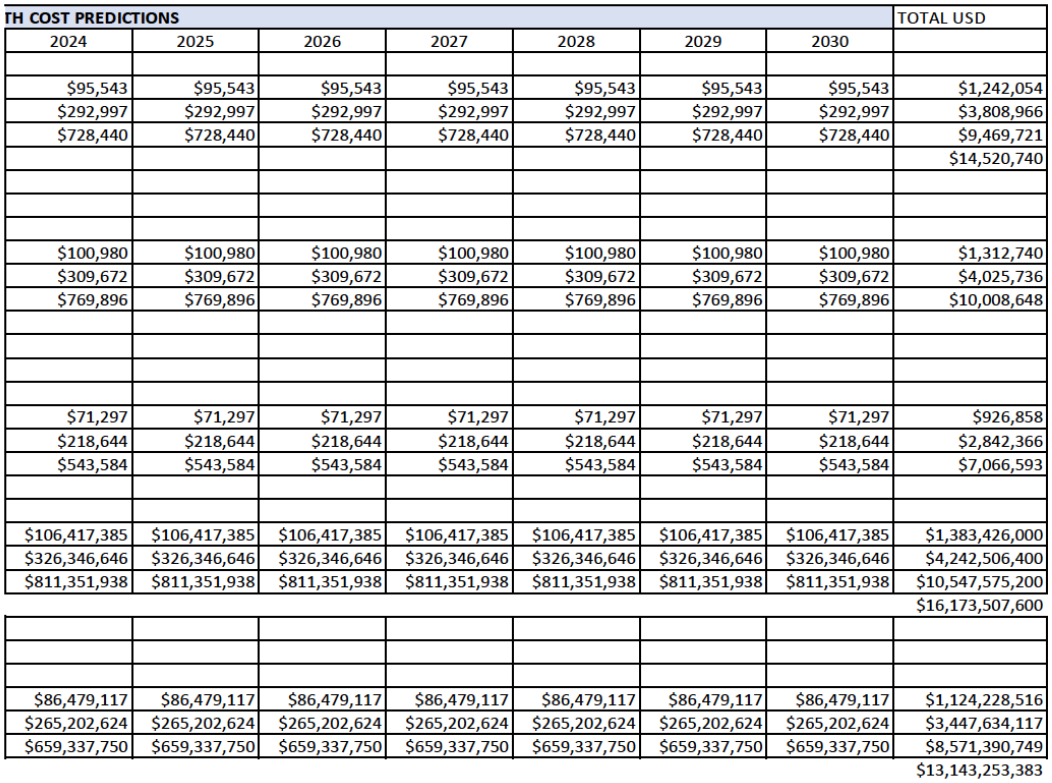
DERA WOREDA SCENARIOS WITH COST PREDICTIONS

Scenario 1: 100% CWS		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Total cost of CWS (borehole/pump) well	$1,230										
Cost of CWS/person for small town	$15	$50,956	$50,956	$50,956	$50,956	$50,956	$50,956	$50,956	$50,956	$50,956	$50,956
Cost of CWS/person for village cluster	$77	$498,559	$498,559	$498,559	$498,559	$498,559	$498,559	$498,559	$498,559	$498,559	$498,559
Cost of CWS/person for remote households	$127	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820	$1,361,820
Scenario 2: 50% CWS &50% piped											
Total cost of CWS (borehold/pump well)	$1,230										
Total cost of piped	$1,370										
Cost of CWS+piped for small town	$16	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856
Cost of CWS+piped for village cluster	$82	$526,932	$526,932	$526,932	$526,932	$526,932	$526,932	$526,932	$526,932	$526,932	$526,932
Cost of CWS+piped for remote households	$134	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322	$1,439,322
Scenario 3: 50% piped, 30% CWS & 20% SS											
Total cost of CWS (borehold/pump well)	$1,230										
Total cost of SS	$87										
Total cost of piped	$1,370										
Cost of CWS+piped+SS for small town	$11	$38,025	$38,025	$38,025	$38,025	$38,025	$38,025	$38,025	$38,025	$38,025	$38,025
Cost of CWS+piped+SS for village cluster	$58	$372,040	$372,040	$372,040	$372,040	$372,040	$372,040	$372,040	$372,040	$372,040	$372,040
Cost of CWS+piped+SS for remote households	$95	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231	$1,016,231
Scenario 4: 100% piped											
Total cost of piped	$1,370										
Cost of piped for small town	$16,440	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938	$56,755,938
Cost of piped for village cluster	$86,310	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262	$555,305,262
Cost of piped for remote households	$141,110	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954	$1,516,823,954
Scenario 5: 80% piped 20% SS											
Total cost of piped	$1,370										
Total cost of SS	$87										
Cost of piped+SS for small town	$13,360	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196	$46,122,196
Cost of piped+SS for village cluster	$70,139	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754	$451,263,754
Cost of piped+SS for remote households	$114,672	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146	$1,232,633,146



		TOTAL USD
2029	2030	
$50,956	$50,956	$662,429
$498,559	$498,559	$6,481,264
$1,361,820	$1,361,820	$17,703,661
		$24,847,353
$53,856	$53,856	$700,128
$526,932	$526,932	$6,850,116
$1,439,322	$1,439,322	$18,711,186
$38,025	$38,025	$494,324
$372,040	$372,040	$4,836,516
$1,016,231	$1,016,231	$13,211,009
$56,755,938	$56,755,938	$737,827,200
$555,305,262	$555,305,262	$7,218,968,400
$1,516,823,954	$1,516,823,954	$19,718,711,400
$46,122,196	$46,122,196	$599,588,542
$451,263,754	$451,263,754	$5,866,428,804
$1,232,633,146	$1,232,633,146	$16,024,230,904
		$22,490,248,250





FARTA WOREDA SCENARIOS WITH COST PREDICTIONS														TOTAL USD
Scenario 1: 100% CWS		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Total cost of CWS (borehole/	$1,230													
Cost of CWS/person for small	$18	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$95,543	$1,242,054
Cost of CWS/person for villag	$54	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$292,997	$3,808,966
Cost of CWS/person for remo	$84	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$728,440	$9,469,721
														$14,520,740
Scenario 2: 50% CWS &50% piped														
Total cost of CWS	$1,230													
Total cost of piped	$1,370													
Cost of CWS+piped for small	$20	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$100,980	$1,312,740
Cost of CWS+piped for village	$57	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$309,672	$4,025,736
Cost of CWS+piped for remot	$88	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$769,896	$10,008,648
Scenario 3: 50% piped, 30% CWS & 20% SS														
Total cost of CWS	$1,230													
Total cost of SS	$87													
Total cost of piped	$1,370													
Cost of CWS+piped+SS for sm	$14	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$71,297	$926,858
Cost of CWS+piped+SS for vill	$40	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$218,644	$2,842,366
Cost of CWS+piped+SS for re	$62	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$543,584	$7,066,593
Scenario 4: 100% piped														
Total cost of piped	$1,370													
Cost of piped for small town	$20,550	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$106,417,385	$1,383,426,000
Cost of piped for village clust	$60,280	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$326,346,646	$4,242,506,400
Cost of piped for remote hous	$93,160	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$811,351,938	$10,547,575,200
														$16,173,507,600
Scenario 5: 80% piped 20% SS														
Total cost of piped	$1,370													
Total cost of SS	$87													
Cost of piped+SS for small to	$16,700	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$86,479,117	$1,124,228,516
Cost of piped+SS for village cl	$48,986	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$265,202,624	$3,447,634,117
Cost of piped+SS for remote	$75,706	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$659,337,750	$8,571,390,749
														$13,143,253,383

MECHA WOREDA SCENARIOS WITH COST PREDICTIONS														TOTAL USD
Scenario 1: 100% CWS		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Total cost of CWS (borehole/pump) well	$1,230													
Cost of CWS/person for small town	$15	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$34,743	$451,656
Cost of CWS/person for village cluster	$42	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$298,595	$3,881,732
Cost of CWS/person for remote household	$84	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$577,502	$7,507,526
														$11,840,915
Scenario 2: 50% CWS &50% piped														
Total cost of CWS (borehold/pump well)	$1,230													
Total cost of piped	$274													
Cost of CWS+piped for small town	$16	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$36,720	$477,360
Cost of CWS+piped for village cluster	$44	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$315,588	$4,102,644
Cost of CWS+piped for remote households	$88	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$610,368	$7,934,784
Scenario 3: 50% piped, 30% CWS & 20% SS														
Total cost of CWS (borehold/pump well)	$1,230													
Total cost of SS	$87													
Total cost of piped	$1,370													
Cost of CWS+piped+SS for small town	$11	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$25,926	$337,039
Cost of CWS+piped+SS for village cluster	$31	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$222,821	$2,896,667
Cost of CWS+piped+SS for remote househ	$62	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$430,950	$5,602,344
Scenario 4: 100% piped														
Total cost of piped	$1,370													
Cost of piped for small town	$16,440	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$38,697,231	$503,064,000
Cost of piped for village cluster	$46,580	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$332,581,200	$4,323,555,600
Cost of piped for remote households	$93,160	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$643,233,969	$8,362,041,600
Scenario 5: 80% piped 20% SS														
Total cost of piped	$1,370													
Total cost of SS	$87													
Cost of piped+SS for small town	$13,360	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$31,446,952	$408,810,370
Cost of piped+SS for village cluster	$37,853	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$270,269,078	$3,513,498,010
Cost of piped+SS for remote households	$75,706	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$522,718,216	$6,795,336,810
														$10,717,645,190

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