Ph.D. Dissertation in Engineering

Study on Future Water Services with an ICT Application in Ethiopia.

-An AHP and Discrete Choice Experiment Analysis-

ICT 기술을 적용한 에티오피아의 미래 수도 서비스에 대한 연구

-AHP 및 이산선택실험 분석-

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Abstract

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Understanding the preferences for fluoride safe water services and identifying the challenges of fluoride safe water service providers are useful for clean water service supply policy and planning. The purpose of this research is to reach an understanding of the Rift Valley's residents' preferences for fluoride safe future water services, their attributes, and potential willingness to pay using different valuation methods. The study also identifies the bounding constraints that water service providers have. Since previous studies conducted on this field is limited particularly when it comes to the role that ICT can play in prior information notification services and online-based fluoride level monitoring using conjoint experiment data, contingent valuation and analytical hierarchy process methods simultaneously to address the overall specific research question, my research provides insights for both academics and policymakers in fluoride safe water supply in the fluoride concentrated regions. This study used stated preference methods, both the indirect and direct surveys, to elicit preferences of the Rift Valley's residents about fluoride safe water supply connections. Based on the random utility theory the study uses mixed and latent class logit models for samples representing Adama, Lume, Bora, Zuway Dugda and Adami Tulu and Jido *kombolcha woredas* in the central Rift Valley region in Ethiopia. Using the compensating surplus Hicksian theory, it also estimates the censored Tobit model to estimate the mean WTP, so as to able to conduct a cost benefit analysis for fluoride-safe water supply projects in the study area. An analysis of the gathered data is done based on different methodologies.

In the first part the study used analytics hierarchy process methods using experts pairwise judgement rated data and accordingly financial factors is found to be the most important constraints followed by technical and institutional factors respectively. Furthermore, to ensure supply of fluoride safe water services, the water providers' experts preferred online-based fluoride monitoring, regardless of its high initial cost of investment, to off line lab-based fluoride monitoring.

In the second part in order to conduct consumer preferences for future water service attributes, the mixed logit model is used to capture heterogeneity of the preferences and to identify the share of population who prefer a given attributes from some threshold levels on wards or downwards since we can estimate the distribution of each parameter estimates, and the latent class logit is used to implicitly derive heterogeneous groups of household behavior. The result from this both model are consistent with related to each attributes and direction of influences. The tested attributes are quality of water service with regard to fluoride level of concentration (taking WHO standard as a reference guideline of 1.5mg/l), frequency, and duration of water service interruption, number of prior days service notification received, means of information notifications and additional prices aimed to cover cost of service improvement. The analysis from both estimated model shows that frequency of service interruptions, duration of interruption and internet-based service notification have negative marginal utility upon the consumer preference for future water service improvement. On the other hand the quality of water service above or equal to WHO standard, number of days of prior notification and mobile-based service notification have positive marginal utility towards future water service improvement. But the relative importance of each attributes varies from model to model. For instance, the additional fee for water service clearly exerts the greatest impact on preference formation followed by quality of water above WHO standard in the mixed logit model whereas quality above WHO is the most important followed by quality equal to WHO standards in the case of latent class logit model.

In the third part, in order to know the affordability of the preferred attributes, the study conducted consumers' willingness to pay for fluoride safe water service connection by estimating mean WTP via latent class logit model and contingent valuation methods using Tobit model. Adopting the adjacent woreda's cost of water supply projects as a proxy for cost of fluoride safe water supply in the study area, the study further conducted the cost benefit

analysis, by calculating the present values of the mean WTP for the life span of the water supply projects. Accordingly the result shows that the mean WTP per households for fluoride safe water supply per month ranges from 3percent of share of their income to 16 percent of share of their income and possible to overcome financial burden with regard to fluoride safe water supply given other things are constant. Hence, based on these findings and results the overall policy implications are; (1) the government need to mobilize fund from households and from different donor agents including from the World Bank since the main constraint that bounds water provider to provide fluoride safe water service is financial constraint. At same time the households are also willing to pay up to plus 75 percent of surcharge in addition to the current bill if fluoride safe water service is provided. (2) Another solution is that the water providers need to raise water bill revenue via controlling illegal connection, leakages and increasing tariff rate. Out of total produced water about 37 percent is lost due to different reasons and hence water provider need to save this lost revenue via adopting strict regulation, incentives for informers and adopting leakage detection technologies. (3) The government has to reform its water supply institutions or need to privatize water supply sector so that efficiency and fluoride safe water supply coverage is increased. The private sectors can easily be attracted because the fluoride safe water supply is economically feasible according to the cost benefit analysis of the third study. For instances, England and Chile has fully privatized water sector and other are partially privatized. (4) The government needs to adopt an online monitoring system in order to ensure quality of water supply; brings transparency and creates interoperability within and with other institutions. (5) The government has to install community-based fluoride safe public tap in order to fill the gap of lack of clean water supply coverage. This is viable since the households have enough willingness to pay for the nearest public taps fluoride safe water supply connection. (6) Another solution is that the government should allow public private partnership modes of water service supply. This is a successfully practiced experience in many countries including USA, South Africa, Malaysia, France and Kenya regardless of their modality of partnership. So depending on the country situation and convenience the Ethiopian government should also need to adopt public private partnership modes of water service supply in order to achieve the universal safe water supply coverage and the GTP –II of the water sector target. (7) Another alternative policy implication is that the government needs to facilitate microcredit for the poor households for water supply connection. Since the households need installment-based payment than lump sum fee for initial connection cost, it would be very productive if they are provided microcredit targeted for water supply and sanitation connection, particularly for the poor households. For instance countries such as India, Bangladesh, Kenya, Uganda, and Vietnam has been benefiting from water credit initiates move. (8) Another recommendation is that the government has to consider source of the water supply for different population size. For scattered rural population better to provide drilled borehole in the center of the community and for densely populated area pipeline-based water supply distribution network seems more efficient. Safe source vs treating water source is also

need to be considered. (9) At last the water provider needs to adopt water service interruption notification system which automatically notifies a household if there is interruption occurrence. City of Asheville is a good example for this, and for the study area case households would like to receive notification via mobile-based service notification (Voice call, SMS and MMS).

Keywords: Fluoride safe water service, discrete choice method, willingness-to-pay, analytics hierarchy process, ICT application, rift valley region of Ethiopia

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Chapter 1. Introduction

1.1. Overview

Water is very significant for all living things and access to clean water is a major aspect of human lives as it can help unlock education, create work opportunities and improve women and children's health all over the world (Hulton et al., 2012*)*. History shows that during different phases people followed different methods to produce clean drinking water, starting with the ancient Egyptian civilization when water was boiled using fire and heated under the sun and by dipping of heated irons in water. People during this phase of history also filtered water through gravel and sand to purify it for drinking purposes. In 18th century filtration become the favored water purification method among many communities and in 1804 Scotland introduced the first municipal water purifying plant in the world (Baker et al., 1981). Since then it has become normal and mankind has realized the importance of water in improved quality of health. For instance, it was realized that cholera deaths reduced significantly after the water treatment system was installed in London. After recognizing the importance of having a safe water supply the London metropolitan city passed the Water Act of 1852 to guarantee that all water supplied to the city was filtrated (Baker et al., 1981).

As water supplies became more polluted as a result of the industrial revolution in the 19th century more advanced water treatment systems were developed to overcome this issue to ensure that populations had access to safe drinking water. Since then onwards water purifying technologies have been widely diffused across the globe and today safe drinking water is so widely available that many people take it for granted. Later with the 4th industrial revolution, people in developed countries had an opportunity to use smart water management services including internet of things-based quality monitoring of drinking water.

However, despite these developments even today there are two worlds on a single planet, where in one world people are denied access to safe drinking water particularly in rural areas in developing country and in the other world people have access to safe water for drinking and sanitation purposes. According to World Health Organization data (2012), access to clean drinking water can reduce a million deaths caused by water related and water borne diseases every year, help increase school attendance and reduce child deaths as one-third of child deaths are caused by diarrhea and increase economic benefits by saving time which is otherwise wasted in getting clean drinking water. This is estimated to be US$ 32 billion per year by reducing healthcare costs if there is universal access to basic water and sanitation services (Hulton et al., 2012).

According to the report of World Water Development (WWDR, 2015)[1], as demand for water services increases across the globe, the availability of fresh

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[1]https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=1711&menu=35.

water in many regions is likely to decrease because of climate change and other factors. Further, an unbalanced supply and demand for clean water services can be attributed to either physical resource scarcity or economic scarcity.[3] It is estimated that water shortages will have a serious impact on more than 40 percent of the world's population which are forecast to increase by the end of 2030 under a business-as-usual scenario (2030 Water Resource Group, 2009).[4] By 2025, just seven years from today, around 1.8 billion people will be living in countries with absolute water scarcity, and two-third of the world's population could be living under water stressed situations (Bosman, 2017).

According to a World Health Organization report (2015), as shown on Figure 1.1, access to improved water services across the world is increasing and is likely to reach about 91 percent; in sub-Saharan Africa it is likely to 68 percent of the region showing least access to clean water service in this region. As far as Ethiopia is concerned the figure -- only about 57.5 percent of the total population will have access to safe drinking water -- is very low compared to sub-Saharan Africa.

[3] Physical scarcity refers to a circumstance where there is not enough water to meet existing demand. Economic scarcity occurs due to lack of proper investments in water resources' construction and management to meet the required water demand.

[4] https://www.2030wrg.org/.

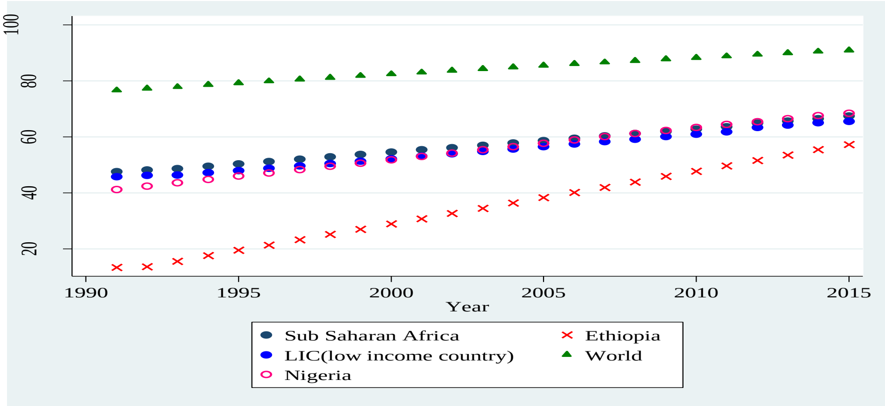

Figure 1. 1 Comparison of household access to safe water (WHO, 2015)

As we can see in Figure 1.1, although the percentage of safe drinking water access has increased over time in all regions, 9 percent of the world population, 32 percent of the sub-Saharan population and 42.5 percent of the Ethiopian population have no access to clean drinking water (WHO, 2015). Further, access to clean water is totally different from connection to water services. There are people in the safe water accessible radius who are not connected to water services due to economic, institutional capacity and other problems. Connections to clean water services do not guarantee the quality of connected water services.

The problem of drinking water is more severe among the rural population as compared to urban residents in Ethiopia as there are huge disparities between the two locations in terms of safe water supply coverage (Figure 1.2).

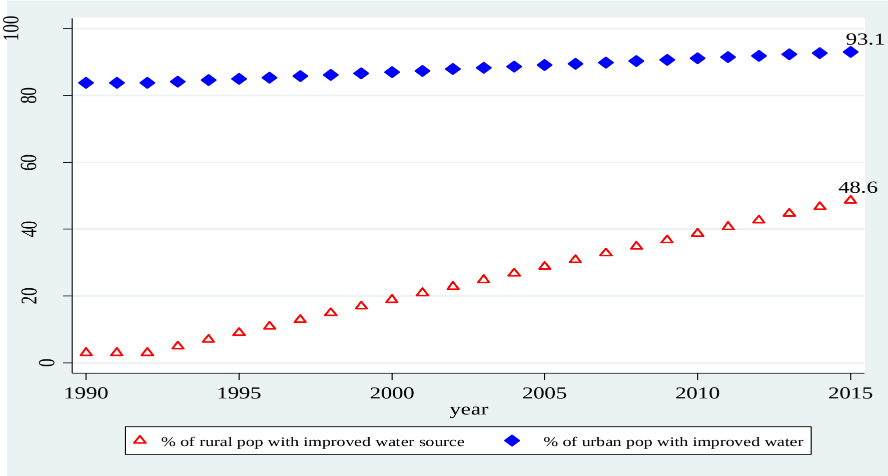

Figure 1. 2 Safe water supply in rural-urban households in Ethiopia (WHO, 2015)

Figure 1.2 shows that although differences in access to safe drinking water in urban and rural areas of Ethiopia is narrowing, a majority of the rural population still depends on unimproved water sources. The problem is more severe and intense in rural villagers in the country where people need to walk for more than half hour to fetch water whose source has not been improved. At an aggregate level a significant amount of time (hours) is spent just fetching water by trading-off other income generating economic activities that could be used for producing goods and services (CSA, 2016).

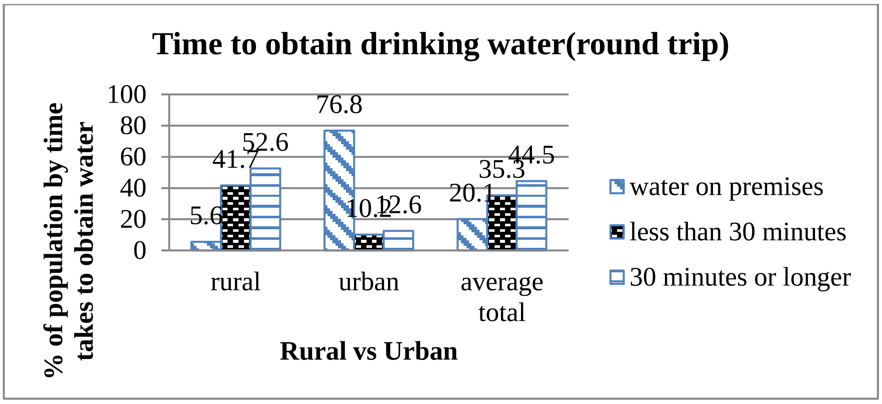

Figure 1. 3 Time to obtain drinking water (CSA, 2016)

As Figure 1.3 shows most of the population (about 44.5 percent) spent more than 30 minutes to fetch water, trading-off other income generating economic activities that has deteriorating impact on their livelihood in Ethiopia according to demographic health survey in 2016.

1.2. Research motivation and objective

Although ensuring clean drinking water is challenging across the globe because of excessive pollutants generated by the overutilization of natural resources, urbanization, industrialization and non-enforcement of laws (Geetha and Gouthami, 2017), disparities in access to clean drinking water between developed and developing countries is getting larger over time. This can perhaps be attributed to fast-developing technologies in developed countries and less adoption of these technologies by developing country. For instance, the quality of water supply is monitored online in advanced countries including South Korea, USA and other European countries, whereas in developing countries the quality of water services is monitored offline using traditional lab-based testing mechanisms which are not efficient and effective in monitoring the quality of drinking water.

Offline lab-based quality monitoring is used in urban areas in Ethiopia whereas most of the people residing in rural areas source waters from open springs, lakes, rivers and boreholes and rarely from public tabs whose quality is not tested and monitored. In addition to relying on unimproved source of drinking water, long distances for fetching water is another problem which is worsening the situation for rural residents. Even in relative terms, in urban areas where water services are better, the supply and quality of water is inadequate and unreliable. Therefore, considering clean pipeline water services as a new service in rural districts in developing countries, my study examines what kinds of demand phenomena are going to take place in the future for water services in relation to consumers and what supply constraints bind service providers.

Hence, the purpose of my study is identifying and analyzing the preference structure of Rift Valley households by conducting a comprehensive investigation of the tastes and taste variances of Rift Valley future water service consumers in terms of quality of water service in the context of fluoride level concentration using WHO standards as a reference line, frequency of service interruptions, length of service interruptions, length of days of prior service interruption notification, means of information communications and additional price to be paid for improving the services. Further, I also identify the main constraints that hinder service providers in supplying fluoride safe water services to the residents in the Rift Valley region of Ethiopia. All this will help me show the importance of the various components of future water services. Secondly, my study discusses household preferences for future water service attributes considering preference heterogeneity across individuals and groups. Thirdly, it estimates the willingness to pay using the latent class logit and contingent valuation methods for comparison purposes and conducting a cost benefit analysis of fluoride safe water supply projects in the study area. Fourthly, the study identifies and prioritizes the main challenges that hinder water providers in providing fluoride safe water services to the Rift Valley region. Fifthly, the study derives some policy implications through empirical estimation results and simulation of the effects of water service attribute levels on household preferences. Further, household preferences for attributes and experts' judgments for factors and criteria are also analyzed and identified for further policy implications.

A few relevant observations led the author to further the research and are seen as the motivation for doing this research. There are several studies on water service demand (Hensher et al., 2005; Kwak et al., 2013; Lee, 2014; Whittington et al., 1990) but most of them have been done using developed country perspectives. There are only a few studies like Bayrau (2005); Huber et al., (2013); Hundie et al., (2016); Lemma et al., (2012); and Tarfasa (2013) which have been conducted using the Ethiopian context. These studies explore households' WTP for improved water service connections in different regions of the country. However, my study believes that the consumers who have been suffering from an excessive fluoride concentration problem will have different behavior and perspectives about their preferences for future water services as compared to consumers who live in non-fluoride regions.

To the best of my knowledge, there are no prior studies that investigate consumer preferences for future water services in the Rift Valley region. Further, no studies have been conducted to identify the providers' main challenges in the supply of fluoride safe water for the residents. This makes my study important for the policy implications that it suggests.

This research addresses four research questions, providing room for the limitations that have been uncovered in previous literature:

- What are the preferences of the Rift Valley region's households with respect to the attributes of future water service connections?
- What is the households' WTP for fluoride safe water services connections via pipeline at home, and at the nearest public tab?
- Are there differences in WTP measures? This is explored using a conjoint analysis and contingent valuation methods.
- What are the main constraints that constrain service providers in supplying fluoride safe water services in the Rift Valley region?

Based on the answers to these questions, I discuss the policy implications of households' preferences regarding future water services connections and providers' technology preferences regarding the supply of future water services.

To provide deeper insights into the questions and to make the policy implications the first, second and third research questions are further divided into the following sub-questions. The first research question:

- What are the parameter values of the attributes given in the choice sets?

By analyzing respondents' choice patterns, the utility that every attribute provides to an average consumer is derived. With this knowledge it is possible, for example, to rank attribute levels and attributes according to their relative importance.

- What impact does each component have on service connection decisions of an average household?

By including stated preference data in the choice estimations, my study reveals the influence of every attribute on preference formation by average household consumers. This enables me to draw conclusions on the impact of every change in the choice set on the probability of a service connection being successful.

To provide detailed insights into the second research question, the following questions are explored in the study:

- What is a household's relative willingness to pay for the various components of water services?

By calculating the implicit values of the attributes it is possible to estimate the relative WTP of one attribute compared to another.

- What is a household WTP for fluoride safe water connected at home and at the nearest public tab?

I estimate the average WTP for fluoride safe water by using direct CVM survey data and then compare it with the WTP doing a conjoint analysis. Based on this information, my study does a broader cost benefit analysis of fluoride safe water supply projects.

To provide detailed insights into the fourth research question, the following questions are explored in the study:

- What are the main challenges that providers face in supplying fluoride safe water to the Rift Valley region?

The study identifies the main challenges by considering a pairwise comparison of factors filled out by water supply experts in the sampled *woreda* by using the analytics hierarchy process methods. This knowledge guides the researcher to compare and contrast household preferences with providers' challenges in future water services to make comprehensive and relevant policy suggestions.

- What are a provider's preferences in fluoride level monitoring technologies?

Within the main constraint factors, my study further decomposes the technical factors and addresses the providers' preferences for fluoride level monitoring technologies. This is done by comparing online-based and existing lab offline mechanisms. Based on this the study gives appropriate policy implications for future water supply and future household demand.

The findings of my study are expected to be generalized for the underserved households in the Rift Valley region of Ethiopia, where the water supplied has high fluoride concentration. The region also has low water pipeline connection coverage; residents have to spend long hours to fetch water. They also have to incur additional costs for fetching water from another city for their healthcare needs which has an adverse impact on their quality of life. My study uses a discrete choice analysis to examine the WTP values to help improve the quality of water services.

This rest of this dissertation is organized as follows. Chapter 2 discusses the background and discusses the problem statement explaining how important fluoride safe water supply is for Rift Valley's residents to help reduce socioeconomic and health related expenditure and address other psychological problems caused by excess fluoride concentration in the water. Further, this chapter also explains the need for a demand-based analysis for future water services and technology-based supply of future water services in the study area. It also includes the current water services scenario. Chapter 3 gives a literature review which discusses previous studies on subjects related to demand for water services, stated preferences, conjoint analysis and contingent valuation methods in eliciting consumer preferences. In addition, it also covers literature on the role of smart online applications in controlling water quality and other smart water quality sensor technologies. Chapter 4 deals with the theoretical framework of the methodology used in the study on consumer preferences and willingness to pay for fluoride safe water services. It uses the analytics hierarchy process methods for identifying main constraints in water supply services. Starting with the random utility theory, it defines different household behavioral models for the quality of water services and discusses the WTP models and AHP models. Chapter 5 shows gives details of the research process followed in addition to the estimation results. This chapter also includes simulation results based on the latent class logit model to draw efficient policy implications by understanding consumers' grouping behavior with regard to future fluoride safe water services and the attributes that they would prefer. Chapter 6 gives the conclusions and policy implications and makes suggestions for future research.

Chapter 2. Research background and problem statement

2.1. Water supply and socioeconomic development in Ethiopia

2.1.1. Problem statement

This thesis considers two different scenarios concerning water supply where both situations exist in different places within a country or between two countries. The first is a remote region scenario where people are denied access to clean drinking water, where mothers and new born babies are vulnerable to water borne disease because of lack of clean water, where people are suffering because of using excess fluoride concentration water from open lakes, rivers, groundwater, private and common boreholes. As a result they suffer from dental fluorosis, skeletal and bone crippling and brain and kidney malfunctions. They also have to deal with excess healthcare expenditure caused by lack of clean water and lack of proper sanitation. They are also vulnerable to social exclusion and psychological problems which lead to lower living standards and push them towards the poverty trap.

In the other scenario everyone has access to safe and sufficient drinking water at home, residents spend no time spent in fetching water which is instead allocated to productive activities, no mothers or babies are vulnerable to water borne disease and nobody worries about the presence of excess fluoride in the water, there is no healthcare expenditure because of by lack of clean water and there are no problems of sanitation. Instead the people enjoy their baths with cold or hot water depending on the weather, people do not face any psychological problems caused by lack of water and no one is being pushed closer to the poverty trap because of lack of clean water. Instead, they use the steady water supply as a means of escaping the poverty trap by saving money that would have been spent had there been no clean water supply. Such a world of clean water saves time, money and health and improves their livelihood. Unfortunately, it is the first scenario that is playing out in the Rift Valley region of Ethiopia.

Access to a clean and adequate drinking water is very essential for the survival and well-being of human beings. Particularly in developing countries access to safe water leads to significant improvements in health via reducing water borne illnesses such as diarrhea and fluorosis. As a result it is also possible to reduce morbidity, mortality rates and the number of working days lost and hence increase production and productivity eventually raising the gross domestic product. Further, by improving the quality of drinking water it is possible to reduce illnesses which will lead to a reduction in the expenditure incurred on imported expensive medicines thereby easing the trade balance deficit problem facing the least developing countries (Bayrou, 2002). According to the World Health Organization (2015), access to clean water is a pre-requisite for the realization of various human rights including rights of survival, education and standard of living.[5]

In this context the United Nations' envisioned a sustainable development goal (Goal 6) to realize and ensure access to clean drinking water for all by 2030 (UNSDG, 2015).[6] However, such a goal in country such as Ethiopia, particularly in the Rift Valley region, will not easy to achieve because of the region's geological character of the region and an abundant supply of fluoride in the underground water. Lack of clean water sources and lack of commitment to adopting different technologies which enable water purifying both by suppliers and consumers have triggered severe challenges among the residents in the Rift Valley region of Ethiopia.

2.2. Water supply situation in the Rift Valley region

Residents of the Rift Valley region residents face all the problems mentioned in the previous section thanks to its unique geographical nature that makes it vulnerable to excess fluoride concentration in underground water.

Fluorine is one of the most abundant (0.06 percent) elements in the earth's crust and fluorides are negatively charged ions of fluorine which are the most reactive and most electronegative of all elements (Yeung, 2007). Fluorides are available in nature and can also be increased by manmade activities such as large industrial application of the elements in aluminum, glass and electronic

[5] In July 2010, the UN recognized the right of everyone to have access to safe and sufficient water for domestic and personal uses (50-100 liters per day per person), which should be affordable and up to 3 percent of household income and physically accessible (water source should within a km from home and collection time should be less than 30 minutes). See http://www.un.org/en/sections/issues-depth/water/.

[6] https://www.un.org/development/desa/disabilities/envision2030-goal6.html

industries. Humans can uptake fluoride from various food products and from drinking water. But because of its adverse effect the World Health Organization (WHO) has restricted the maximum fluoride concentration suitable for safe drinking water to be 1.5mgL (Neha et al., 2016). Fluoride is available in abundance in a few countries across the globe and its distribution varies from country to country.

2.2.1. Global and regional status of fluoride

A high concentration of fluoride in water occurs in huge and extensive geographical belts and is related to volcanic rocks, sediments of marine origins in mountainous areas and granitic and gneissic rocks (Neha et al., 2016). According to Neha et al., (2016), fluoride first spread from Iran and Iraq via Syria and Turkey to the Mediterranean region. It then spread from Algeria to Morocco and later through the East African Rift Valley to countries like Ethiopia, Kenya, Uganda and Tanzania because of volcanic activity. Lakes in the Rift Valley are mainly soda lakes which have high fluoride concentrations. For instance, in Ethiopia lakes such as Langano, Shala and Abijata have high fluoride concentrations and in Kenya lakes like Elmentaita and Nakuru have high fluoride concentrations up to 2,800 mg/L (Neha et al., 2016). The fluoride concentration belt across the globe is presented in Figure 2.1.

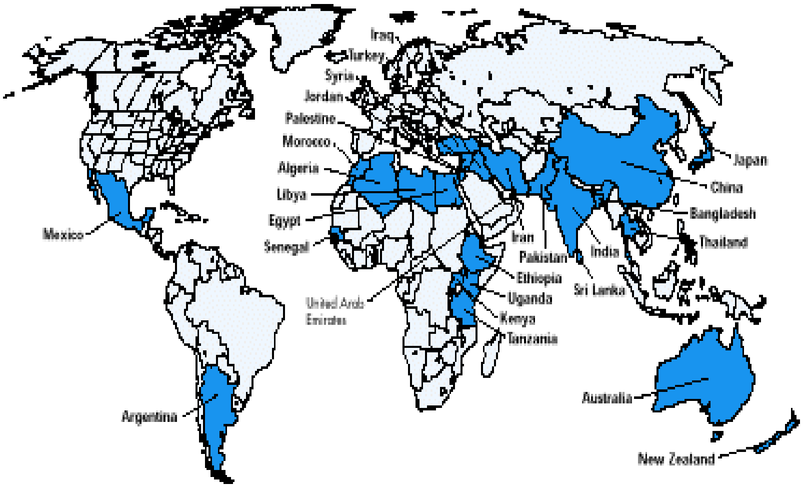

Figure 2. 1 Widespread fluorosis distribution belt (WHO report, 2015)

As we can see from Figure 2.1, concentration of fluoride in groundwater is very high in countries such as those in the Middle East, India, Pakistan, Thailand, China, Sri Lanka, Australia, Argentina, Mexico and western, northern and eastern Africa.

2.2.2. National status of fluoride

In Ethiopia, about 14 million people are vulnerable to a widespread fluorosis which is a result of excessive fluoride intake through drinking water (Tekle-Haimanot et al., 2006). Rango et al., (2012) show that there is excess fluoride in underground water surfaces is (9.4 plus or minus 10.5 mg/l and up to 50 times greater than the WHO standards of safe water guideline limit which is 1.5 mg/l) in the Rift Valley region of Ethiopia**.** By dissolving in water, fluoride leads to toxic effects on human bodies by damaging mainly calcium-containing body parts such as teeth, skeletal and others (McDonagh et al., 2000). Because of this, excessive fluoride concentration intakes lead to dental and skeletal fluorosis. This in turn results in different psycho-social impacts such as discrimination and social exclusion (Tekle-Haimanot et al., 2006).

According to Neha et al., (2016) and Tekle-Haimanot et al., (2006), the effect of excessive intake of fluoride has a severe impact on the bones, brain and kidneys. The extent of fluoride and its possible impacts is summarized in Table 2.1.

Table 2. 1 Fluoride concentration and effects on human body

Level of fluoride in mg/l	**Its effects on human body**
Less than 0.5	Dental caries
From 0.5 to 1.5	Take care of bone and teeth
From 1.5 to 3.0	Dental fluorosis
From 3 to 10.0	Skeletal fluorosis i.e adverse change in bone structure.
> 10.0	Crippling skeletal fluorosis and other problems

Source: Neha et al., 2016; Tekle-Haimanot et al., 2006

My study mainly focuses on the households residing in the Rift Valley region of Ethiopia who are severely affected by excess fluoride concentration of drinking water.[7] The concentration levels of fluoride varies from area to area and from lake to lake (Table 2.2).

Table 2. 2 Fluoride concentration across woredas in Rift valley region of Ethiopia

Rift valley Lakes and villages	Fluoride concentration (mg/l)	Woreda/district	Sources
Shala	264.0	Shala	Tekle-haimanot, 2006.
Abijata	202.4	Arsi Negelle	Tekle-haimanot, 2006.
Beseka	32.2	Fantale	Tekle-haimanot, 2006.
Langano	12.89	Arsi Negelle	Tekle-haimanot, 2006.
Chamo	8.4	Arba Minch	Tekle-haimanot, 2006.
Zuway	1.7	Adami Tulu & Jido kombolcha	Tekle-haimanot, 2006.
Wonji Shoa area	From 6-22.6	Adama	Helmut, et al 1999
Bora woreda	Up to 26	Bora	Datturi s, et al 2015

[7] Video-based evidence of excess fluoride problem in the drinking water supply in the Rift Valley region is available at.

https://www.facebook.com/OBNAfaanoromo/videos/2037504872928336/.

The Rift Valley region stretches from the northern part of Ethiopia from the Tigray region through Afar and goes through Oromia up to Somalia. My study focuses on the central Rift Valley areas where there is high concentration of fluoride in the groundwater. Specifically my study is conducted in five districts of the central Rift Valley region -- Adama (Dibimbisa and Wonji), Lume (Koka Ejersa 02), Bora (Malima Bari), Zuway dugda (Wayyu Gabriel) and Adami Tulu and Jido kombolcha (walin bula) *woredas*. The study area's location is given in appendix I in annex 1

The people living in these districts are severely affected by the fluorosis and become a victim of other socio economic problems since long time. What is needed to reduce this deep-rooted problem is an integration of different stakeholders such as the government, water supply companies, non-governmental organizations and water users. Many scholars have done research, especially from public health perspectives and different non-governmental organizations have also tried to install community-based fluoride filtering water taps in the region (Datturi et al., 2015). Various fluoride detection mechanisms like colorimetric, ion selective electrode method, UV-Vis method and the fluorescence method have been used. However, I exclusively focus on the application of online technology for detecting the level of fluoride concentration and instantly communicating the results to the concerned stakeholders. At the same time, since household contributions for financing water supply projects are very significant in Ethiopia, I also look at demand side perspectives.

2.3. Online technology adoption in the water service sector

The application of online technologies in a utility sector helps in improving efficiency and reducing costs while at the same time also enhancing customer services. Today most of the developed countries have already adopted smart water management systems in which the water supply system is controlled by ICT solutions such as smart meters, communication systems, software and services including sensors and detectors (Turcu, 2012). Further, a monitoring system can provide a real time analysis of the data collected and suggest suitable corrective measures and automatically inform water treatment centers and end users. Online water monitoring is recommended since it is better than the traditional means of controlling the quality of water. Traditional ways of quality monitoring mainly consist of manual collection of water from several places, storing the samples in a centralized location and subjecting them to laboratory analytical testing (Pandian et al., 2015; Thinagaran et al., 2015). Such approaches are considered inefficient because of the unobtainability of real time water quality information, delayed detection of contaminants particularly fluoride in my study context and the methods being cost ineffective. The need for continuous online water quality monitoring is highlighted by various other studies including Bhatt & Patoliya, (2016);

Cloete et al., (2016); Lambrou et al., (2014); Ma et al., (2011); Poonam et al., (2016); Sathish et al., (2016); Vijayakumar et al., (2015); Wang et al., (2011). My study proposes an online technology for online fluoride level monitoring at the reservoir and the water treatment plant center to monitor the quality level and provide early warnings of hazards (Figure 2.2).

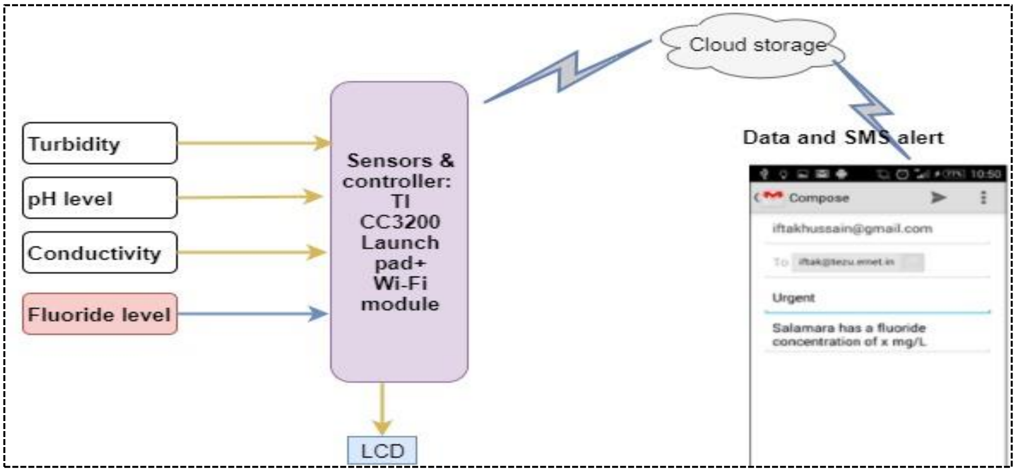

Figure 2. 2 Proposed online technology to monitor fluoride level

Figure 2.2 propose an integrated online system contains different sections such as data collection, management and transmission. The data collection sub-system consists of different parameter sensors and detectors with wireless communication instruments to transfer the sensor information to the controller. The data management section includes applications that access data from cloud storage and show similar ways to the final end users. The data transmission part/component consists of wireless communication machines together with built-in security features, that transfer the data from the controller to the data storage cloud (Geetha et al., 2017).

2.3.1. The need for online technology adoption in the water supply sector in Ethiopia

According to drinking water supply standardization regulations in Ethiopia, the sampling frequency for examining physical and chemical characteristics of drinking water should be carried out at least two times per year, once during the rainy season and during the dry season (CES, 2013)[8]. The guidelines says that the frequency of examination may increases when toxic substances are known to be present at sub-tolerance levels in the source of supply or in certain special circumstances when new industries that may discharge toxic waste are established in the area. This implies that at the moment, no one is monitoring the quality of water supply on a regular basis when these situations do not exist, particularly in the Rift Valley region where there is excess fluoride in the groundwater and where pipeline coverage is very low. Due to volcanic activities in the region and the presence of granite and soda ash, there is a dynamics in the concentration of fluoride levels in the water. Besides there are also seasonal changes (rainy and dry season). Even during these seasons a one-time quality check is not a guarantee that end users have safe drinking water. Instead there should be continuous quality monitoring, particularly fluoride levels in the study area so that any possibility of unsafe water distribution is detected.

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[8] Ethiopian government report (2013). *Compulsory Ethiopian Standard First Edition 2013: Drinking Water–Specifications*. Accessed from: https://reliefweb.int/report/ethiopia/compulsory-standard-first-edition-2013-drinking-water-specifications

To deal with this situation there is a need to adopt online technologies in the study area. These can be installed at different water source points such as water treatment plants and the technology can detect the level of fluoride and send the information to the concerned stakeholder, that is, the water supply company for treatment and to the end consumers.

Many initiatives have been taken up that seek to bring affordable and clean water to consumers, including those by the government. In 2005 the Government of Ethiopia launched the five-year program PASDEP (Plan for Accelerated Sustained Development to End Poverty) which aimed to increase access to improved water sources and sanitation to 84 percent and 80 percent respectively by the end of 2010. However, at the end of PASDEP plan in 2010 access to drinking water was estimated to be 68.5 percent (91.5 percent coverage in urban and 65.8 percent in rural areas of water sources within a 0.5km to 1.5 km radius respectively). Following the end of this program the government proposed another over-ambitious five-year growth and transformation plan (GTP-I) that aimed to increase water coverage from 68.5 percent to 98.5 percent at the end of 2015 (MoFED, 2010).[9] However, GTP–I was not successfully realized and instead safe water access was reported at 58 percent achieving just the millennium development goal of having a water source within a 1 km radius. In 2015, the Government of Ethiopia again presented another growth and transformation plan (GTP-II) for

[9] http://www.mofed.gov.et/.

the period 2016-20 which is a continuation of GTP-I. At the end of GTP-II the target for safe drinking water coverage is 85 percent of the total population.

2.4. Ethiopia's water supply policy

As a part of GTP-II, Ethiopia has set a goal with regard to clean water supply. The goal is to contribute to the realization of the vision of the country to become a middle-income country by 2025 through access to safe and sustainable water supply and urban waste water management using low cost technologies and community mass mobilization. To realize the goal based on household settlement patterns, there are specific goals and policies for each location, that is, for rural and urban areas (WSS, 2015).[10]

2.4.1. Rural water supply

Since most of the population lives in rural areas which have scattered settlements, having an effective and efficient water supply network is very challenging. The government has prepared a policy to address their water needs which has the following aims: to "maintain the sustainability of water supply infrastructure via strengthening cost recovery methods and the development of well-organized supply chain for its spare part. Then followed by increasing the operational budgets and focus more on capacity building at the woreda level to support the implementation of cost effective new technology strategy. And the third policy is aimed at implement the national

[10] http://www.washplus.org/sites/default/files/Ethiopia2010.pdf.

WASH (water supply, sanitation and hygiene) inventory to establish baseline data on rural water supply infrastructure” (WSS, 2015, p 3).

2.4.2. Urban water supply

people have relatively better access to water supply networks in urban areas but these areas also have illegal connections which do not pay the bills. To address this issue the government framed a policy aimed at “practicing cost recovery strategies through supporting capacity and financial autonomy of towns utilities and pay attention to sustainability of water resource via encouraging demand management approaches and reduction in missing water” (WSS, 2015,p 3).

According to the Ethiopian water supply policy, one of the central focuses of urban and rural water supply is a full cost recovery strategy. Social tariffs were finalized in 2003 to as per the cost recovery policy for the drinking water sector. To maintain the sustainability of water projects and for meeting the required quantity and quality of water demand, establishing cost recovery tariff rates is one of the most important policy issues in water supply.

As estimated by UNDP (2006a), the financial requirements for reducing the share of population without sustainable access to safe drinking water by 50 percent in 2015, was 23.3 billion birr out of which 3.4 billion birr should be got from the user households; birr 3.7 billion from the government and birr 16.1 billion from external partners. As the role and share of households is paramount for sustainable financing of water supply the demand side issues in clean water supply need to be explored.

To implement the cost recovery system one also needs to examine households' affordability and willingness to pay. My study also explores the main constraints that water providers have to face in supplying fluoride safe water to Rift Valley's residents. Besides it also looks at demand side preferences and potential willingness to pay. The overall research framework is as below figure2.3.

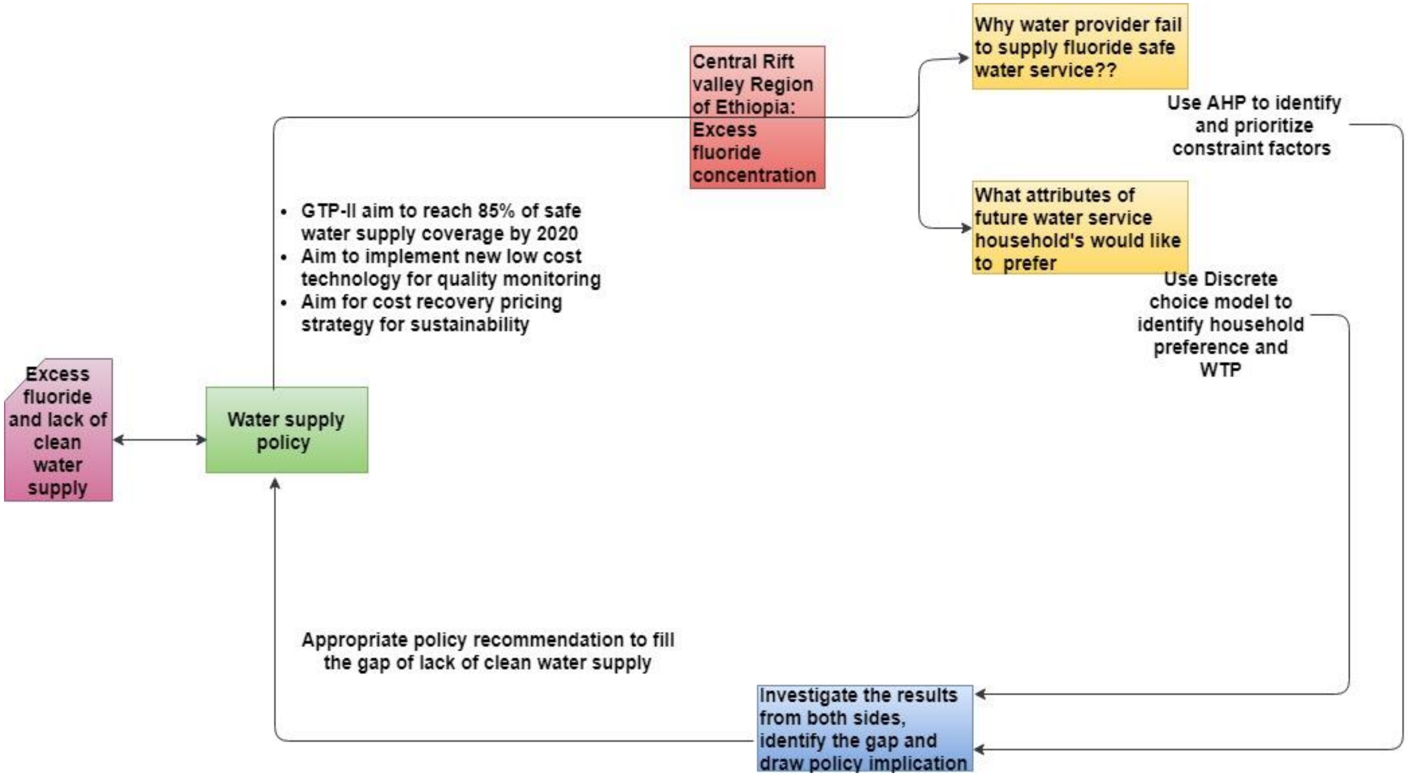


Figure 2. 3 Overall research framework

Chapter 3. Literature review

In recent times consumers have started worrying about the quality of drinking water that they are supplied. To respond for this increased demand for quality water services, scientists are developing applications that help in monitoring the quality of water online. One of the technologies that can be used to monitor the quality of drinking water is internet-based. This chapter reviews existing literature on the demand for water service improvements together with literature on the state of art methodologies for deriving utility maximizing behavior for water service consumers in general, thereby, providing the rationale for the study.

3.1. Studies on online technology (IoT) adoption for water quality monitoring

In recent years, there has been a fair amount of research on smart water quality monitoring as a response to demand for quality water among consumers and improvements in living standards. Water quality monitoring is used for protecting water sources by identifying the types of pollutants and their locations in the source water.

Sridharan (2014) explains how water quality monitoring sensor using efficient wireless sensor network (WSN) was developed. His study examines water quality testing for different uses such irrigation, domestic use and industry.

Simbeye and Yang (2014) created a design for the control system and water quality monitoring system that was applied for aquaculture using a single chip computer technology and wireless sensor networks as a base in the operations. Their study found that the system was appropriate for long-term stability under growth conditions thus increasing yield per unit area. Another study by Sutar and Patil (2013) explains the monitoring system for fish farms using wireless sensor networks. The sense parameters with their exact values are transmitted to the observing station through wireless communication and the details are monitored by the administrator. When any of the attribute parameter deviates from the stated threshold level there is an alarm thus alerting the monitoring personnel. According to this study the system has many advantages including lower power consumption and flexibility in its deployment.

Khetre and Hate (2013) explored a wireless sensor network for monitoring water quality parameters. This parameter comes with many useful features like lower power consumption, low cost, flexible configuration, a large monitoring range and insignificant damage to the natural environment. According to their findings the system can successfully provide online automatic monitoring of the turbidity, temperature, salinity and water level.

Wang et al., (2009) explain the shortcoming of the manual analytical method used in monitoring water quality as having poor real time abilities and as an alternative they present novel remote water quality monitoring and measuring system based on wireless system networks. Regan et al., (2009) developed an automated water environment monitoring system using a global system for mobile communication technology that sends the online measurements of water parameters directly to mobile phones.

In their study Geetha and Gouthami (2017) propose systems which monitor water quality online using a controller with an in-built WiFi module to monitor attribute parameters such as conductivity, turbidity, water level and pH level. The system also has a facility which gives an alert in advance when there is a deviation in the parameters from the adjuster standards so that the users can take appropriate measures. They demonstrate their system using a sample of water with some pollutants to check the efficiency of detector and the notification that it provides.

Pandian and Mala (2015) discuss installing water quality monitoring sensors like Arduino IDE, ZigBee module and a data concentrator module in different water sources including rivers and lakes. By doing this the smart devices collect and censor the quality of water and remotely communicate with different stakeholders. They suggest that it is possible to store data on water quality parameters in the cloud and then securely provide it to users using cryptographic techniques.

Zhenan et al.'s (2013) study investigates the control and monitoring of water quality in water bodies including lakes and rivers. They have designed an intelligent system that combines monitoring and actuation capabilities through appropriate algorithms based on the system's design requirements.

Banna et al., (2014) reviewed online water quality control technologies and explain why the technologies are not diffused among more consumers. Although the technology has made progress for the surveillance of water sources and water treatment plants’ operations, the distribution of these technologies is very slow because of high costs associated with installation, maintenance and calibration of a large number of monitoring sensors. The study explains and reviews important parameters in water quality monitoring and suggests why people are looking for technologies that can be economically deployed on a large scale.

Hussain et al., (2016) demonstrate the working of low cost, robust and field portable smartphone fluoride detectors for rural households in India who are vulnerable to excess fluoride in underground water. They developed an android application ‘FSense’ which can detect and analyze fluoride concentrations and even can communicate with the central water quality monitoring station from the location. These kinds on technologies are very important for governments, non-governmental organization and households who are working on fluoride level detection and fluoride removal from drinking water.

To sum up, most studies discussed here test the workability of online water quality monitoring systems. To the best of my knowledge there are no studies on the acceptance of technology for drinking water by a large number of different stakeholders. Existing studies also provide little information on the important places that that water suppliers and households occupy in online-based water supply. The applications and parameters monitored and tested in previous studies are given in Table 3.1.

Table 3. 1 Studies on applications of smart water quality monitoring

Applications	Parameters monitored	References
Domestic stored water	water level, PH sensor, Temperature, Turbidity sensor, Chemical Oxygen Demand (COD)	Pandian and Mala (2015), Thinagaran et al. (2015), Vinod and Sushama (2016), Sathish et al. (2016)
Domestic running water	pH,flow sensing, Turbidity, Conductivity, Dissolved oxygen, Temperature, oxidation reduction potential	Poonam et al., 2016, Vijayakumar and Ramya (2015), Nier et al. (2016), Jayti and Jignesh (2016), Xiuli et al. (2011), Xin et al. (2011)
Lake, river, sea	pH, Chlorine concentration, chlorophyll, dissolved oxygen, temperature, conductivity	Vinod & Sushama (2016)
Drinking water distribution system	Chlorine concentration,	Yue et al (2011)
Aquaculture center	Temperature, Turbidity, pH level, conductivity,	Wiranto,G et al (2015)
Water and air quality	Air temperature, Humidity, presence of organic compound	Mitar et al. (2016)

Not limited to specific application	pH, dissolved oxygen, temperature	Wei et al. (2012)
Water distribution system	Leakage and water sensing	Turcu & GAITAN (2012).
Surrounding water pipes	Leakage &water movement	Kang & Lee (2015).
Drinking water treatment center	Fluoride concentration	Hussain et al (2016)

As summarized in Table 3.1, online technology has the potential to monitor the quality of water services with regard to different parameters including fluoride levels and hence they have the potential of becoming breakthrough solutions for developing countries that are vulnerable to problems of water quality. My dissertation identifies the main constraints that bind water providers in supplying fluoride safe water services taking into account online-based fluoride monitoring versus offline-based fluoride monitoring.

3.2. Studies on demand for water service improvements

Since water is a necessity a lot of research has explores demands for improving water services in different countries. Since there is often absence of pre-existing data on household demand for future water service improvements, policymakers mostly depend on stated preference data to understand and estimate consumer demand,[11] (Pattanayak et al., 2006). This sub-section focuses on reviewing literature that studies stated preference and revealed preference data concerning demands for improvements in water services.

Hensher et al., (2005) studied households' WTP for water service attributes focusing on drinking water and sewage services in Canberra city, Australia. Their study concentrated on consumer preferences for drinking water services' attributes to avoid the frequency, timing and duration of service interruptions since better services are attainable only after incurring higher costs. The issues that their study focused on for waste water were overflows and how they can be reduced as the frequency and time for repair overflows leads to higher costs, which eventually lead to higher prices for households. To decide the appropriate level of these service attributes in terms of price, their study used stated preference data using a choice experiment survey involving water customers in Canberra. Using the mixed logit method their results show that the frequency and duration of service interruptions, additional prices, service interruption notifications and timing (evening after 6 pm) were very important for consumers. Their study also did an experiment of forced choices, by not providing status quo alternatives. Accordingly, customers on average were WTP A$4.15 per year to reduce frequency of interruptions by 0.1 from 2 per year to 1.9 per year, A$4.38 to reduce length of interruption when they faced

[11]Because of the hypothetical nature of the survey we may face potential problems such as demand over estimation or underestimation. Such an error can trigger and mislead leading to a negative impact on public and private investments in the water sector.

24 hour interruptions, A$142 (19 percent of their annual bill) to receive advance notification for all interruptions. Households with children and higher incomes were more concerned about obtaining prior notifications.

Willis et al.., (2005) explored consumer preferences and WTP for water service improvement employing a choice experiment survey conducted with 1,000 respondents in United Kingdom. The findings of their study revealed that customers placed high value on maintaining a good water supply with regard to reliability of services (high pressure and minimum interruptions). The study estimated the benefits of a Yorkshire water supply company for identifying consumer preferences and their WTP comparing it with the cost of sustaining and improving service provision based on which appropriate investment decisions can be made. Based on this study the Yorkshire water supply company increased water bills on average by UK pound 45, from pound 243 in 2004 to pound 288 in 2010. This enabled the water provider to provide regular, safe, reliable and efficient services and at the same time increase investments to improve the quality of drinking water, clean up rivers and estuaries and to help deal with problems of sewer flooding (Willis et al., 2005).

Jonson et al., (2003) did a study in Sri Lanka focusing on unpackaging demand for water service quality using stated preference data along with a survey of 1,800 respondents in three towns -- Negombo, Kalutara and Galle.

An insightful finding of the study is that poor households do not necessarily prefer home taps to public taps or mini grids because of high connection costs. Vásquez et al.'s (2009) study in Mexico shows that households' median WTP for clean and reliable drinking water was greater than their current water bill at least by 45.6 percent. By adding this median WTP to current water tap expenditure, this accounted for more than 5.7 percent of customer median income; this is more than the recommended affordability threshold of 3 percent of household income (OECD, 2003).

Choi et al., (2016) did a study on willingness to pay for the land agriculture restriction policy to improve water quality in Korea and compensating farmers who are expected to lose their incomes thanks to the restrictions downstream. The study also explored water consumers' willingness to pay. According to their results, the estimated welfare gained from the policy on average was 2,861 Korean Won per month per household and the total benefit from the land use restriction policy was about 297.73 billion Korean Won with 129.44 billion Korean Won as the total cost; and 168.29 billion overall positive net effect. This was achieved just by increasing the unit price of highland purchase so as to cover the compensations for policy victims. Another study in South Korea by Lee (2014) focused on determining the benefits of residential WTP for improved quality of water services in Ulsan city. The study shows that although most of the respondents said no to pay for improved quality of water (55.6 percent), the estimated household WTP was about 18.2 percent of their current bill rate per cubic water consumption. This result implies that the public was ready to accept a significant increase in prices or other costs to improve the quality of water in Ulsan city.

In general, a lot of studies have been conducted on the demand for improvements in water services across the globe mainly using stated preference data for new customers. To understand previous literature on this specific research topic, I summarize some selected previous works mainly focusing on those that used stated preference data in Table 3.2.

Table 3. 2 DCE and CVM based water service demand studies

Authors	Data and country	Model	Attributes	Findings/implications
Hensher, D., Shore, N. and Train, K. (2005)	SP data. 211 respondents. Australia.	Discrete choice experiment. Mixed logit model.	Frequency of interruptions/year. Duration of interruption/hr. Notification of interruption. Information through call. Time of day. Price for water service.	Households are willing to pay to avoid water interruptions and longer durations. They also prefer weekdays and day time interruption with low prices.
Jonson, F. R., Pattanayak, S. K., Mansfield, C., van den Berg, C., Jones, K., and Yang, J. C. (2003)	SP data. 1,800 respondents. Sri Lanka.	Discrete choice experiment. Conditional logit and mixed logit.	Price. Quantity. Safety and Reliability.	Both non-poor and poor households place similar values on water service attributes in terms of hours of supply, safety and volume but consumption charges are a source of disutility for the poor.

Vásquez, W. F., Mozumder, P., Hernández-Arce, J., and Berrens, R. P. (2009).	SP data. 400 respondents. Mexico (Parral city).	CV methods. Censored logistic for binary response and OLS for open ended questions.	Variables such as reliability, safety, storage facility use, filter tap water at home, purchase bottled water, drink tap water, treat tap water at home with chlorine, boil tap water, income, price, age, education, own house and family size.	Household median WTP for reliable and clean water were 45.64 percent above their current bill and greater than 5.74 percent of stated median incomes.
Willis, K. G., Scarpa, R., and Acutt, M. (2005).	SP data. 1,000 respondents. UK.	Discrete choice experiment. Conditional logit. Nested logit. Mixedlogit comparison.	Water supply. Water quality. Wastewater disposal.	Customers placed high value on minimizing interruptions of water supply along with adequate main pressure.
Kanyoka, P., Farolfi, S., and Morardet, S. (2008).	SP data. 169 respondents. South Africa.	Discrete choice experiment. Conditional logit model.	Quantity of water. Frequency of water supply. Quality of water. Price of water, Productive use.	Water quality and reliability are more important than the quantity of water delivered. Productive uses of water services is not common in the area whereas there is high demand for

			Source of water.	domestic use of water.
González-Davila, O. (2013).	SP data. 300 respondents. Mexico.	CV methods. Tobit model with binary selection.	Water quality. Reliability and other socio demographic variables (sex, age, education, family size, food expenditure, number of children).	Arsenic and fluoride are different contaminants and hence had differing effects on values. The respondents on average were willing to pay US$2.70 for fluoride and US$ 3.22 for arsenic removal per month.
Echenique, M., and Seshagiri, R. (2009).	SP data. 400 respondents. South India.	Discrete choice model. Conditional logit model.	Quantity. Quality. Pressure. Frequency. Summer supply. Water supply provider. Cost.	There is a demand for water service improvements because 90 percent of the study area's population preferred improvements in services with proposed water tariff increments.
Burt, Z., Njee, R. M., Mbatia, Y., Msimbe, V., Brown, J., Clasen, T. F.	RP data. 556 respondents. Rural Tanzania.	Revealed discrete choice model. Binary logit model.	Water source. Perceived water quality. Water collection. Usage practices.	Most households preferred boiling first and then using the pot filter system, whereas chlorine additive systems such as siphon filter and PUR had lower preference. Improving liquidity will

and Ray, I. (2017).				increase the adoption of household water treatment systems.
Gunatilake, H. (2012).	SP data. 3,000 respondents. Bangladesh.	CV methods. Bivariate probit model to estimate WTP.	Variables such as public hand pump, tube well, private well, household expenditure (income), expenditure on electricity bill, education level.	Though the median WTP is higher for richer households, however, the share of household expenditure is higher for the poorer households that makes piped water connections difficult for the poor.
Kwak, S. Y., Yoo, S. H., and Kim, C. S. (2013).	SP data with one and one half bounded dichotomous choice (OOHBDC). 400 respondents. Busan city,	CV methods. Logistic and spike model to estimate WTP.	Variables such as odor of water, gender, age, education, income and bids.	Respondents who experienced chlorine odor while using tap water had less WTP for water quality improvements which implies that people who experienced chlorine odor may be skeptical about the new proposed water quality improvements and hence prefer other preventive behavior such as buying bottled water and water

	Korea.			treatment equipment to drinking tap water.
Huber, A. C., and Mosler, H. J. (2013).	Cross-sectional data. 211 respondents. Ethiopia.	Linear regression model (percent of fluoride free water consumption as dependent variable).	Perceived distance. Perceived cost. Taste. Commitment. Perceived habits. Self-efficacy. Personal norms.	Findings imply highest intervention potential in distance, factual knowledge, commitment and taste of water which strongly influenced participants' consumption behavior and therefore should be tackled for interventions. Perceived habits also positively influenced filter usage.
Hundie, S. K., and Abdisa, L. T. (2016).	SP data. 210 respondents. Ethiopia (Jigjiga).	CV methods. Logit model and linear regression model.	Variables such as monthly income, age, family size, initial bid and source of water supply were used to estimate WTP.	The results reveal that households that got water from sources other than pipes had more WTP for improved water supply compared to those who used pipelines.
Choi, I. C., Kim, H. N., Shin, H. J., Tenhunen, J.,	SP data. South Korea.	CV methods. Random effect interval regression model.	Variables used are income, gender, household size, resident area, resident duration of living in the area, water quality, need for	The total benefit from land use restriction policy was greater than total cost. So WTP from downstream users was good financing mechanisms for

and Nguyen, T. T. (2016)			turbid water inflow prevention.	compensating upstream farmers (who expected income loss).
Lee, J. S. (2014).	SP data. South Korea. Ulsan city.	CV methods. Spike model using SBDC.	Income, gender, education, age, policy and bids.	The public is ready to accept significant increase in prices or other costs to improve the quality of the water.
Dharmaratna, D., and Harris, E. (2012).	Panel data. Sri Lanka.	Stone Gary functional form. Almost ideal demand function.	Water volume, price, income, family size, temperature, water fall, marginal price.	The level of water use with inelastic price was between 0.64 and 1.06 m^3 per capita per month.
Wang, H., Xie, J., and Li, H. (2010).	SP data. China. Chongqing city.	CV methods (MBDC). OLS regression.	Connected to pipeline, current satisfaction, price, water volume, gender, age, education, urban, income, WTP bids.	Significant increase in prices of domestic water is economically feasible as long as the poorest households are properly subsidized.

3.3. Review of empirical studies in the Ethiopian context

Bayrau(2005) conducted study on household willingness to pay for improved quality of water services aiming to estimate whether the household WTP can able to recover coat of service improvement or not. The study was conducted in Adama city using a CV method. It concluded that the average WTP for improved water services was greater than the average water tariff. Concerning the affordability of cost recovery prices, the study found that consumers can pay if they were provided clean water service prices that are equal to the average incremental cost of providing improved water.

Minota (2014) did a study on household WTP for improved water services and estimated factors determining household willingness to pay for clean water services in Dilla town, in the southern nation and nationalities people region. The study used a contingent valuation method using a single bounded dichotomous elicitation format followed by open ended questionnaires. It found that the mean WTP for improved water services using a closed ended format was a bit less than that using an open ended questionnaire format and both mean values were larger than the time water tariff. The study shows that household income, source of water, household occupation and wealth status positively influenced WTP whereas family size, quality of water being used and the bid negatively affected WTP for improved water services.

Fentahun (2014) also conducted a study on demand for water service improvements in a rural village of Ankasha *woreda* in Amhara regional state, Ethiopia. The study used a single bounded dichotomous elicitation format followed by an open ended questionnaire and found the average WTP for the improved water service at 1.52 per jerry can ($US 0.06). Another study by Lemma and Beyene (2012) used household willingness to pay for improved water services in rural areas of Goro-Gutu *woreda* in Oromia regional state, Ethiopia. The study found those households with higher incomes and those who spent long hours in collecting the water were more willing to pay. But those with larger family sizes, those who used reliable water sources from convenient water points and those who got higher starting bids were less likely to pay for improved water services in the study area.

Saleamlak (2013) examined household WTP for proposed improved water services in the northern part of Ethiopia, in Tigray region, Mekelle city. Employing the contingent valuation methods, the mean WTP for water service improvement was ETB 29.60 per jerry can ($ US 1.07). Further, variables such as education level of household, monthly income of household and satisfaction level from the existing water source significantly affected households' willingness to pay (Table 3.3).

Table 3. 3 WTP for water service improvement study in Ethiopia and in other cities

Authors and year	**City /woreda**	**Mean WTP (US$/m^3)**[12]

[12] 1 bucket is equal to 18.2 liters, 1 jerican is ~20 liters and 1m^3 is equal to 1000 liters in the conversion. Exchange rate was $ 1USD= 27.5 ETB on January 15, 2018.

Bayrau (2005),	Adama	16.82
Minota (2014)	Dilla	34.47
Fentahun (2014)	Ankasha woreda	2.76
Lama & Beyene (2012)	Goro Gutu woreda	2.21
Bogale and Urgessa (2012)	Haramaya	49.64
Saleamlak (2013).	Mekelle	53.82
Hundie and Abdisa (2016)	Jigjiga	1.71
Tarfasa (2013)	Hawasa	8.01
Lee (2014)	Ulsan city, South Korea	0.095
Wang, Xie & Li (2010).	Chongqing city, china	0.35
Gonzalez-Davila,O.(2013)	Mexico	2.7 for fluoride and 3.2 for arsenic removal /month

3.4. Summary of literature review

As revealed-preference methods analyze user behavior in the real market, in general experience of 'improved' water services, stated-preference or indirect methods make increasing use of valuation techniques (Echenique et al., 2009). All the studies reviewed here focus on stated preference data-based valuation of the demand for improvements in water services. Within stated preference analyses, some studies used indirect survey methods using a conjoint analysis while others used the contingent valuation method to estimate households' willingness to pay for improved water services. Although the contingent valuation method has been employed for a long time to estimate values of goods by consumers, this method is facing criticism that nothing is revealed about the value of different attributes that comprises a good which leads to overestimation or under-estimation of the valuation. To overcome this limitation the researchers started focusing on conjoint based valuation for goods and services. Moreover, from a policy point of view, there is merit in seeking to know households' preferences for several defining attributes of a good and in knowing if, and to what extent, households consider one attribute more, or less, important than another (Echenique et al., 2009). As Lancaster (1966) observes, “the consumer obtain the utility from, not the goods per se, rather from the characteristics of the goods.”

The studies reviewed in this chapter used either one of these methodologies to estimate and realize their objectives. However, my study uses both contingent valuation and a conjoint analysis-based method for further understanding the structure of consumer preferences, factors influencing WTP and estimating willingness to pay so as to conduct a cost benefit analysis and to able to make comprehensive suggestions for a policy on fluoride safe water. Demand for improvements in water services has been studied in Ethiopia but there have been no studies on the fluoride problem and the estimated mean WTP for improved water service varies from 94 cents ($ US 0.03) per jerry can in Jigjiga to 29.60 cents ($US 1.07) in Mekelle city.

3.5. Contributions to academic literature

The main contribution of this dissertation is suggesting an efficient policy design with regard to fluoride safe water services. This is done by exploring the gap between what providers lack and what households need and then forwarding relevant policy implications. Some of its other contributions to academic literature are:

Since the studies reviewed in this chapter used either of one of two methodologies(direct survey i.e CVM vs Indirect survey i.e conjoint analysis) and based on the findings using those methods, the policy implications that they draw may fail to address the reality because of the methodology's limitations and bias. To overcome this problem my study uses both the conjoint analysis and contingent valuation method to estimate mean willingness to pay. It also conducts a cost benefit analysis of the fluoride safe water supply project in the Rift Valley region of Ethiopia. It thus helps widen the scope of the cost benefit measurement for fluoride safe water supply to the Rift Valley region's households.

Another limitation of previous research is that it either focuses on consumer perspectives or water providers perspectives. Knowing consumer preferences may not be enough to make relevant policy suggestions as we also need to know problems from the supplier side. As a result, my study considers both views and identifies providers' main constraints in supplying fluoride safe water to residents and consumer preferences for the future water service attributes.

Previous research considers only consumer preferences for different water service attributes and not ICT attributes in water service improvements. However, the role of ICT in water service improvement is significant as it ranges from quality control to information communications platforms. Nowadays the role of ICT in the utility industry including in the water services sector is very important in terms of detecting leakages, censoring and quality monitoring which contribute to efficient service usage and distribution. Therefore, my study considers the role of ICT in water service improvement from both water providers' consumers' perspectives thus bridging the gap between prior information communication using an ICT infrastructure and platforms. The valuation of online based water quality monitoring is a timely topic for both the quality of water provision (from water providers side) and for ICT technology diffusion which jointly have implications for improving social welfare.

To sum up, this dissertation is a pioneer study which explores consumer preferences for fluoride safe water's attributes and examining consumer potential WTP using both a conjoint analysis and contingent valuation method simultaneously. My study also conducted a cost benefit analysis to give clear insights about how the supply of fluoride safe water can be financially manageable by consumers. My study also contributes to identifying the main constraints that bind water providers in the supply of fluoride safe water services, by considering fluoride level monitoring technologies in the Rift Valley region and then drawing relevant policy implications by bridging the providers' main challenges and consumers' water service preferences.

Chapter 4. Models and methodology

The selection of future drinking water quality levels by households can be regarded as a choice from among limited alternatives. In econometrics, marketing, transportation and resource valuation research, such choices are usually modelled by discrete choice approaches. Accordingly this chapter provides details of the theoretical foundations of the discrete choice approach that is used in the context of consumer preferences for future water services.

4.1. Foundations of the discrete choice analysis

Psychologists have been using choice techniques since the 1960s (Luce & Tukey, 1964) and in the early 1970s this was also introduced to marketing literature, where it got much attention in both academic and industrial areas (Green & Rao, 1971). In marketing this choice procedure became known as a conjoint analysis,[13] a term conceived by Green and Srinivasan (1978). The conjoint analysis technique has played a vital role in understanding and predicting consumers and households' decision making and choice behavior. In addition to fast emerging application of the conjoint technique, economic theory has also used a theoretical foundation for this methodology which includes other discrete choice models and is known as the random utility theory (Ben-Akiva & Lerman 1985).

Today discrete choice models are derived from the random utility theory, the probabilistic choice theory and the Lancaster economic theory of values

[13] The term conjoint analysis comes from a combination of two words 'considered' and 'jointly' (Green and Srinivasan 1978).

(Lancaster, 1966) which assumes that consumers derive satisfaction from the underlying attributes of the goods or services under valuation, rather than from the goods per se. The probabilistic choice theory assumes that one cannot perfectly predict an individual choice due to unobservable parameters. Thus, a model based on theory which explains consumer choices, does not identify alternatives as chosen options and instead assigns probabilities to them.

The stated preference data uses discrete ranking experiment techniques enables the construction of goods and services characterized by attribute levels that currently do not exist. This feature is useful in marketing studies when the purpose is to estimate preferences for new products or for future technology adoption and investment decision-making. It answers research questions or ideas for which getting data is difficult or there is no historical data. It also helps predict future market share for new products, which cannot be done using any other methodology. The development and derivation of this theory is summarized in Figure 4.1.

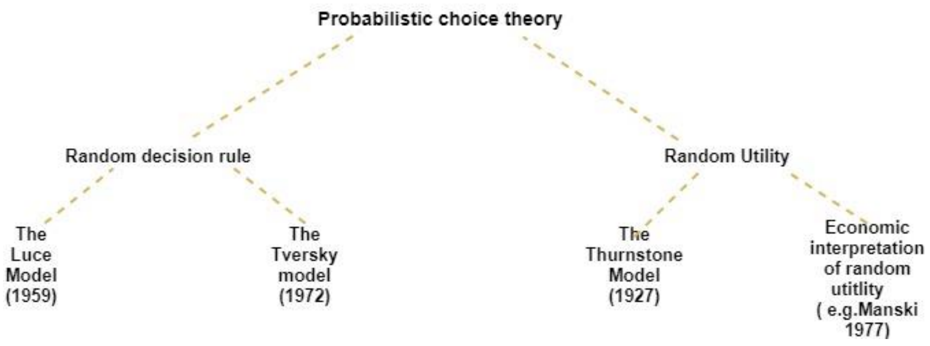


Figure 4 1A trees of probabilistic choice theory

Source: Anderson et al., (1994).

4.1.1. The random utility model

The theory of random utility (McFadden, 1973) is basically used as the theoretical basis for examining consumer preferences using discrete choice methods. The model's assumption is that respondents choose their preferred alternatives on the basis that they maximize their utility. The model further implies that there is a function containing attributes of alternatives and individual characteristics that describe an individual utility valuation for each alternative. Thus, my study assumes that each consumer perceives the utility associated with each attribute of improved water services' options and chooses the one with the greatest possible perceived utility. In a random utility model, the linear utility function is decomposed into a deterministic component and a stochastic (unobservable by the researcher) part as:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (4.1)$$

where, subscript n stands for the nth consumer and j stands for the jth alternative of a choice situation. U_{nj} is the utility obtained from alternative j by the nth consumer. V represents the deterministic utility while ε represents the unobservable utility which captures excluded factors that could affect the utility of an alternative in V_{nj} and factors that are fundamentally unobservable (Ben-Akiva and Lerman, 1985). The deterministic utility part comprises of attributes of goods and services and consumer characteristics:

$$U_{nj} = V_{nj} + \varepsilon_{nj} = V(X_{nj}, D_n) + \varepsilon_{nj} \quad (4.2)$$

where, X_{nj} vector is composed of attributes of alternative j to nth consumer and D_n is a vector composed of characteristics of the nth consumer.

Assuming a linear relationship in the deterministic part of utility in Eq (4.2), we can rewrite it as:

$$U_{nj} = \beta_{nj}{}' x_{nj} + \lambda_{nj}{}' D_{nt} + \varepsilon_{nj} \qquad (4.3)$$

where, β and D represent the degree of influence on the deterministic part of the utility by attributes of improved water services and characteristics of individuals respectively.

Concerning the stochastic part, $\varepsilon = \{\varepsilon_{n1}, \varepsilon_{n2}, ...\varepsilon_{nj}\}$ follows joint distributions which help in making probabilistic decisions about an individual consumer's choice. Hence, the probability that the nth consumer chooses alternatives i from a set of available alternatives J_n is:

$$P_{ni} = P(U_{ni} \geq U_{nj}, \forall j \neq i) = P(\mathrm{V}_{ni} + \varepsilon_{ni} \geq \mathrm{V}_{nj} + \varepsilon_{nj}, \forall\ \mathrm{j} \neq \mathrm{i}) \qquad (4.4)$$

Rearranging this equation as:

$$\mathrm{P}_{ni} = \mathrm{P}(\varepsilon_{nj} - \varepsilon_{ni} \leq V_{ni} - V_{nj}, \forall j \neq i) \qquad (4.5)$$

Hence, the possibility that alternative i is chosen depends on the joint distribution of the differences between the error terms, that is, probability P_{ni} is the function of integration over distribution $\mathrm{f}(\varepsilon_n)$. Different models have been developed using different specifications of this density according to the distribution assumed for the stochastic part of the utility (Train, 2003).

Multinomial logit models, particularly conditional logit models, are the most used random utility models (Verma & Plaschka, 2003) in which the extent of the effects of the attributes of products /services and individual characteristics are assumed to be homogenous (Manandhar, 2012). As a result, the stochastic part of the utility function is assumed to be identically and independently distributed (IID). Following the probability in the multinomial logit model that a consumer n chooses one of the k alternatives, c_i from the choice set C is (Ben-Akiva &Lerman, 1985):

$$p(c_i / C) = \frac{e^{U_{ci}}}{\sum_{j=1}^{k} e^{U_{C_j}}} = \frac{e^{x_i \beta}}{\sum_{j=1}^{k} e^{x_j \beta}} \qquad (4.6)$$

where, x_i denotes a vector of alternative attributes and β denotes a vector of parameters that are estimated. $U(c_i) = x_i \beta$ is alternative c_i 's utility, and for the above context, the probability of choosing ci out of C choices is exponential of the utility of the alternative divided by the sum of all the exponential utilities.

By using this choice probability, the likelihood and parameters are estimated using the maximum likelihood estimation method. The model assumes a Gumbel /extreme value distribution error which produces a closed form probabilistic choice model (Hensher et al., 2005). The conditional logit model further assumes that the error components are IID across the respondents and across alternatives. Another restrictive assumption of the model is its independence from irrelevant alternatives which states that if k is the preferred alternative out of the given choice set $\{k, h\}$, the preference should not change towards h if a third alternative j is added, supplementing the choice set to $\{k, h, j\}$. This means that j is to be considered as irrelevant and should not change the choice between g and h. Because of this assumption the multinomial logit model is very simple to estimate. However, it leads to a restriction in reflecting the realistic substitution pattern caused by a change in the attributes of other alternatives. Further, assuming the same coefficient over all consumers, irrespective of the realistic heterogeneity in consumer preferences may mislead its implication (Koh, 2007). Hence, to relax these strong assumptions and consider the realistic heterogeneity in households' preferences my study uses the mixed logit model.

4.1.2. The Mixed Logit Model

Until Boyd and Mellman (1980) and Cardell and Dunbar (1980) first applied the mixed logit model in their studies to estimate the demand for automobiles, discrete choice literature was dominated by traditional logit models with its potential problems (Train, 1998). Train (1998) emphasized the need for an explicit recognition of taste heterogeneity in choice estimations to avoid biased utility results thus breaking the dominating assumption of homogeneity of discrete choice analysis in preference literature. Given the need for a more flexible logit model to give space to random variations in taste, independence from irrelevant alternatives and correlation among unobserved factors in repeated choices, different flexible models such as multinomial probit, mixed logit and latent class model have also been developed.

A mixed logit model, is a state of the art model in the logit class. It is used as a highly flexible model to accommodate unobserved heterogeneity in estimation, approximating any random utility model and is widely applied in modelling for improved water demand choice using the stated preference method (Hensher et al., 2005; Whittington et al., 1990).

In mixed logit models, the unobservable factors can be decomposed into two additive parts $(\varepsilon_n = \eta_n + \delta_n)$: stochastic (η_n) which is correlated over alternatives and heteroscedastic over consumers and alternatives, and stochastic part (δ_n) which is IID over alternatives and consumers (Train, 1998). Accordingly, the utility of consumer n from choosing alternative j can be defined as:

$$\mathrm{U}_{nj} = X_{nj}\beta_n + \varepsilon_{nj} \qquad (4.7)$$

where, unknown parameter β_n which comprises of a vector of coefficients of explanatory variables X_{nj} allows a variation in tests with respect to consumers. To allow the coefficients to vary with respect to consumers in the population, β_n is assumed to have density $\mathrm{f}(\beta)$. For instance, the utility of household n choosing water level j can be defined as:

$$U_{njt} = \beta_{abovewho} ABOVEWHO + \beta_{equalwho} EQUALWHO + \beta_{disfreq} DISFREQ + \beta_{disdur} DISDUR + \beta_{nudaynot} NUMDAYNOT + \beta_{mobile} MOBILE + \beta_{internet} INTERNET + \beta_{addprice} ADDPRICE + \varepsilon_{njt} \quad (4.8)$$

where, $ABOVEWHO$ and $EQUALWHO$ are dummy variables that represent the quality (fluoride concentration level) of future water quality with reference to World Health Organization standards (1.5 mg/l); $DISFREQ$ is expected disconnection of future water service frequency per month; $DISDUR$ is disconnection duration in hours once the supply stops; $NUMDAYNOT$ is the expected number of days prior to the disconnection when the notification is delivered; $MOBILE$ is a dummy variable that defines how the respondents want to receive the service notification; $INTERNET$ is another dummy variable that defines how the respondents want to receive the service notification; and $ADDPRICE$ is the additional price that consumers are willing to pay for improvements in service.

The choice probability with regard to the random coefficient framework is:

$$\mathrm{P}_{nj} = \int L_{nj}(\beta) f(\beta) d\beta \quad (4.9)$$

where, $\mathrm{f}(\beta)$ is the density function and $\mathrm{L}_{nj}(\beta)$ is the logit choice probability at parameter β :

$$\mathrm{L}_{nj}(\beta) = \frac{e^{V_{nj}(\beta)}}{\sum_{k=1}^{K} e^{V_{nk}(\beta)}}$$

$V_{nj}(\beta)$, is the deterministic part of the utility. If utility is linear in β, $V_{nj}(\beta)$ becomes $\beta' X_{nj}$ and the choice probability takes the form of (Train, 2003):

$$\mathrm{P}_{nj} = \int \left(\frac{e^{\beta' X_{nj}}}{\sum_{k=1}^{K} e^{\beta' X_{nk}}}\right) f(\beta) d\beta \tag{4.10}$$

Like the multinomial probit model, the choice probability of a mixed logit model has no closed form expression; hence, it should be approximated numerically. To sum up, a mixed logit model can overcome the IIA assumption of a multinomial logit model and accommodate any pattern of correlation and heteroscedasticity arising from an error term or coefficients with density.

Different kinds of distributions such as normal, log-normal, censored normal, triangular and uniform can be assumed in a mixed logit model (Train, 2003). This flexibility relaxes situations that may lead to an inappropriate assumption in reality (Train, 2003). For example, with normal distribution the model is considered unbound, that is, there is the existence of some extreme values, both negative and positive in terms of various attributes. In such a case with price, the positive value infers higher prices of certain goods or services. Moreover, if the marginal rate of substitution with the price coefficient is calculated as the denominator in such an 'expected' sign situation, the WTP results is unusable and similarly if it overlaps with zero, the marginal rate of substitution becomes unboundedly large for some consumers (Train & Sonnier, 2003).

Log-normal distribution is applied in cases where the response parameter requires a specific sign and is different from zero, for instance, price (Kim et al., 2005). In other words, such a distribution is specified when a researcher wants to declare that a particular coefficient takes the same sign for the entire population.

A censored normal is useful when indifferent responses are expected (Train, 2003). The important aspect with regard to different distributions is arbitrariness in real behavioral profiles. Which distribution to follow for estimation should be led by the sense that the "empirical truth is somewhere in their domain" (Hensher & Green, 2001). My study applies two kinds of distributions -- normal and log-normal for random parameters of future water service attributes.

The random parameter (mixed) model can be estimated either following classical approach or by the Bayesian approach. My study uses the Bayesian approach because of its advantages in estimation over the classical simulation likelihood methods.

4.1.3. Bayesian Estimation

Considering Bayesian approach's superiority in terms of efficient estimation and time saving, my study uses the Bayesian approach. The Bayesian approach begins with the specification of the distribution of the data y, given the unobservable parameters θ and $P(\mathrm{y}/\theta)$ as a likelihood function. In addition, $\mathrm{P}(\theta)$ is also needed which denotes prior belief about parameters of interest θ. The following Bayes' rule provides the updating mechanism for how prior beliefs are converted into posterior beliefs (Rossi et al., 2005).

$$P(\theta / \mathrm{y}) = P(y / \theta) P(\theta) / P(\mathrm{y}) \propto P(\mathrm{y}/\theta)\,\mathrm{P}(\theta) \qquad (4.11)$$

where, $P(\theta / \mathrm{y})$ is posterior distribution and reflects both prior belief as well as sample information.

The Bayesian approach requires multi-dimensional integration over the posterior distribution in many cases. One of them is Markov Chain Monte Carlo (MCMC), which is a simulation method suitable for building models from a sequence of conditional distributions (Koh, 2007). In addition, Metropolis-Hastings (MH) algorithms and Gibbs sampler (one of the members of MH algorithms) provide a set of methods for constructing Markov chains. Some significant advantages of the Bayesian approach over the classical approach are:

First, the Bayesian approach requires no direct estimation of the non-trivial likelihood function and the connected problems of approximating choice probabilities. Second, the Bayesian procedures provide more relaxed conditions for desirable estimation properties, namely, efficiency and consistency. The classical simulation method (MSL) is consistent only if the number of draws used in a simulation increases with the sample size. Further, efficiency is obtained only if the number of draws increases more quickly than the square root of the sample size; this is unlike the Bayesian approach (Train, 2003).

Moreover, the estimation results following the Bayesian approach can be interpreted from both classical and Bayesian perspectives. According to the theorem of Bernstein von Mises, the mean of the Bayesian posterior estimates is a classical estimator that is asymptotically equivalent to the maximum likelihood estimator. Similarly, the covariance of the posterior is the asymptotic covariance of this estimator (Train and Sonnier, 2003).

4.1.4. **The latent class logit model**

It is important to understand individual preferences as explained in the previous section, rather than assuming that individuals might have behaviorally different perspectives about the attributes and their levels. Nevertheless, the results of individual heterogeneous preferences need to be aggregated based on their similarity groups. To meet these needs, my study uses the latent class logit model which assumes discrete mixing distribution where the unobserved heterogeneity is not distributed across individuals but across groups whose behavior is considered to be homogenous within.

Assume that the entire unit of analysis is categorized into unobservable Q classes and individuals belonging to the same class are assumed to have a common preference structure. Based on the random utility theory, we assume that the utility function of individual n belonging to q class for alternative j in choice situation t can be expressed as (McFadden, 1974; Train, 2009; Woo et al., 2017):

$$U_{njt/q} = V_{njt/q} + \varepsilon_{njt/q} \tag{4.12}$$

where, $V_{njt/q}$ is the deterministic part of the utility function, $\varepsilon_{njt/q}$ is stochastic term which is supposed to follow a type I extreme value distribution, whose probability density is $f(\varepsilon) = e^{-\varepsilon} / (1+e^{-\varepsilon})^2$ with the cumulative distribution $F(\varepsilon) = 1/(1+e^{-\varepsilon})$.

The utility function for n households belonging to class q, choosing water level j is:

$$\begin{aligned}U_{nj/q} = \beta_{abovewho/q}ABOVEWHO + \beta_{equalwho/q}EQUALWHO + \beta_{disfreq/q}DISFREQ + \beta_{disdur/q}DISDUR + \\ \beta_{nudaynot/q}NUMDAYNOT + \beta_{mobile/q}MOBILE + \beta_{internet/q}INTERNET + \beta_{addprice/q}ADDPRICE + \varepsilon_{nj/q}\end{aligned} \tag{4.13}$$

where, all the variables are already defined in Eq. (4.8) but constrained to the probability of class q, and the error terms also belong to class q.

As a household decides to maximize their utility, the choice probability for alternative i by household n belonging to class q in choice situation t can be expressed as (Greene & Hensher, 2003; Train, 2009; Woo et al., 2017):

$$
\begin{aligned}
\mathrm{P}_{nt/q}(i) &= P(U_{nit/q} > U_{njt/q}, \forall j \neq i) \\
&= P(V_{nit/q} + \varepsilon_{nit/q} > V_{njt/q} + \varepsilon_{njt/q}, \forall j \neq i) \\
&= \int I(\varepsilon_{njt/q} < V_{nit/q} - V_{njt/q} + \varepsilon_{nit/q}, \forall j \neq i)\, f(\varepsilon_{nit/q})\, d\varepsilon_{nit/q} \\
&= \frac{\exp(\mathrm{X}'_{it}\,\beta_q)}{\sum_{j=1}^{J} \exp(\mathrm{X}'_{jt}\,\beta_q)}
\end{aligned} \tag{4.14}
$$

where, I (.) is an indicator function equal to 1 when the equation in the parenthesis is true and 0 otherwise. For a particular class, the probability of n household belonging to a q latent class is:

$$
P_{n/q} = \prod_{t=1}^{T} P_{nt/q} \tag{4.15}
$$

The most important part is identifying class assignment. To identify the unknown class assignment, the prior probability of household n belonging to class q (q=1….Q) is defined as (Greene & Hensher, 2003; Train, 2009; Woo et al., 2017):

$$
H_{nq} = \frac{e^{(Z'_n \theta_q)}}{\sum_{q=1}^{Q} e^{(Z'_n \theta_q)}}, \theta_Q = 0 \tag{4.16}
$$

where, Z_i is an observable set of characteristics that determine the model for class membership and θ_Q is set to be zero for identification purposes (Greene & Hensher, 2003; Woo et al. , 2017).

The probability of individual choice is the expected value of the class specific probabilities:

$$P_n = \sum_{q=1}^{Q} [e^{(Z_n' \theta_q)} \Big/ \sum_{q=1}^{Q} e^{(Z_n' \theta_q)}] * P_{n/q} \qquad (4.17)$$

The log likelihood to be maximized can be expressed as:

$$LnL = \sum_{n=1}^{N} \ln P_n = \sum_{n=2}^{N} \ln \left[\sum_{q=1}^{Q} e^{(Z_n' \theta_q)} \Big/ \sum_{q=1}^{Q} e^{(Z_n' \theta_q)} * \left(\prod_{t=2}^{T} P_{nt/q} \right) \right] \qquad (4.18)$$

There is a large body of literature which compares the latent class logit model with the mixed logit model by applying each of them in different domains in empirical studies. These studies found that there is no consensus in showing that one model is better than the other and thus conclude that these models are entirely data dependent (Green & Hensher, 2003). However, some studies argue that the selection of the model depends on the researcher's contextual situation. For instance, if a researcher is interested in uncovering individual heterogeneity for identifying decision makers' preferences, the mixed logit model is preferred. Whereas if a researcher understands that individual behavior ultimately converges into homophile latent groups thus identifying the heterogeneity of latent groups is important, the latent class model is preferred.

4.2. Willingness to pay (WTP)

In consumer research the main focus of study is optimizing the prices of the services, in addition to likes and dislikes. For doing this it is helpful to know what a consumer is prepared to spend on a certain good or service. The willingness to pay for goods and services can be elicited in various ways, for example, using surveys and observations. The survey method is often referred to as the stated preference method as households can be asked directly or indirectly how much their WTP is. Breidert (2006) sub-divides the survey method into direct surveys and indirect surveys. While in direct surveys experts or actual consumers are explicitly asked about their WTP, indirect surveys such as a conjoint analysis apply a subtle method which helps in estimating willingness to pay for single respondents, segments or aggregated to the whole sample or market. Direct surveys may bring deflated results as asking consumers directly about what they are willing to pay might unnaturally increase the respondent's price perceptions. In addition, respondents could feel that they have direct influence on a product's pricing, which might incentivize them to understate their true willingness to pay (Breidert, 2006). My study uses both methodologies to estimate the potential WTP for future fluoride safe water services in the study area. Since both methods have their own comparative advantages in estimating consumers' willingness to pay, my study first uses the conjoint analysis in measuring willingness to pay. In the context of discrete choice models, the willingness to pay principle is used to convert part-worth into dollar terms (Ethiopian birr in this study) to make the results more communicable. Willingness to pay is estimated calculating the implicit value of the attribute levels included in the design, that is, by dividing a level by the linear price parameter. Different factors affect WTP and marginal valuations for future water services. Willingness to pay for future water services connections is affected by proposed characteristics such as water quality in terms of fluoride concentration attributes, quality of service attributes, information communication attributes and affordability and ability to pay attributes.

A welfare analysis is frequently done by estimating willingness to pay for policy changes. When households are utility maximizers their willingness to pay is measured by the Hicksian consumers' surplus attached to the equivalent price change (Hicks, 1939; Diamond & McFadden, 1974).

Accordingly, the willingness to pay for a one unit improvement in that attribute is the ratio of its marginal utility or attribute coefficient to the coefficient of price $\left(\beta_i / \beta_{price} \right)$. The willingness to pay is the marginal rate of substitution between an attribute and the cost attribute, that is, the WTP value gives necessary compensation in monetary terms for a one unit deterioration of an attribute to remain at the same level of utility. In this case the WTP is in additional to the monthly water bill (in percentage terms). For example, an increase in the duration of water service interruption by one hour has to be compensated by a decrease of the monthly water bill by some (length of interruption coefficient) percent. Based on different models, we may have different values of willingness to pay [14] (Sagebiel, 2011).

My study also uses an open ended contingent valuation method (CVM) to estimate the WTP for future fluoride safe water supply in the Rift valley region of Ethiopia, to compare and contrast the maximum potential WTP for future water services. This can help water service providers to become aware of whether the households have the potential to cover the costs of service improvements.

4.2.1. Willingness to pay using contingent valuation (CV) methods

According to the water resource management policy[15] water is both a 'social and an economic good'. On the one hand everybody has the right to get clean water at affordable prices and on the other hand, water supply and sewerages services should generate enough funds to cover their costs for sustainability and for further expansion into new areas. Therefore, considering clean water supply as a quasi-public good in the sense that everybody has the right to access clean water but not necessarily have a connection at home, the value of a quasi-public good can be measured by the total benefit derived by every individual to whom the good/service is provided. The benefit is estimated

[14] In the latent class logit model, WTP is calculated for only significant attributes and it may even lead to a large figure if the individual cost parameter is too small while the attribute parameter is large. In the Tobit and OLS models the expected WTP is calculated linearly using coefficients and the average values of the attributes.
[15] https://www.slb.com/services/additional/water/resources/policy.aspx.

using the net change in households' incomes that is equivalent to the change in quality of water services. My study deals with the valuation of fluoride safe water service provision to Rift Valley residents in Ethiopia and hence I consider a change in the quality of the water to calculate the benefit derived from this quality improvement. Accordingly, let an individual choose his w_i, volume of water to draw from a tap; and then the public determines the quality level of the water q_j. w is supposed to be available at prices, p_1, p_2. . . p_n ~ p, which may or may not be determined by the market. A household maximizes its utility subject to income Y; the indirect utility function is given as (Haab & McConnell, 2003):

$$V(p,q,\mathrm{Y}) = \max_w \{u(\mathrm{w},q) / p.\mathrm{w} \le Y\} \qquad (4.19)$$

Using the dual of indirect utility function which is expenditure minimization function $m(p,q,\mathrm{u})$:

$$m(p,q,\mathrm{u}) = \min\{p.\mathrm{w}/ u(\mathrm{w},q) \ge \mathrm{u}\} \qquad (4.20)$$

This expenditure or indirect utility function provides the theoretical structure for welfare estimation. Welfare measures such as ideas of compensating and equivalent variation and the willingness to pay and willingness to accept are directly derived from the area under the demand curve (the Marshallian and Hicksian demand curve). Suppose the quality of water supply increased from its current status to a fluoride safe level of water services $q*$. To measure how much the households value fluoride safe water in the Rift Valley region, we used consumer WTP based welfare measures using an open ended contingent valuation based hypothetical scenario elicitation method. For a household, willingness to pay is the amount of income that compensates for (or equivalent to) an increase in the quality of water supply:

$$V(p, q^*, \mathrm{Y} - WTP) = \mathrm{V(p, q, Y)} \qquad (4.21)$$

when $q^* \geq q$ and an increase in q is desirable ($\partial V / \partial q_i > 0$). By the same fashion, we can define WTP with the expenditure function (Haab & McConnell, 2003):

$$WTP = m(p, q, u) - m(p, q^*, u) \, when \quad u = V(p, q, \mathrm{Y}) \qquad (4.22)$$

Willingness to pay for improved water quality is simply the difference between two expenditure functions with $q^* > q$. From the Hiksian demand function, $w_i^u(p, q, u) = m_p(p, q, u)$,we estimate the willingness to pay for access to w_i changes when their qualities change. If the water quality improves from q to q*, individual willingness to pay for access to fluoride safe water is:

$$WTP(fluoridesafe) = \int_{p}^{p^*} w_1^u(p', q^*, u)dp' - \int_{p}^{p^*} w_1^u(p', q, u)dp' \qquad (4.23)$$

Eq. 4.24 shows the change in the area under the Hiksian demand curve for quality changes from q to q* and price changes from current p to choke price p*.[16] Since such demand functions are derivatives of the expenditure function with respect to price, putting into integral we can express the changes as:

$$WTP(fluoridesafe) = m(p^*, q^*, u) - m(p, q^*, u) - [\mathrm{m(p^*, q, u) - m(p, q, u)}] \qquad (4.24)$$

Weak complementarity implies that at choke price (p*) or higher, an increase in quality does not shift the expenditure function, and hence $m(p^*, q^*, u) = m(p^*, q, u)$. Rearranging Eq. 4.24, the WTP for access to fluoride safe water service is:

[16] Choke price is the minimum price at which the quantity demanded of a good is equal to zero. At any price below the choke price, consumers will demand some quantity of the good.

$$WTP(\,fluoridesafe) = \int_{p}^{p^*} w_1^u(\,p', q^*, u)dp' - \int_{p}^{p^*} w_1^u(\,p', q, u)dp' = \mathrm{m(p, q, u)} - \mathrm{m(p, q^*, u)} \qquad (4.25)$$

This estimates the compensating surplus measure for water quality connection at home and at the nearest public tap. In other words, it is the additional charges that each consumer is WTP and remains at the utility level before the change. Using Whittington et al., (1990) and Whittington et al.'s (2002) specification, we estimate WTP using a multivariate regression analysis because willingness to pay varies across households based on demographic characteristics, economic characteristics and the perceived attitudes towards quality of water services that can be denoted by X_i in the expenditure function. Hence, in general the WTP for an improved fluoride safe water connection is:

$$WTP(\mathrm{q}^*) = m(\mathrm{p, q, u_0; X}_i) - m(\mathrm{p, q^*, u_0; X}_i) \qquad (4.26)$$

4.3. **Model estimation**

The random utility model provides the framework for household choices among the proposed water service alternatives. Under the assumptions of the random utility models, consumer utility for water services is expressed as a function of future water service attributes and socio-demographic characteristics. As discussed in next chapter in detail, households were asked to consider six attribute scenarios using conjoint methods: quality (in terms of fluoride concentration levels) of water with reference to the World Health Organization's standards, frequency of interruption, duration of interruption, prior notification of service disconnection, means of notification and expected additional fee for service improvement.

My study uses a rank ordered conjoint experiment to measure the importance of the features of water services in making decisions about connection for which the respondents were asked to rank their preference alternatives in descending order in a six-rank set. As a starting point for empirical investigation, data from the rank ordered experiment was analyzed using the mixed logit model outlined by Train (2003). The setting of the choice probability for maximum likelihood estimation was done as outlined in equations 4.9, and 4.10 with random coefficients except additional price variables. The mixed logit model was used to incorporate individual heterogeneity in preferences for future water service connections and usage in the Rift Valley region of Ethiopia. This allowed variations across respondent preferences based on their tastes, abilities, perceptions, affordability and so on.

Finally, my study estimated the model using latent class logit to consider grouping behavior heterogeneity in preferences for future water service connections and usage, instead of individual level differences. This approach was found to be more practical for policymaking purposes if the groups were clearly differentiable and behaved differently because of some unobservable factors.

To elicit more information every respondent was asked to rank the alternatives in order of preference among j alternatives in each T choice sets as prescribed by Layton (2000). Accordingly, assuming a mixed logit model the utility of n households from j alternatives is:

$$\mathrm{U}_{njt} = \beta_n' X_{njt} + \varepsilon_{njt} \qquad (4.27)$$

where, X_{njt} is the vector of the attributes connected to alternatives j, β_n' is the vector of the parameter of part-worth distributed normal with b mean and variance covariance matrix W and ε_{njt} is an error term assumed to have an IID distribution.

As described earlier, in a mixed logit model, some coefficient vectors β_n' are assumed to have normal distribution with mean vector b and variance-covariance matrix W. However, some attributes have no normal distribution in coefficients, for instance, coefficients of the price and quality of water services. Hence, to incorporate this reality the log normal distribution was assumed. The log normal distribution can also be obtained from the transformation of normal β using $H = \exp(\beta)$ and then changing the utility specification as (Choi et al., 2008; Kim, 2005):

$$\mathrm{U}_{njt} = H(\beta_n)' X_{njt} + \varepsilon_{njt} \qquad (4.28)$$

where, C is a transformation. Hensher and Green (2001) point out that the model may not converge or, even if it converges it may converge with unacceptable large estimates when an attribute is specified with a random parameter in log-normal distribution with a positive sign. As a solution, the negative of the attribute should be defined instead of imposing a sign change on the estimated parameter.

Using β_n samples taken from the retained draws of b and W in the Bayesian process, the relative importance of each attribute can be calculated by using the part-worth of each attribute following Shin et al., (2014) as:

$$RI_k = \left[(part - worth_k) / \left(\sum_k part - worth_k \right) \right] * 100 \qquad (4.29)$$

where, $part - worth_k$, can be found by multiplying β_k, the coefficient value of attribute k, by the value of the difference between maximum and minimum levels. The term denotes the impact of changing the attribute's level within a particular attribute.

Studying consumer preferences for future water services is important for policymakers and other stakeholders; however, demand side information alone may not be sufficient to make strong policy recommendations. Hence, my study also explored water providers' challenges in supplying clean water in the study areas. As explained in Chapter 2, online technology has the potential to monitor the level of fluoride in remote areas and hence my study considered technology aspects along with the other challenges that prevent the supply clean water using the analytic hierarchy process.

4.4. The Analytical Hierarchy process method (AHP)

First introduced by Thomas Saaty (1980) the analytical hierarchy process is a popular method for dealing with a complex decision making process. It is an effective tool for a decision maker to get to know the priorities and take appropriate decision. By using a pairwise comparison of complex decision factors and criteria it reduces and then synthesizes the results. The method also enables capturing both the subjective and objective aspects of a decision. It is used to select the best technology and identifying priorities among many alternatives and can be applied in different fields of study that aim to take the best decision. Accordingly, my study identifies the main factors that limit clean water supply and selects potential technology that will enable water providers to monitor the level of fluoride in drinking water.

AHP broadly follows four steps in solving a decision problem (Saaty, 2008). The first step, converting the structure of a decision into a hierarchical model, involves the disaggregation of the problems into individual elements at their respective levels according to their common characteristics. The upper level represents the overall main goal whereas the middle level corresponds to criteria and sub-criteria under the nearest criteria. And lastly the lower level comprises alternatives to the decision (Saaty, 2008).

In the second stage the judgmental matrix is formed from pairwise comparisons of factors. This matrix is used for computing and identifying priorities of the corresponding elements. Initially the factors are compared pairwise with respect to their immediate goals and then a judgmental matrix, represented by, H, is created from the comparisons. Each entry (h_{ij}) of the matrix is made from the row element (H_i) with the column element (H_j):

$$\mathrm{H} = (\mathrm{h}_{ij}) \qquad (i, j = 1,2 \ldots n, number\ of\ criteria)$$

A comparison of any two criteria, A_i *and* A_j, with respect to the target is done using questions like, 'Of the offline versus online criteria which is more important for monitoring the level of fluoride in the water supply instantaneously?'

Saaty (2008) suggests using a nine-point scale to convert subjective judgments into objective numerical quantities, indicating the values of h_{ij}. The measurement scale is presented in Table 4.1

Table 4. 1 Relative importance measurement scale

Importance level	Meaning	Description
1	Indifferent /equal important	Two criteria are considered equally important
3	One is moderately important as compared to the other	One criteria is marginally favored over another
5	Significantly important	One criteria is strongly preferred over another

7	Very significantly important	One criteria is very strongly preferred and its domination is revealed in practice
9	Extremely important	Evidence favoring one criteria over another is of the highest possible order
2, 4, 6, 8		Intermediate values between two adjacent judgments

Source: Millet and Saaty (2000).

The entries in h_{ij} are governed by:

$$h_{ij} > 0;\ h_{ij} = 1/h_{ii};\mathrm{h}_{ii} = 1\ for\ all\ i.$$

Because of this rule, the judgmental matrix H is a positive reciprocal pairwise comparison of the matrix.

The third step is obtaining the local priority of the criteria and determining the consistency judgments. This could be done after the second step (constructing the judgmental matrix of the comparisons of the criteria with respect to the goals at every level). Priority of the factors or criteria can be estimated by calculating the principal Eigen vector *w* of the matrix H, that is:

$$\mathrm{H}w = \lambda_{\max} w \qquad (4.30)$$

The priority of the vector of the criteria with regard to its goal is obtained by normalizing the vector w in Eq. 4.30. $\lambda_{\max}$ is the largest eigenvalue of matrix H and the corresponding Eigen vector W contains only positive entries. The consistency of the judgmental matrix can be determined by the measure of consistency ratio (CR), defined as:

$$CR = \frac{CI}{RI} \tag{4.31}$$

where, consistency index (CI) and RI are the random index. By turn the consistency index is defined as:

$$CI = \frac{\lambda_{\max} - n}{(n-1)} \tag{4.32}$$

where, n is the number of criteria within that level. CI is a randomly generated reciprocal matrix from the nine-point scale. If the consistency ratio of the matrix is high, it means that the inputs' judgments are inconsistent and hence unreliable. After obtaining the local priorities for every element at each level these are combined to obtain the final priorities of the alternatives. According to Saaty (1980) a consistency ratio of less than or equal to 0.10 is considered acceptable. A graphic representation of the problem under study is shown in Figure 4.2, where the AHP design in the procedure is shown in three levels.

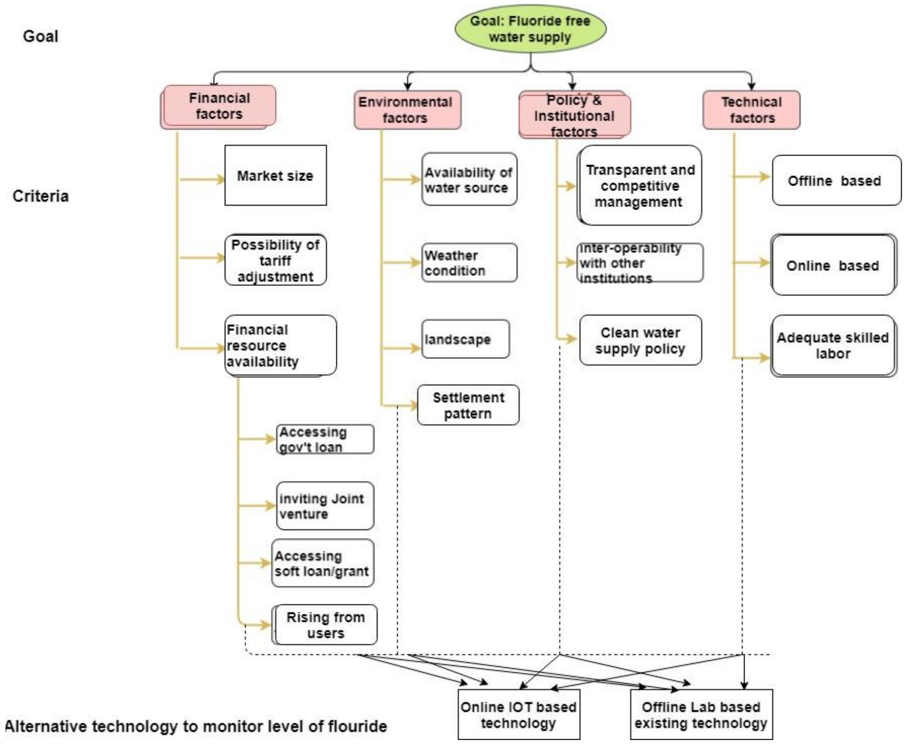


Figure 4 2 hierarchical representation of the problem

The top level represents the goal which is identifying the main constraint factors affecting the fluoride safe water supply. The second level represents different constraint factors considered as criteria, followed by different sub-criteria under each factor. From the second, third and fourth levels the most important priority solutions that enable fluoride free water supply are selected.

The overall methodological framework used in my study is summarized in Figure 4.3.

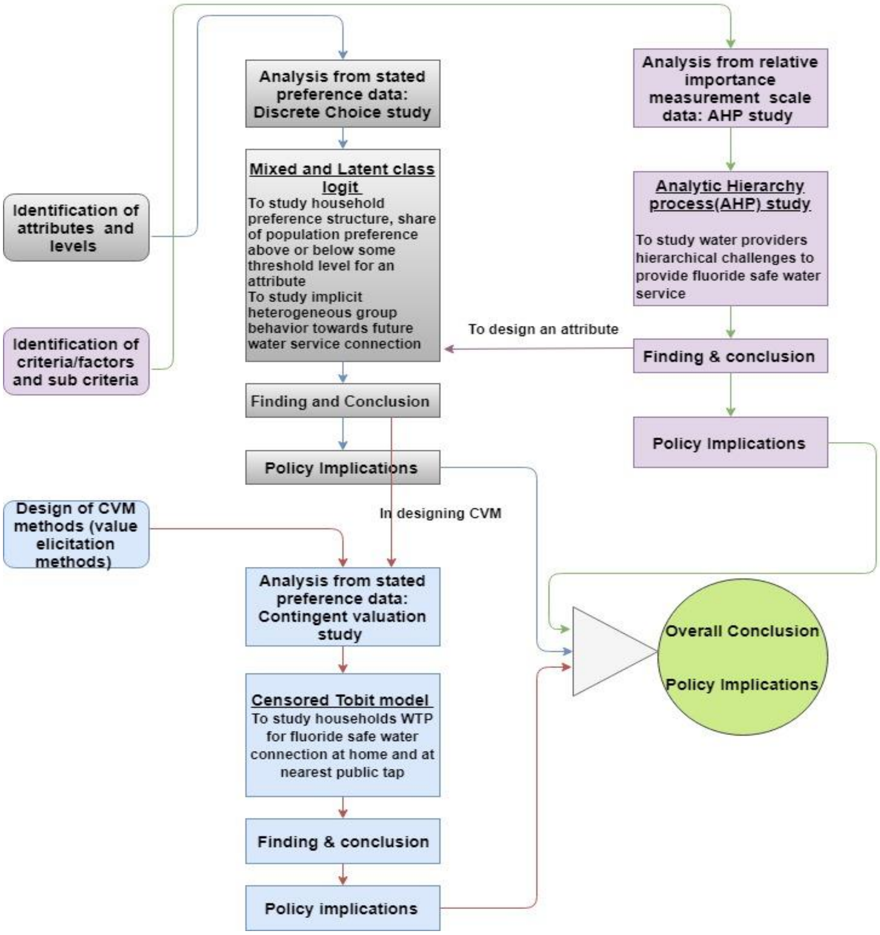


Figure 4 3 overall methodological framework

Chapter 5. Experimental design and estimation results

A crucial part of the discrete choice procedure involves the experimental design stage since the design of the experiment has a substantial impact on the accuracy of the estimated model. This chapter describes how I carried out the experiments and includes the survey area, survey design and data. It also deals with estimation results and provides a policy scenario for the study area.

5.1. Survey design and data collection

5.1.1. Conjoint survey

A conjoint analysis is done to measure the utility of the products by merging the separate utilities attached to each attribute and deals with the measurement of psychological judgments as household preferences and perceived differences and similarities between choice alternatives (Green & Srinivasan, 1990). This implies that it is based on the premise that a household evaluates a product as a bundle of attributes so that the value or utility associated with its 'total worth' is obtained by combining separate amounts of utility provided by each attribute or 'part-worth.' The conjoint methodology is based on rigorous utility theoretic principles (Louviere et al., 2000) and has been adopted as an alternative to CV methods with validity concerns (Ryan et al., 2001). Further, a conjoint method uses more information of a higher quality with lower costs than a contingent valuation method for service valuations (De Shazo & Fermo, 2002). It is also a popular method for examining the relative importance of attributes and thus estimating WTP for them. Rolfe et al., (2002) also argue that a discrete choice experiment has substantial framing advantages over contingent valuation methods as it allows respondents to rank or choose from a large pool of potentially substitutable goods and reveals a realistic trade-off between opportunity costs. In contrast, a contingent valuation method assumes that respondents have considered substitutable goods and alternatives though the researcher has no direct observation of the fact. The ability of a choice experiment to disguise the goods to be valued within a basket of potential trade-offs is an important way of reducing information transfer and other potential biases and of modelling realistic choices. As DeShazo and Fermo (2002) recommend, during a conjoint analysis, many design issues and options such as attribute definitions need to be considered at the outset to prepare a conjoint survey to ask respondents to choose or rank among hypothetical scenarios in an experiment to reveal the value they place on different criteria.

I use conjoint methods which enable the use of a stated choice survey of households to measure their preferences in hypothetical situations (Green & Srinivasan,1990; Louviere et al., 2000). Such stated preference data is usually much richer than revealed preference data and, hence, opens up opportunities to enhance the behavioral capability of the mixed logit model (Hensher et al., 2005) in situations where market data is scarce, or where it is useful to know about consumer preferences for products/services that do not exist in the market (Jeong, 2008; Kim et al., 2005).

My study did a household survey, which is essential for an analysis of most policy issues since accurate, up-to-date and relevant data from household surveys is instrumental for making sound economic and social policy decisions (Grosh & Glewwe, 2000). The conjoint survey asked respondents to state their preferences for each alternative box in which a hypothetical bundle of water service attributes was provided.

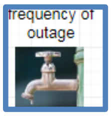
5.1.2. Attributes and their levels

The first stage of a discrete choice experiment and a conjoint survey involves identifying the attributes relevant to the stated research questions and then assigning levels for each of these attributes (Hensher et al., 2005). Working on this design is important since the attributes and the levels describe the hypothetical scenarios that the research considers.

As Hensher et al., (2005) suggests taking precautions when recognizing ambiguity inherent in establishing the meanings of attributes and their influence on an individual's choice, which in my case is use of clean water. My study recognizes this and made substantial efforts to work through ambiguity in meanings and measurements as much as possible. As Do and Bennett (2010) explain, focus group discussions help understand the nature of phenomena in a holistic sense particularly in establishing plausible and understandable scenarios for respondents who may never have experienced such choice tasks before.

I did pilot testing of the questionnaire to identify the possible difficulties that respondents might face in understanding the survey questions. For instance, it was found that instead of using the term ‘percentage’ when questioning uneducated people in rural areas, the questionnaire should explain how much additional price they would be willing to pay with selected alternatives like services (using local terminology which they use in their daily activities) because they are not familiar with percentage and they may not know how much, for example, plus 25 percent is in addition to their current water bill. So I used local terminology like *dabalata ruubi*. I also made additional price adjustments after the pilot survey and added some questions for the main survey. Further a day before leaving for the survey, the researcher trained data enumerators and did a demonstration by letting them interview each other. This made them internalize the questionnaire and its contents and how to clarify in case they did not understand something.

Table 5. 1 Service attributes and variable definitions

Attribute picture/	Levels	Description	Previous research
Quality of water supply(flouride level /l) 	Above WHO standards Equal to WHO standards Below WHO standards	This attribute measures the proposed fluoride concentration levels with reference to WHO standards (maximum 1.5 mg/L).	
	Once in 3 months Once in 2 months Once in a month	Number of water service disconnections per month	Hensher, D., Shore, N., and Train, K.

			(2005)
	1hour 12 hours 24 hours	Duration of hours for which water is unavailable each time that it goes off (on average)	Hensher, D., Shore, N., and Train, K. (2005)
No. of days for prior notification 	1 day 4 days 7 days	Number of days prior to service interruption that a notification is received by users	Hensher, D., Shore, N., and Train, K. (2005)
Means of information notification   	Mobile based Internet based Mass media based	Means of information service delivery for notification of service interruption. Mobile based means it can be through voice call or SMS. Internet based means it can be through email or through different social media such as Facebook, WhatsApp, and twitter and mass media includes local TV channels, radio or personal announcements	Hensher, D., Shore, N., and Train, K. (2005) using fixed line only
Additional cost in current bill/month 	**Same level** **+ 25 percent** **+ 50 percent**	Additional payment that households are WTP for service improvements per month	

In the final version of the questionnaire, six attributes (Table 5.1) were decided on to express future water and its service characteristics based on the existing situation in the study area; these are also based on the literature review and holding focus group discussions with people in the study area.

The first attribute 'quality of water' describes the concentration level of fluoride in the drinking water in the study area. This attribute is captured as a dummy variable with three levels which indicate the concentration level of fluoride in line with WHO's acceptable limits. The quality of water above the WHO standard is when fluoride concentration is less than 1.5mg/L. The quality of water equal to the WHO standard means that the fluoride concentration is equal to 1.5 mg/l and the third level less than the WHO standard means that the fluoride concentration is greater than 1.5 mg/L, like the current situation in the study area. This attribute was included to recognize consumers' awareness levels, degree of prevalence of fluoride (explained in the willingness to pay section) and desire to have a connection to improved water services. Information on consumer preferences regarding the quality of water services can help the local government (*woreda*, zone and regional) and other stakeholders to search for technology that can help them monitor the quality of water service provision, given that other bounding factors are managed.

The second attribute 'frequency of disconnection' is a continuous variable in my study and it has three levels in the survey design which capture the number of times consumers are willing to tolerate water service disconnection per month. As explained by Hensher et al., (2005), interruption of water services may occur for planned maintenance or due to unexpected system failures. The expected number of times of water service disconnection can be affected by capital investments and the operational level of the supplier, with better levels of service generally being attainable through higher costs and hence higher prices. Hence, considering developing countries, particularly the existing situation in the study area the survey proposed three levels for frequency of interruptions -- once a month, once every two months and once every three months.

The third attribute ‘duration of interruption’ is also treated as a continuous variable in the estimation. This attribute is important since interruption avoidance is hardly possible in the study area because of factors including limitations of financial, environmental, institutional and technical capacity. However, consumers value shorter service interruptions than longer disconnections and hence the attribute has three levels -- one hour duration outage, 12 hour outage and 24 hour water service outage.

The fourth attribute ‘length of prior notification days’ is proposed assuming that before a service interruption occurs, consumers will receive a notification so that they can plan and store water for the number of days that the service will be unavailable, except in case of emergency interruption when the prior notification is not possible. But the question here is that some people may need to receive the notification very early so that they can get time to manage and store enough water or other people may want to receive notification just a day before the interruption. Basically the number of days required to receive a prior notification may depend on people’s work load, work area, type of job, family size and own sufficient storage capacity. Three levels were used to capture this attribute -- one day before service interruption, four days earlier before service interruption and seven days before service interruption.

The fifth attribute ‘means of information service notification’ is a dummy variable with three levels – mobile-based service notification, internet-based service notification and mass media-based service notification. The compatibility of the means of information delivery also matter for the effectiveness of service improvement. For instance, a consumer who has no internet connection cannot get the notification on internet platforms such as on the water provider’s website, on social media or through email. People may have different information communication devices and may affect their decision to connect to improved water services with regard to lack of information notification devices or they may be forced to buy a new device. Therefore, this study considers three levels as given in Table 5.1 as service notification platforms for the water provider company.

The sixth attribute ‘additional price’ also has three levels showing the expected percentage of additional price that households are willing to pay for service improvements. This attribute is an important variable used to measure the willingness to pay for other attribute levels mentioned earlier. Hensher et al., (2005) used price to determine consumer demand for drinking water services and waste water treatment. In my study the first additional price is the same as the existing current bill, which is very low and may be targeted at people who cannot afford to pay for improvements in water services and may require other means of support for their water connections. The second level is plus 25 percent of the current bill and the third level is plus 50 percent of the current bill which all are tolerable considering the existing water supply (both quantity and quality) deficiency and consumers spending extra on averting activities in the study area. Finally, I converted these attribute levels to continuous a variable to measure the value of other attributes in terms of a one unit price change.

In general, the six attributes were defined to establish the choice experiment considering the requirement of a good understanding of the target population's perspective and experience (Coast & Horrocks, 2007) based on an exploratory identification process: results of earlier studies and focus groups and a pilot study (Lancsar & Louviere, 2008). The identified attributes fit the goal of my research and are relevant with assigned levels that are realistic.

While generating hypothetical alternatives to create choice sets, my study considers the goal of ensuring maximum efficiency in designing the experiment as prescribed by Huber and Zwerina (1996), encompassing the principles of level balance, orthogonality, minimal overlap and utility balance. By considering six attributes with three levels each, the total choice set becomes 729; I used a fractional factorial design to develop an orthogonal array of hypothetical future water service packages. Finally the array contained six choice sets with three alternative services in each set that each consumer had to rate in terms of likelihood to connect (Table 5.2).

As consumer preferences vary according to their socioeconomic background (Wareham & Levy, 2002), it is necessary to investigate consumer demands for water service improvements in terms of these characteristics. Hence, demographic data such as sex, age, education, income and household size are included in the survey instrument to ensure that a broad consumer base is covered.

Table 5. 2 Generated choice cards

services	Quality of water supply standarda	Frequency of disconnection	Duration of disconnection	length of prior notification received	Means of information notification	Additional price to current bill
Service 1	Below WHO	once in 3 months	24 hour	7 days	mass media based	+ 25%
Service 2	Equal to WHO	once in 2 months	1 hour	1 day	mass media based	+ 25%
Service 3	Above WHO	once a month	1 hour	1 day	mobile based	same level
Service 4	Above WHO	once in 3 months	12 hour	4 days	mobile based	same level
Service 5	Below WHO	once in 3 months	24 hour	1 day	mobile based	+ 50%
Service 6	Equal WHO	once a month	1 hour	4 days	internet based	+ 25%
Service 7	Below WHO	once in 3 months	1 hour	4 days	mass media based	+ 50%
Service 8	Above WHO	once a month	12 hour	7 days	mobile based	+ 25%
Service 9	Equal WHO	once a month	24 hour	7 days	internet based	+ 50%
Service 10	Below WHO	once in 2 months	12 hour	4 days	internet based	+ 50%
Service 11	Equal	once a	12 hour	1 day	mass	+ 50%

	WHO	month			media based	
Service 12	Above WHO	once in 2 months	24 hour	1 day	internet based	same level
Service 13	Equal WHO	once in 2 months	1 hour	7 days	mobile based	+ 50%
Service 14	Above WHO	once a month	24 hour	4 days	mass media based	same level
Service 15	Below WHO	once in 2 months	24 hour	4 days	mobile based	+ 25%
Service 16	Below WHO	once in 3 months	12 hour	1 day	internet based	+ 25%
Service 17	Equal WHO	once in 3 months	1 hour	7 days	internet based	same level
Service 18	Above WHO	once in 2 months	12 hour	7 days	mass media based	samele vel

The socio-demographic variables were interacted with this part-worth to find out how such factors impacted consumer preferences. Psychographic variables were also included in the survey to measure the consistency of the responses in the choice set section (see survey questionnaire in the appendix).

5.2. Descriptive statistics

My study is mainly targeted at an area where there is an excess fluoride in underground water and which has a clean water supply deficiency. Specifically, data was collected from Oromia regional state, East Shewa zone covering five *woredas* Adama, Lume, Bora, Zuway Dugda, and Adami Tulu and Jido Kombolcha. This *woredas* are known as the central Rift Valley region with the maximum fluoride concentration and low-quality water supply.

The study did multi-stage sampling in such a way that the study area was first identified as the Rift Valley region where there are problems of excess fluoride with low water service supply. The study also covered both urban and rural populations where some had private pipeline connections and others had no connection. In the second stage the zone and *woredas* were purposively selected guided by the regional water supply office's expert in identifying areas with excess fluoride. Then we selected five *woredas* and in each *woreda* the water supply office assisted the researcher in identifying specific *kebeles* with excess fluoride and water supply problems. Finally, we got a list of households from each selected *kebele* and using systematic random sampling identified the sample size proportion from each *woreda* (Table 5.4). For the sake of reliability of the data, the survey was conducted through personal interview. The sampling design is presented in Table 5.3.

Table 5. 3 Sampling design

	Description
Target population	Ranging from 21 to 60+ years living in 5 *woreda*s (districts) in the Rift Valley region of Ethiopia
Period of the survey	December 10, 2017 up to February 10, 2018
Total sample size	330 households
Means of drawing the sample	Randomly, allocation by *woreda* and age group

Table 5. 4 sample size

Woreda	Percentage of sample size drawn from woreda household[17]	Sample size	Percentage of each woreda respondents out of total sample
Adama	0.2	106	32.1
Lume	0.1	25	7.6%
Boora	0.3	66	20
Zuway dugda	0.4	67	20.3
Adami Tulu & Jido kombolcha	0.4	66	20
Total	0.3	330	100

*source, calculated from: *CSA 2013, population projection data*

A majority of the respondents were male household heads (63.3 percent) (household head is by default a husband, which is an inherited cultural influence in Ethiopia, unless they are divorced or widowed), about 47.9 percent of the respondents' education level was primary school followed by illiterate (40.6 percent). The average family size was 6 persons per household with majority of the profession of the respondents being farmer followed by own business.

Regarding current water supply characteristics the source of water supply for most of the respondents' is a public tap (32.4 percent), followed by open source including lakes, river, springs and public bore holes (21.2 percent). For those who get water from the pipeline the frequency of water service

[17] The percentage size of the sample is based on the amount of fluoride level concentration available in each woreda.

disconnections is three times per month on average (although this varies from *woreda* to *woreda*) (60.8 percent). Once the supply stops it stays this way for more than 24 hours according to most of the respondents (43.5 percent), and there is no official time schedule when the service will be disconnected and there is also no prior notification about service interruption (Table 5.5).

Table 5. 5 General descriptive statistics of the survey

Variables	Levels/category	Frequency and percentage in brackets	Remarks
Gender	Male	209(63.3%)	Out of all 330 respondents
	Female	121 (36.7%)[18]	
Education level	No formal school	134((40.6%)	
	Elementary school	158(47.9%)	
	High school	28(8.5%)	
	Diploma	9(2.7%)	
	Degree or greater	2(0.08%)	
Age	21-29	61(18.5%)	Out of all 330 respondents
	30-39	102(30.9%)	
	40-49	79(23.9%)	
	50-59	40(12.2%)	
	60+	48(14.5%)	
Marital status	Single	4 (1.2%)	Out of all 330 respondents
	Married	278 (84.8%)	
	Divorced	24 (7.3%)	
	Widowed	22 (6.7%)	
Family size (average)	Mean value	6	
Number of	0	169 (51.2%)	Out of all 330

[18] Man and women household head size is not proportional in Ethiopia and the man is predominantly the household head by default (cultural issues)

Children <5 years	1	117 (35.5%)	respondents
	2	38 (11.5)	
	3	6 (1.8%)	
Monthly income	Mean value	2260 ETB~ (83 USD)[19]	Out of all 330 respondents
Own house	Yes	317 (96.1%)	Out of all 330 respondents
	No	13 (3.9%)	
Type of house living in	Grass roof	68 (20.6%)	Out of all 330 respondents
	Metal sheet roof	260 (78.8%)	
	Condominium	1 (0.3%)	
	Villa or apartama	1 (0.3%)	
Profession of respondents	government /private employee	13 (3.9%)	Out of all 330 respondents
	own business	46 (13.9%)	
	Farmer	259 (78.5%)	
	un-employed	5 (1.5%)	
	Other	7 (2.1%)	
Current source of water supply	Private pipeline	63 (19.1%)	Out of total 330 respondents
	Public tap	107 (32.4%)	
	From private vendors buying from neighbor	59 (17.9%)	
	Private borehole	31 (9.4%)	
	From open source(lake, spring, common borehole)	70 (21.2%)	
Water bill	Average	113.20(US$ 4. 12)	Out of 229 respondents

[19] Exchange rate by December 2017 is 1 USD= 27.5 BIRR.

Volume of water consumption/month	In m^3	25.2	Out of 229 respondents
Frequency of disconnection per month	twice per month	6 (2.6%)	Out of 229 respondents
	three times per month	140 (60.8%)	
	greater than 3 times per month	85 (36.6%)	
Length of disconnection in hours once goes a way	Less than 1 hour	1 (.4%)	Out of 229 respondents who have access to pipeline water services.
	From [1-12] hour	37 (15.9%)	
	From (12-24] hour	93 (40.1%)	
	greater than 24 hour	100 (43.5%)	
Official time schedule for water service disconnection	Yes	0(0%)	Out of 229 respondents
	No	231(100%)	
Receive prior information about service disconnection	Yes	0 (0%)	Out of 229 respondents
	No	231 (100%)	
Aware presence of excess fluoride in drinking water	Yes	325 (98.5%)	Of 330 respondents
	No	5 (1.5%)	
Ever Uses bottle or other water for drinking as averting from fluoride effect	Yes	105 (31.8%)	Out of 330 respondents
	No	225 (68.2%)	
How much jerican of clean	Mean value	10.9 jerican	Out of 105 respondents who

water you buy per month(1 jerican=20 liters)			buy clean water
How much birr spent to buy clean water per month	Mean value	99.40 birr($US 3.6)	Out of 105 respondents who buy clean water
How much minutes' walk/ would like to sacrifice to fetch fluoride free water	Mean value	14.71	Out of 330 respondents
Means of information communication consumers would like to use for water service notification	Mobile based	271 (82.1%)	Out of 330 respondents
	Internet based	6 (1.7%)	
	Mass media based	53(16.2%)	
Use internet	Yes	14 (4.2%)	Out of 330 respondents
	No	316 (95.8%)	

Notes: *For about 101 households, the source of water supply is from open lakes, rivers and springs.

Segregating the respondents by *woreda* a majority of the respondents in Adama *woreda* got water from a public tap followed by open source with relatively low fluoride concentration whereas a majority of respondents in Bora *woreda* got water from private bore holes followed by open source with very high fluoride concentration. This implies that there is heterogeneity in water supply sources across *woredas* with different experiences thus changing the preference scenarios for improved services. The summary of water sources across the *woredas* is given in Table 5.6.

Table 5. 6 Households source of water supply by woredas

	Adama	Lume	Boora	Zuway Dugda	Adami Tulu and Jido Kombolcha	Total
Pipeline connection at home	0	8	0	41	14	63
Public tap	52	9	7	12	27	107
Private borehole	1	0	28	1	1	31
From open source (lakes, spring, common borehole)	37	2	24	1	6	70
Private vendors buying from neighbor	16	6	7	12	18	59

With regard to connecting to safe water pipeline at home and using other alternative mechanism to obtain quality of water the survey's descriptive result shows that income was important in opting for a pipeline connection at home , but it was not so for households getting alternative mechanisms such a drinking bottled water. Instead, this perception came from awareness about the risk of consuming water that was not clean. The cross-tabulation summary between household income versus pipeline connection at home and alternative bottled water consumption are given in Table 5.7.

Table 5. 7 Cross Tabulation between income vs private connection & bottled water

	Do household have private water pipeline connection at home/yard		**Have you ever used bottled water for drinking, for aversion purpose**	
	No	Yes	No	Yes
Household income per month in ETB (average)	2012 ($73.2)	3308 ($120.3)	2306 ($83.9)	2160 ($78.6)

Regarding to the alternative water usage, the average money expenditure on drinking bottled and other clean water was about 99.40 ETB (UD $3.62) per month per household. Compared to their total water bills per month and their total incomes per month, the amount of money spent on getting safe water quality services was 87 and 4 percent respectively. This is a very big amount compared to monthly earnings and implies the existence of a serious water supply problem and households' commitment to pay for better quality water. In addition, households were willing to travel for about a quarter of an hour on average to get better quality water by trading-off a big opportunity cost of their time. Currently, water expenses account for nearly 5 percent of the monthly income as shown in Figure 5.1.

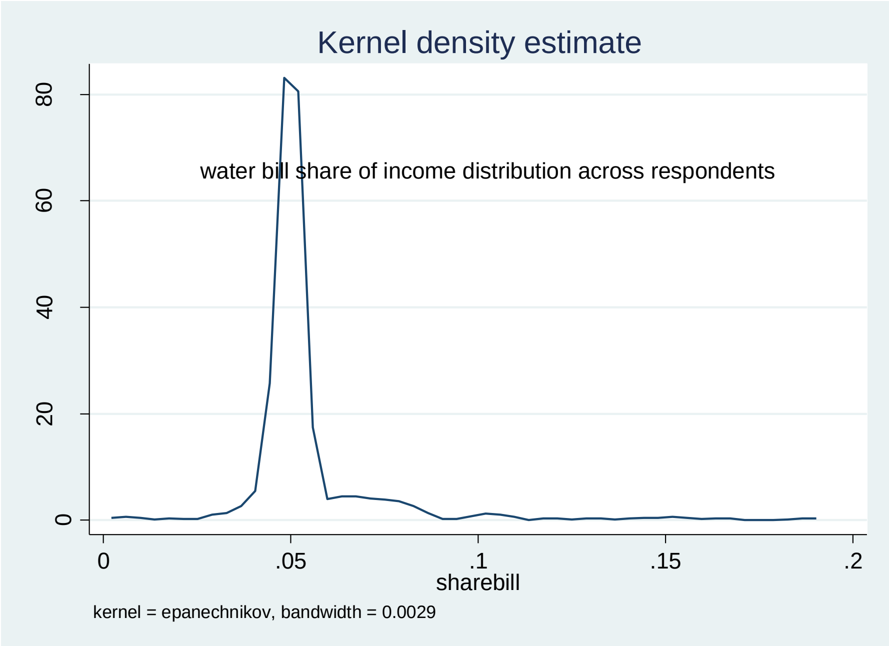


Figure 5. 1 Current share of expenses on water in income

As can be seen from Figure 5.1 for about 80 percent of the respondents the average share of water in their bills was around 5 percent of their incomes primarily because of the necessity to search for clean water from other sources. If clean water is be provided to these people their water bills will come down and because they will be able to transfer the existing extra expenditure they are incurring to access clean water from other sources to the new water supply connection.

From this descriptive statistics part, I drew a demand curve for future water service connections by identifying the respondents first choice among the alternatives with the proposed additional price levels (Figure 5.2).

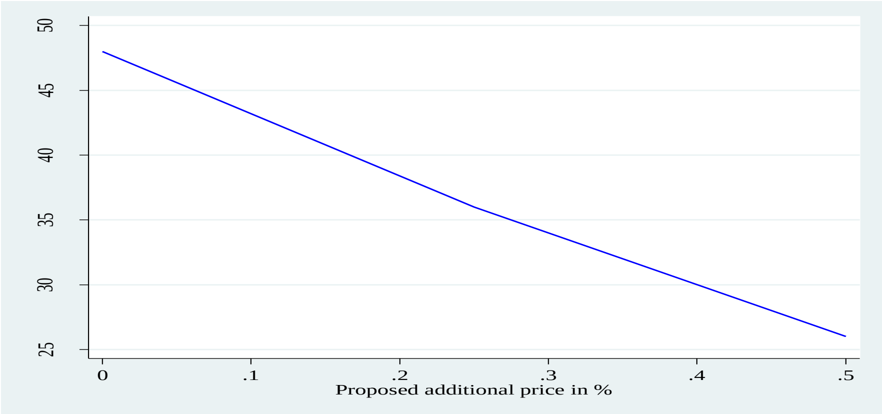


Figure 5. 2 demand curve for improved water service

As can be seen from Figure 5.2, the number of households who choose the proposed future water services decreases as the price level increases, confirming the law of demand. The proposed additional prices are at same level as the current bill, plus 25 percent of current bill and plus 50 percent of current bill (as described in Chapter 5).

Regarding information communication related to water services a majority of the households would like to get notifications via their mobile phones followed by local mass media. This result matches the current situation in Ethiopia where mobile phone penetration is large while internet penetration is small and only concentrated in big towns. According to my survey's results about 82.1 percent households prefer mobile-based notifications such as voice call, SMS and MMS, whereas about 16.2 percent prefer mass media-based notifications (these are mainly aged people who are always at home) and very few households (about 1.7 percent) prefer internet-based services via websites, social media platforms and through email.

Households' perceptions about improved water services were also investigated using the Likert scale. The result of this psychographic information is given in Table 5.8.

Table 5. 8 Psychographic information summary

Variable |	Mean	Min	Max
I Prefer pay more tariff _than frequent interruption	4.71	1	5
I Value quality of water more than always availability	4.60	1	5
I believe to get prior_ notification before interruption	4.45	1	5
I Prefer prior notification by mobile phone	4.46	1	5
I Prefer prior notification by internet based	2.04	1	5
I am WTP_somemoney _to remove fluoride	4.43	1	5
I am not satisfied with existing drinking water supply	4.88	1	5

As Table 5.8 shows the average value of all the perceived factors is above the mean value of the Likert scale measurement (from 1 up to 5 Likert scale points with mean 3), except the preference for prior notification of services using the internet. This is because many people are not using internet services due to poor internet penetration in the country in general and in the study area in particular. As evidenced by the survey data, only 4.2 percent of the respondents were using internet services. Hence, many people preferred paying more tariffs than facing frequent interruptions or frequent interruption of services. Not only this, but many people also wanted to have quality water and not just uninterrupted low quality services. This implies that people do not want to compromise on the quality of drinking. This tells water service providers and the government a lot about preferences for the quality of water. In addition to the quality of water the people are also ready to pay more to remove fluoride and to avoid frequent interruption of services. The amount they are willing to pay is addressed in the empirical estimation section.

In general the consumers are not satisfied with the existing water supply sources and are therefore looking for better water service connections.

5.3. Empirical models and estimation results

Chapter 4 briefly explained the modelling framework for my study. This section presents the estimation results, discussion and implications of the results. This section is divided into three sub-sections.

Sub-section 5.3.1 discusses the providers' main challenges in providing fluoride tolerable water services to the residents in the study area. This sub-section discusses the providers' hierarchical challenges based on pairwise relative importance measurement data collected from water providers' expert judgement survey.

Sub-section 5.3.2 presents consumer preferences for future water service attributes in the excess fluoride region of Ethiopia. It assumes that households have heterogeneous preferences with regard to the quality of water services and hence introduces heterogeneity in decision making. This means that consumer preferences for future water services depend on individual characteristics and alternative service attributes. Since individual consumers are behaviorally different because of their different socioeconomic and cultural backgrounds and taste variations their individual behavior affects the overall aggregate preference. However, managing every individual behavior is very complex where everyone has a different preference structure. After identifying individual behavior, the study categorized consumers into different groups based on their common preferences. Assuming there are q number of groups whose preferences are homogeneous within the group but heterogeneous across the groups, the modelling allows us to draw better implications.

Sub-section 5.3.3 discusses consumer WTP by comparing estimates from the conjoint analysis and the contingent valuation analysis. After estimating individual mean WTP, a benefit cost analysis is conducted by calculating the aggregate present value of mean WTP for fluoride safe water supply.

5.3.1. Providers' constraints in supplying fluoride safe water services in the Rift Valley region

This section provides rigorous explanations of the providers' hierarchical challenges that bound fluoride tolerable levels of water supply services. This is based on a pairwise relative importance measurement data collected from water providers' expert judgment survey (Table5:9).

Table 5. 9 Descriptive statistics of an experts' survey

Variables	Levels/ category	Frequency and percentages	Remarks
Education level	Diploma or technical vocation	10 (50 percent)	Five selected water provider

	Bachelor’s degree	7 (35 percent)	woredas were: Adama Lume Bora Dugda Adami Tulu and Jido Kombolcha
	Master’s degree	3 (15 percent)	
	PhD	0 (0 percent)	
Profession of the respondents	IT/computer related engineer	2 (10 percent)	
	water supply engineer,	10 (50 percent)	
	marketing, business expert,	3 (15 percent)	
	civil engineering	3 (15 percent)	
	Geologist	1(5 percent)	
	Electro mechanical engineer.	1(5 percent)	
	other field	0(0 percent)	
Position of the respondents	Head of the company	3 (15 percent)	
	experts	14 (70 percent)	
	team leader	3 (15 percent)	
	other staff	0 (0 percent)	
Gender	Male	12 (60 percent)	
	Female	8 (40 percent)	
Age of respondent	Average	31	
Work experience in years	Average	7.4	

*Four respondents from each sampled *woredas water provider* organization were interviewed

According to the survey average age of the respondents was 31 years with 7.4 years of work experience in water providers’ organizations. A majority of the respondents were trained water supply engineers and had diplomas or were experts.

The study reveals that fluoride safe drinking water supply in the Rift Valley region is limited by financial, environmental, institutional and technical factors. Applying the analytical hierarchy process model (AHP) as used by Goepel (2013),[20] the main constraints that limit the supply of fluoride free water for the Rift Valley region is summarized in Table 5.10.

Table 5. 10 Overall relative weight of constraint factors and their rank

Factors/ criterion	Weights	Rank	Performance indictor
Financial factors	48.3%	1	*Eigenvalue=4.2*
Environmental factors	11.3%	4	*CI=0.28*
Institutional factors	14.7%	3	*CR=0.079*[21]
Technical factors	25.7%	2	

The relative weight of different criteria and the rank of each criterion were calculated as shown in Table 5.10. As per expert opinion, financial factors were the most important hindrance that limited the quality of water services to the Rift Valley residents. Of the total weights the importance of financial factors was 48.3 percent. This seems logical since water supply projects are capital intensive in any case and the suppliers also have to incur fluoride removal costs which exacerbate their financial problems. The second most important criteria were technical factors (25.7 percent) followed by institutional factors (14.7 percent). By further decomposing each of these criteria into sub-criteria, the pairwise comparison results of each matrix are presented in the next section.

[20] http://bpmsg.com: AHP estimator software.

[21] According to saaty (2004) for the pairwise comparison results to be consistent, the consistency ratio should be less than or equal to 0.1.

5.3.1.1. Financial factors criteria

Under financial factor my study considered three sub-criteria -- market size, possibility of tariff adjustments and availability of financial resources. According to expert opinion, availability of financial resources is the most important for overcoming financial factors' constraints that will enable provision of fluoride safe water services. Financial resources are needed at various levels starting with initial investment followed by market size (63.7 percent and 25.8 percent respectively).

Table 5. 11 Pair-wise comparison of sub criteria weight for financial constraints

Factors/sub criterion	Weights	Rank	Performance indicator
Market size	25.8%	2	*Eigenvalue=3.039*
Possibility of tariff adjustment	10.5%	3	*CI=0.12* *CR=0.04*
Financial resource availability	63.7%	1	

The financial resource availability sub-criteria has its own sub-sub-criteria using different means of financial resource accessibility. Using a pairwise comparison between these sub-sub-criteria, the important criteria to access financial resource availability were identified by using the experts' judgment data.

Table 5. 12 Pairwise comparison of sub- sub criteria with for financial resource

Factors/sub criterion	Weights	Rank	Performance indicator
From government loan	12.4%	3	*Eigenvalue=4.182*
Accessing Soft loan or grant	35.6%	2	*CI=0.24* *CR=0.067*
From Inviting joint venture (PPP)	5.6%	4	
Fund rising from end user	46.4%	1	

According to the experts' opinion, fund rising from end users is the most important means of accessibility to financial resources to overcome the financial burden of supplying fluoride tolerable water services in the study area. The second most important means of accessing financial resources is soft loans or grants which make sense in countries such as Ethiopia where funds for major water supply projects depend on loans and donations. Loans or budget from the government and getting into joint ventures are the least important criteria for generating financial resources to overcome the financial burden related to providing fluoride tolerable level of water. The results also show that the 'raising funds from end users' criteria is the most important way of getting financial accessibility to overcome financial resource problems making 'financial resource availability' the main solution for the financial problems vis-à-vis market size and possibility of tariff adjustments. Hence, this result implies that there should is a need to study demand side phenomena from the consumers' perspective with regard to future water services.

5.3.1.2. Environmental factors criteria

After going through literature I identified four environmental criteria that impact fluoride free water supply: lack of alternate sources of water supply, bad weather conditions, landscape and settlement patterns of the dwellers in the study area. A pairwise comparison of these criteria is summarized in Table 5.13.

Table 5. 13 Pair wise comparison of sub criteria for environmental constraints

Factors/sub criterion	Weights	Rank	Performance indicator
Lack of alternative source of water	12.4%	3	*Eigenvalue=4.182* *CI=0.24*
Bad weather condition	35.6%	2	*CR=0.067*
Landscape	5.6%	4	
Settlement pattern	46.4%	1	

According to experts' opinion, settlement patterns and bad weather conditions are the first and second most important criteria that hinder fluoride tolerable level of water supply (46.4 percent and 35.6 percent respectively). The results make sense as the study area is characterized by scattered settlements particularly in rural areas leading to inconvenient pipeline supply of water. Another aspect adding to the problem is that the Rift Valley region is characterized by bad weather conditions. It is a very hot region and hence creates problems of monitoring the dynamic level of fluoride in underground water. Lack of water sources and landscape are ranked third and fourth environmental factors affecting fluoride safe water supply.

The solution is mainly working on population settlements and weather conditions in the Rift Valley region to supply fluoride safe water assuming other things are normal.

5.3.1.3. Policy and institutional factors criteria

We considered three sub-criteria -- transparency and competitive management within the water provider company, interoperability of water supply company with other institutions (stakeholders) and water supply policy. Using a pairwise comparison of these sub-criteria with respect to the required policy and institutions for supplying fluoride tolerable levels of water we identified the most important criteria impacting policy and institutions (Table 5.14).

Table 5. 14 Pair wise comparison of sub criteria for institutional constraints

Factors/sub criterion	Weights	Rank	
Transparency within the operators	58.2%	1	*Eigenvalue=3.004*
Inter-operability with other stakeholder	10.9%	3	*CI=0.01* *CR=0.004*
Water supply policy(quality, pricing)	30.9%	2	

Transparency and competitive management within the water supply office is the most important hindrance according to experts' opinion which influences fluoride safe water supply followed by water supply policy. This result reveals the true behavior of institutions and policies related to clean water supply showing that there is no transparency in procurement issues or during bidding for water supply projects because of hidden corruption. Water supply office workers need bribes to connect water to the homes, they also steal water utilities purchased and cheat during water meter reading. This behavior is attributed to the lack of competitive providers since there is only one water provider in one town or *woreda* in Ethiopia, particularly in the Rift Valley region. In addition, there is no exclusive water supply policy for this excess fluoride region; instead there is a water quality policy across the country which does not work in the Rift Valley region.

As explained in the research statement section, the water supply policy mainly targets pricing issues, water resource sustainability, increasing sustainability of infrastructure and increasing operational budgets. There is no policy that exclusively addresses fluoride issues, which are already known as a serious problem for this marginalized community. Lastly interoperability with the other institutions criteria is the third most important criterion influencing policy and institutions factors. Therefore, by working on transparency and competitive management within the organization and improving the water quality policy, assuming other things are normal, it is possible to improve the policy and institutions perspectives for providing fluoride tolerable levels of water.

5.3.1.4. Technical factors criteria

Under the technical factors criteria we considered three sub-criteria -- existing offline lab-based fluoride level monitoring, online (internet) based fluoride monitoring and having adequate skilled labor. The results using a pairwise comparison among these sub-criteria with regard to fluoride monitoring and providing fluoride safe water services are given in Table 5.15.

Table 5. 15 Pair wise comparison of sub criteria for technical constraints

Factors/sub criterion	Weights	Rank	
Offline lab based monitoring	12.2%	3	*Eigenvalue=3.004* *CI=0.01*
Online based monitoring	64.8%	1	*CR=0.04*
Adequate skilled labor	23.0%	2	

Among the sub-criteria, online-based monitoring is the most preferred that enables provisions of fluoride tolerable levels of water services according to experts' opinion followed by adequate skilled labor both in terms of quantity and quality. Both sub-criteria together account for about 87.8 percent of the total weight as important sub-criteria in solving the technical factors with regard to fluoride safe water supply. The results of a comparison of technology preferences with respect to fluoride level monitoring under different circumstances show that online-based monitoring is more preferred to offline lab-based monitoring.

5.3.1.5. Technology preferences

Considering different specific conditions, the experts gave their judgmental values to find out which technology was more appropriate in monitoring the level of fluoride in drinking water supply services in the Rift Valley region. The results are summarized in Table 5.16.

Table 5. 16 **P**airwise comparison of technology preference **for** water supply

Specific condition/criteria	**Technology choice**	**Weights**	**Rank**	
To monitor level of fluoride from different source point of water supply at a time	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
To monitor level of fluoride under bad weather condition	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Suitable for large market size population	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Suitable to monitor real time data of fluoride level	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Require large initial investment	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Brings transparency and competitive management	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Facilitates interoperability	Offline lab based Online IOT based	10.0% 90.0%	2 1	Eigenvalue=2 CI=NA CR=0
Require more	Online IOT based	10.0%	2	Eigenvalue=2

skilled labor both quantity and quality	Offline lab based	90.0%	1	CI=NA CR=0

With respect to all specific criteria/conditions except the fifth (require large initial investments) online- based fluoride level monitoring is preferred to offline lab-based monitoring. Despite the fact that it requires large initial investments (Table 5.16) online-based fluoride level monitoring is preferred in all the dimensions considered in this study. Therefore, the results show that financial factors followed by technical factors are the main constraint factors in the supply of fluoride safe water. To complement this experts' opinion and to identify demand side information, the study also found out consumer preferences for future water services as explained in the next section.

The overall results of the AHP model are summarized using the hierarchical decision structure in Figure 5.3.

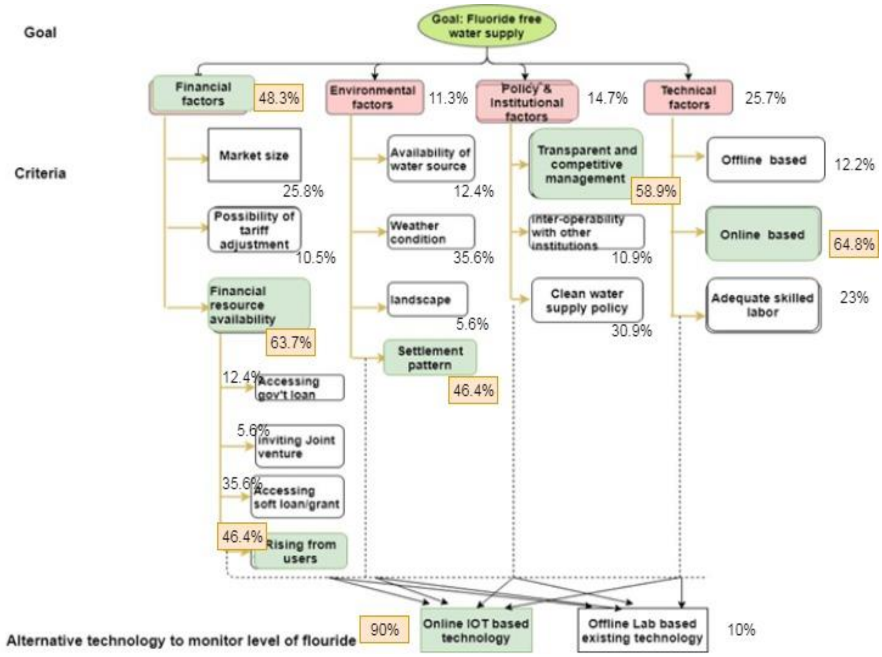


Figure 5. 3 Hierarchical representation of AHP estimation result

As shown in Figure 5.3, the green shaded criteria and alternative technology are the most important factors that affect the supply of fluoride safe level of water in the Rift valley region. Hence, decision makers can prioritize the factors accordingly to overcome the accompanying burden and provide clean water in the study area, assuming other things are normal.

To sum up, in countries such as Ethiopia that have excess fluoride levels in underground water, projects that aim to provide fluoride safe water to residents should only embarked upon after finding out the main constraining factors that limit clean water supply. My study shows that financial factors are the most important criteria followed by technical factors is the second most important criteria after which come policy and institutional factors. Concerning fluoride level monitoring technology preferences, online-based technology is the preferred technology as compared to the existing lab-based technology.

5.3.2. Household preferences on future water service's attributes

This section assumes that households have heterogeneous behavior towards the attributes and their levels. That is, the unobservable factors can be divided into two additive parts $(\varepsilon_n = \eta_n + \delta_n)$, where a stochastic part (η_n) is correlated over alternatives and heteroscedastic over consumers and alternatives, and the second stochastic part (δ_n) is identically and independently distributed over alternatives and consumers (Train, 1998 as cited in Lee, 2012). Consequently, the utility of a household n from alternative j can be defined as:

$$U_{njt} = \beta_{abovewho} ABOVEWHO + \beta_{equalwho} EQUALWHO + \beta_{disfreq} DISFREQ + \beta_{disdur} DISDUR + \beta_{nudaynot} NUMDAYNOT + \beta_{mobile} MOBILE + \beta_{internet} INTERNET + \beta_{addprice} ADDPRICE + \varepsilon_{njt} \quad (5.1)$$

where, $ABOVEWHO$ and $EQUALWHO$ are dummy variables representing the quality (fluoride concentration level) of future water in line with World Health Organization standards (1.5 mg/l); $DISFREQ$ is expected frequency of future water service disconnection per month; $DISDUR$ is disconnection in hours once supply stops; $NUMDAYNOT$ is the expected length of days the prior notification is delivered regarding water services notifications; $MOBILE$ is a dummy variable that defines how the respondents want to receive service notifications; $INTERNET$ is another dummy variable that defines how the respondents want to receive the service notification; and *ADDPRICE* is the additional price that consumers are willing to pay for service improvements. With the first and fifth attributes, the quality of water and means of notification, we have three levels and for the third level (below WHO standards and mass media) are considered as base alternatives respectively.

5.3.2.1.Estimation of the mixed logit model

To estimate a random parameter (mixed) logit model the study used the Bayesian procedure with 5,940 observations. Following the estimation process used by Train (2003); Kim (2005); and Lee et al., (2006), 10,000 draws with Gibbs sampling were generated by considering burn-in and the draws of every tenth iteration was retained after convergence. Then the retained 1,000 draws were used for drawing inferences in which the mean and standard deviations of these draws constitute the estimates and standard errors. A prior distribution of every coefficient (marginal utility) of each attribute was assumed to be normal with log normal distributions. Dummy variables were used for qualitative attributes such as quality of water and means of information communication. In the case of quality of future water supply, quality below WHO standards was used as a base alternative and for means of information communication attribute, local mass media was used as a base alternative. The estimated results of the mixed logit model are given in Table 5.17.

Table 5. 17 Estimation results of the mixed logit coefficient model

	Mean of *B*			Variance of *B*		
Variables	Mean	tvalue	p>(t)	Variance	tvalue	p>/t/
Additional price[22]	-10.67***	-2.58	.0100	4.65*	1.88	.0597
Quality Above who |	1.84***	11.74	.0000	2.32***	16.23	.0000
Quality Equal who |	.75***	4.95	.0000	1.19***	13.23	.0000
Frequency of interruption |	-.14*	-1.81	.0708	.15**	2.29	.0219
Duration of interruption	-1.83***	-4.02	.0001	.59**	2.00	.0455
Number of prior days notification received	.11	1.57	.1156	.24***	3.88	.0001
Mobile based service |	.56***	3.90	.0001	.48***	3.99	.0001
Internet based service |	-.23**	-2.22	.026	.280**	2.36	.018

*,**,*** are significance level at 10 %, 5% and 1% significance level respectively.

These result were estimated using the Bayesian procedure and they can be interpreted from both classical and Bayesian perspectives. The results show that almost all, except the mean of the number of days on which prior notification is received attribute, estimated means and their variances are significant at least at the 10 percent significance level. Although the number of days when the service notification is received is insignificant, consumer

[22] The coeffient of additional price is specified to be fixed, so as to facilitate the estimation of distribution of WTP, like Revelt and Train (1998), Ruud's (1996) and Hensher et al (2005).

preference with regard to this attribute is heterogeneous as can be seen from the estimated variance coefficient results.

A remarkable result is that due to the heterogeneity in preference among the respondents, the quality of water above WHO standards is valued more than the quality of water equal to WHO standards in terms of fluoride concentration. This result has some important clues regarding the fluoride concentration problem in the study area, that is, people do not want fluoride in their drinking water. Therefore, this is call to policymakers and service providers to adopt appropriate technologies to monitor and treat fluoride in the drinking water continuously as the consumers do not want to compromise on the quality of their water. Regarding the variances in the estimates, all are statistically significant; and the hypothesis of no variances can be rejected justifying the use of mixed logit model.

Regarding the frequency of service interruptions, the respondents preferred less interruptions. The current frequency of interruptions is more than three times per months and consumers are dissatisfied with the existing situations and want service improvements. This result is also in line with Hensher et al.'s (2005) study in Australia where consumers were willing to pay significant amounts to reduce interruptions to one time per year.

Regarding the third attribute 'duration of disconnection,' the longer the service interruption the less utility to the consumers. This means that consumers' relative utility increases when the duration of service interruption decreases. It is obvious that consumers do not necessarily want service interruptions from the very beginning; however, because of capacity limitations and other technical failures, it is difficult to completely interruptions in services. Given this situation consumers still do not want to have long service interruptions and also want to avoid or decrease the duration of service interruptions. For this they are ready to pay (explained in the willingness to pay section). Again this result is in line with Hensher et al.'s (2005) findings in Australia.

The fourth attribute is 'number of day's prior notification received' by customers. Because of differences in the socioeconomic conditions of the consumers it is difficult to expect uniform preferences for this particular attribute. Perhaps busy families who are working far away from home may want the notification as early as possible so that they can get time to store enough water. On the other hand, families who are retired, aged and who stay at home or near home may not want very notifications early as they may forget the notification and fail store enough water. The result of the mixed logit model shows that the number of prior days service notification has no an impact that is no different from zero, that is, insignificant, although it confirms heterogeneity. Hensher et al.'s (2005) study considered the interaction term income with obtaining notification or not. And their study reveals that higher income households were more concerned about receiving the notification but were less concerned about using the phone as compared to the lower income households. However, in my study the number of days of prior notification and the means of information communication are designed separately.

When it comes to information communication platforms, we have three levels defined by dummy variables. Considering the local mass media as a reference means of communication, the mixed logit's result shows positive marginal utility for mobile-based services such as voice call, SMS or MMS negative marginal utility for internet-based services such as using the provider's website notice board, social media platforms or email. This result reveals the real situation where many people have adopted mobile services while access to internet service is very limited.[23] This implies that if the water provider wants to provide information to its customers using internet-based platforms because of its convenience, the consumers need a compensation for this as it has negative marginal utility. In general, there is heterogeneity in preferences for mobile and internet-based services, although their mean influence is significantly positive for mobile-based and significantly negative for internet-based service notifications.

With regard to price attributes, the price coefficient is significant in influencing households' preferences for future water services. Hensher et al., (2005) used the share of current bill, instead of just proposed price and found that it negatively and significantly influenced consumers preferences. Consumers preferred quality service at lower prices. From the estimated

[23] The mobile penetration rate is 52 percent whereas internet penetration is 15.6 percent which is mainly in urban areas, according to Ethio telecom annual report 2017 (http://www.ethiotelecom.et/).

variance coefficient we can observe the presence of heterogeneity in preferences that is significant at least at the 10 percent significance level.

To further show whether there is intense heterogeneity across consumers with regard to future water service connections in the Rift Valley region of Ethiopia, the results of the share of population for each coefficient are given in Table 5.18.

Table 5. 18 Shares of population for coefficients of mixed logit model

	below zero	**at zero**	**larger than zero**
Abovewho	20%	0%	80%
Equalwho	20%	0%	80%
FREQ/3months	100%	0%	0%
DURDISC	80%	0%	20%
NUMBDAY	40%	0%	60%
MOBILE	0%	0%	100%
INTERNET	80%	0%	20%
ADDPRICE	100%	0%	0%

According to the shares of the coefficient, attributes such as frequency of water disconnection and additional price have 100 percent population below zero and for mobile-based service notifications the entire population share is above zero. Every respondents want to get water at lower frequency of disconnections and every respondent wants mobile-based service notifications. Apart from these three attributes, there are heterogeneous preferences for the other attributes. Concerning quality of water services, 80 percent of the respondents want the quality of water to be above WHO standards whereas 20 percent of the respondents have negative utility for quality of water service above WHO standards; perhaps they prefer getting improved water services that are equal to the WHO standards first. Further, 80 percent of the respondents also want to get water services with lower disconnections and 80 percent of the respondents do not want to get service notifications through internet-based platforms. These results are as expected since its rational to have smaller water service disconnections than longer ones. This is also in line with Hensher et al.'s (2005) study in which people preferred smaller service interruptions. With regard to internet services, since there is no reliable coverage of internet services in the study area and only a few people subscribe to this service a majority of the respondents did not prefer internet-based service notifications; instead they preferred getting notices through basic mobile phone services such as voice call, SMS and MMS.

Another important result of my study is that the share of price coefficient below zero is 100 percent, which implies that all respondents want improvements in water services at lower prices. This finding is in line with other studies like Hensher et al., (2005) and Manandhar (2012) on internet services. In the mixed logit model estimation results the impact of price is significant with negative marginal utility but with some variations. The mean WTP and the relative importance of each attributes are presented as Table 5.19.

Table 5. 19 Mean WTP and relative importance

Variable |	Mean WTP[24]	Relative importance (RI_B)
Abovewho |	54.25***	11.44%
Equalwho |	36.02**	4.65%
Freq/3months |	-77.90***	0.88%
Duration disc/once |	-45.38***	11.32%
Numb days prior notif |	33.22**	0.66%
Mobile based service |	70.02***	3.48%
Internet based service |	-87.92***	1.34%
Additional price |	---	66.23%

Note: *,**,*** significant at at 10 percent, 5 percent and 1 percent level of significance.

The value of marginal WTP results presented in Table 5.19, back the discussion about consumer preferences for future water services' attributes. For example, they show that a majority (80 percent) of the Rift Valley households were willing to pay more for quality of water above WHO standards (in terms of WTP, ETB 54.25(US $1.97)); this was the second most important preference after price.

The average willingness to pay for quality of water equal to WHO standards, prior notification services and mobile-based service notifications are ETB 36.02($1.3) , ETB 33.22($1.21), and ETB 70.40 ($2.56) respectively. On the other hand, consumers in Rift Valley want to be compensated for frequent service interruptions and length of service interruptions. For instance, consumers want to be compensated about 77.90 ETB ($2.83) for a one-time

[24] Calculated by wtp addprice $randvars command.

blackout of water services every 3 months and about 45.38 ETB ($1.65) for 12-hour service interruptions. Further, the kernel density plots of individual WTP that are quality attribute specific are shown in Figure 5.4 for the mixed logit model.

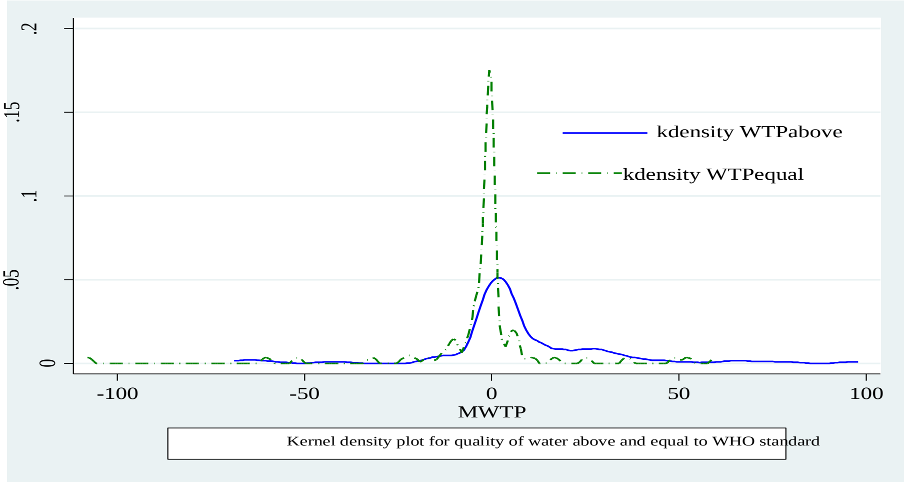


Figure 5. 4 Kernel density plots for quality water above and equal WHO level.

The heterogeneity of individual WTP for quality of water above WHO standards are larger than that for the quality equal to WHO standards.

Another striking result is that consumers want to be compensated for service notifications delivered over internet-based service platforms. Although this result seems surprising in this century, but the reality is that there is no internet service coverage in the study area. This result shows that the government has to do a lot of work not only for water supply but also internet service expansion in the remote areas including in the Rift Valley region.

Regarding the relative importance of each attribute, as obtained according to Eq. 4.29, consumers in the Rift Valley region regard additional price as the most important attribute of water services followed by quality of water services above WHO standards. This implies that consumers are in need of quality water services which have no excess fluoride concentration at lower prices. This has interesting policy implications and is a call for stakeholders to provide clean water at appropriate prices. As explained earlier, the government's water supply policy in both rural and urban areas is targeted at cost recovery. However, my results show that consumers value lower price with higher quality of water services. This implies that there is room for more WTP for fluoride safe water service connections.

However, policymakers cannot prepare policy for an individual and water providers cannot provide water services according to each individual's preferences since water is a quasi-public good. Therefore, without totally compromising the heterogeneous preferences towards future water services, my study estimates the latent class model to observe heterogeneity preferences across the groups.

5.3.2.2. Estimation of latent class logit model

Following the utility Eq. 4.12, consumer n utility with regard to future water service j preferences that belongs to q class is:

$$U_{nj/q} = \beta_{abovewho/q} ABOVEWHO + \beta_{equalwho/q} EQUALWHO + \beta_{disfreq/q} DISFREQ + \beta_{disdur/q} DISDUR + \beta_{nudaynot/q} NUMDAYNOT + \beta_{mobile/q} MOBILE + \beta_{internet/q} INTERNET + \beta_{addprice/q} ADDPRICE + \varepsilon_{nj/q} \quad (5.2)$$

where, all the variables are already defined in Eq. 5.1 but constrained to the probability of class q, and error terms also belong to class q.

To decide the optimal number of latent classes that exhibit the optimal goodness of fit, my study used the consistent Akaike information criteria (CAIC) and the Bayesian information criteria (BIC) (Pacifico and Yoo, 2012). Both information criteria exhibit a different number of classes as can be seen in Table 5.20. According to the CIAC criteria the observations can be divided into two classes whereas according to the BIC criteria there can be four classes. Hence, to minimize the complexity of the modelling and to explain them I used the optimal number of class size according to the CIAC criteria which two classes. Another technical issue when using a larger class size is increased standard errors and number of parameters (Hole, 2008).

Table 5. 20 **I**nformation criteria[25] with number of latent classes

No. of Classes	Log-likelihood	Number of parameters	CAIC	BIC
2	-1731.91	24	3229.248	3602.998
3	-1637.652	37	3349.303	3489.87

[25] The information criteria such as CAIC and BIC measures the extent of model fit for the given data set. $CAIC = -2 * lnL + K * (1 + lnN)$, and $BIC = -2lnL + K * LnN$. where lnL is the maximized value of log-likelihood function, N is the number of observation, and K is the number of parameters to be estimated. Lower CAIC and BIC gives a better model fit.

4	-1590.381	50	3280.762	3470.717
5	-1573.321	63	3272.641	3511.984
6	-1540.893	76	3233.785	3522.516
7	-1528.458	89	3234.917	3573.036
8	-1522.924	102	3249.847	3637.355
9	-1499.624	115	3251.82	3666.144
10	-1496.044	128	3248.088	3734.372

The estimation results show that there is a two-heterogeneous consumers' preference structure for future water service connections. Initially, regardless of the class the higher the quality of water services and the lower the price of water, the higher the consumer preference. But both classes 1 and 2 demonstrate opposite sensitivity towards the quality of water services and different magnitudes in the price of water in the latent class estimation results. Class 1 has more tendency to avoid costs but it values the availability of water services whereas class 2 has a tendency to avoid fluoride risk by showing a strong preference for quality of water services above or equal to WHO standards. The estimation results are given in Table 5.21.

Table 5. 21 Estimation result using Latent class logit model

	Variables	Coefficient	Stand.error	Average MWTP (ETB)	Average RI
Class 1	Quality Above WHO	-.146	.131	~	2.04%
	Quality Equal WHO	-.227	.175	~	4.69%
	Freq. inter/3months	-.183***	.059	-1.60	4.18%

	Duration inter/hrs	-.309***	.061	-2.69	42.21%
	No.days prior notification	.439***	.068	3.81	15.62%
	Mobile based service	.518***	.091	4.50	10.15%
	Internet based service	-.628***	.081	-5.46	7.45%
	Additional price /month	-.251**	.103	-	13.65%
Class 2	Quality Above WHO	2.467***	.385	159.24	50.72%
	Quality EqualWHO	1.168***	.327	75.37	24.01%
	Freq. inter/3months	-.115	.165	~	2.37%
	Duration inter/hrs	-.011	0.090	~	2.55%
	No.days prior notification	.021	.094	~	1.27%
	Mobile based service	.497*	.258	32.10	10.22%
	Internet based service	.272	.244	~	5.59%
	Additional price /month	-.155	.125		3.28%

***, **, * ==> Significance at 1%, 5%, 10% level. WTP is not calculated for insignificant coefficients

The heterogeneity of consumer preferences regarding future water service connections in the mixed logit estimation results has already been shown. Now the latent class logit model is used to categorize their behavior structure. For instance, the first group of consumers perceive negative utility for quality of water services referenced to WHO standards. This shows that people belonging to group 1 either have less fluoride concentrations in their drinking water or think the quality of water above or equal to WHO standards is unaffordable. This argument is supported by the results of the membership function which uses the location dummy as a covariate in estimating the latent class logit model. According to this membership function Adama and Lume are areas with less fluoride concentrations and a relatively low cash crop area as compared to the other areas considered in the study. This has an interesting implication that people who have lower fluoride concentrations or low incomes want the availability of the water first, regardless of its quality. However, those consumers who are in class 2 value the quality of water services, unlike those in class 1. Therefore, consumers belonging to class 2 are probably those who live in high fluoride concentration areas such as Bora and Zuway Dugda *woredas* and those who really want to get rid off the fluoride problem by paying more (the influence of price is not different from zero in class 2).

Regarding the frequency and duration of interruptions, consumers in class 1 prefer less interruptions and shorter interruptions significantly whereas those in class 2 are indifferent to these aspects. Since the study used 'have connection to pipeline or not' as another covariate to categorize consumers into different groups, the behavior of the two classes can be seen from this perspective in Table 5.21. Such behavior may be a result of past experiences that people in class 1 more or less got water from pipeline sources and either had a connection at home or got it from the community center public tap. This experience may be influencing their behavior in such a way that if water is frequently interrupted or interrupted for long durations, they think that they do not have other sources of water, and hence pay more attention to the availability of water than to its quality (fluoride level). Not only less frequency of interruptions and smaller duration of interruptions, but they also want to receive prior notification of services much earlier than the others. They are more cautious about water availability than the quality of water services.

Regarding the means of information communication platforms, consumers in class 1 strongly prefer mobile-based service notifications and they strongly dislike internet-based service notifications because mobile penetration is quite high as compared to internet penetration and it requires less skills to use mobile phones than internet services and as can be seen from the descriptive statistics section a majority of the respondents have studied only till the primary level and more importantly a majority of them were illiterate, so they perceived difficulties in using internet services. Besides there is also poor penetration of these services. This explanation seems true for class 2 as well but consumers in this class have positive preferences for internet-based services, unlike those in class 1, although not different from zero.

Sensitivity towards additional prices is different in the two classes. Class 1 has strong sensitivity for price of future water services whereas those in Class 2 are indifferent to this, that is, not different from zero. Hence, consumers belonging to class 1 want less frequent interruptions and smaller interruption time with longer prior notifications for future water services at lower prices whereas consumers in class 2 want to get quality water above or equal to WHO standards, without worrying much about the price of the future water services. Based on this behavior we can say that group 1 consumers are reliability seekers and class two consumers are quality seekers. The membership function model is presented in Table 5.22.

Table 5. 22 Estimation result for membership function

	Average class probability	**Covariates**	**Coefficient**	**Stnd.error**
Class 1	0.800	Constants	2.79***	.81
		Source of water supply (from pipeline at home or not)	2.25**	1.11
		Location (Adama & Lume)	-2.63***	.97
Class 2	0.200	Reference class		

Note: ***, **, * ==> significant at the 1 percent, 5 percent, 10 percent level significance levels.

Regarding the relative importance of attributes for each group (as estimated in Table 5.21), for class 1, the duration of water service interruptions is the most important attribute followed by the number of days prior notification received and additional prices respectively. Frequency of service interruptions and quality of water services equal to WHO standards are the least important from the bottom upwards for class 1 consumers. For class 2 consumers, the most important attribute is the quality of water services above WHO standards followed by the quality of water equal to WHO standards and mobile-based service notifications respectively. The least valued attribute is the number of days of prior notification received and the frequency of water service interruptions from the bottom upwards.

5.3.3. Policy simulation: Quality vs reliability seekers' perspectives

This section presents a different hypothetical scenario based on the estimation results from the latent class estimation. The class specific parameter estimates were used to draw policy implications. Considering the existing situations' proxies as a base scenario, three different alternative scenarios are considered in the simulation. According to the class probability model presented in Table 5.23, the overall sampled population exhibited two types of water demand behavior -- quality seekers and availability seekers. Based on this broad behavior the study simulated the cases for each scenario and their acceptance rates.

Table 5. 23 Policy Scenario

	Base Scenario (current situation)	**Scenario 1**	**Scenario 2**	**Scenario 3**

Quality of water with referenced to WHO standard in terms of fluoride concentration (1.5mg/l)	Below WHO	Equal WHO	Above WHO	Equal WHO
Frequency of interruption /3months	3 times per 3 months	3 times per 3 months	3 times per 3 months	Once per 3 months
Length of interruption/hrs.	24 hours	24 hours	24 hours	One hour
Number of days of prior notification	No prior notification	No prior notification	7 days earlier	4 days earlier
Means of information communication	No	No	Mobile based	Internet based
Additional price per month	+0% (same level with current water bill)	+50%(plus 50% of current water bill)	+75%(plus 75% of current water bill)	+75%(plus 75% of current water bill)

Based on the proposed policy scenario, a simulation was conducted and is presented in Figure 5.5.

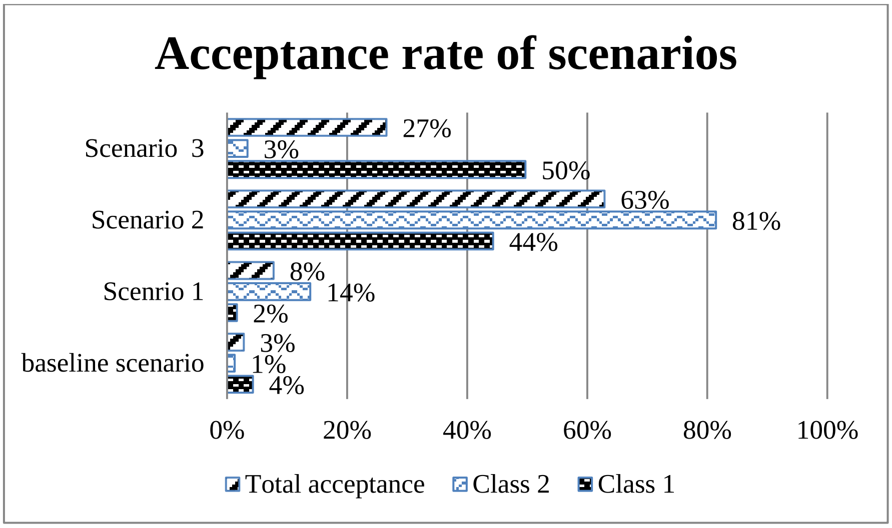


Figure 5. 5 Policy simulation for each scenario and class

From the scenario analysis for the different alternative cases it can be observed that the quality seekers (class 2) had clear preferences for the future water services demand. They show that they are clearly aware of the need for fluoride safe water regardless of the increase in price levels. In addition to fluoride safe water services, the provision of prior notification for service interruption significantly increased the acceptance rate among class 2 consumers as we can observe from scenario 2 and also from the overall acceptance rate. However, service availability seekers (class 1) show their preference for future water services demand in line with frequency of service interruptions and duration of interruptions including earlier prior notification which is captured under Scenario 3. As explained in Table 5.23, under scenario 3, the frequency and duration of interruptions and number of prior notifications are the best levels among all the scenario levels and hence class 1 consumers' preferences are in line with water service availability regardless of the quality level. In general, fluoride safe water with prior notification services is the most demanded future water services attribute according to the simulation results in scenario 2.

5.3.3.1. A comparison of the models

With the aim of incorporating heterogeneity of preferences with regard to demand for fluoride safe water services, the mixed logit and latent class logit models' results are compared by statistical fitness (Table 5.24).

Table 5. 24 Comparison of discrete choice model based on goodness of fit

Model	**Log-likelihood**	**CAIC**	**BIC**
Mixed logit model	-1623.98	3402.595	3384.595
Latent class logit	-1731.91	3229.248	3602.998

Table 5.24 summarizes the goodness of fit measures for each model.[27] The ranking between the mixed logit and latent class logit models cannot be made unequivocally by the statistical goodness of fit criteria. The mixed logit model has lower absolute value of log likelihood at the maximization point and lower value of BIC whereas the latent class logit model has lower values of CAIC. A similar study by Yoo et al., (2014) explores preference heterogeneity

[27] A problem emerges when a function has a lot of local maximums so one needs to identify the global maximum in the maximization process. Sometimes the RPL and LCM log likelihood function has at least one maximum that is globally concave or it may have no maximum in which case the estimated likelihood does not exist (no convergence). We compare the results of the two models by the value of their own statistical fitness at their own convergence levels (maximum level of their log likelihood) regardless of the difference in the number of parameters (k) to be estimated between RPL and LCM, which affect the value of log likelihood and consistent Akaike information criteria (CAIC).

for public goods using different discrete choice models including latent class and random parameter logit models. The public good valued in their study was an increase in renewable energy generation and according to their results all the models were consistent showing that the preference for renewable energy technologies was not homogenous across respondents. However, the degree of dissimilarity differed across different renewable technologies. Comparing the models-based using the statistical fitness criteria the mixed logit and the mixed latent class logit models were the best fit with their data.

Another study by Sagebiel (2011) shows individual WTP for different electricity services in India using different discrete choice models. Employing random parameter and latent class logit models consumer preferences for quality of electricity services shows heterogeneous. Using the statistical fit, the willingness to pay values and the choice probability of each model the study compares the models to find out the one that fits the data best. However, both models have different statistical criteria values at the convergence level and hence the choice of the model depends on the objective of the study and the prior assumption of the researcher.

Shen (2009) applied the random parameter logit and latent class logit models for the valuation of transport mode choices including monorail, car and bus in Japan. The study compared the two models focusing on different statistical fits, value of time saving, direct choice elasticities and predicted choice probabilities. The results suggest that the latent class model performs better than the random parameter logit model in the study's dataset.

Greene and Hensher (2003) compared the latent class with the mixed logit model by employing a dataset of road type choice by cars in New Zealand. Their data came from a sample of car drivers on long-distance trips. The information was collected with the intent of establishing their choices for road environments considering three types of roads -- 2-lane, 4-lane with a median and 4-lane without a median. Using comparison criteria such as value of share of elasticities, saving in travel time, choice sensitivities to a 50 percent increase in travel time and choice probabilities, the authors concluded that the random parameter logit and the latent class logit models provided good specifications as compared to the multinomial logit model, though it was difficult to conclude which one was superior despite some statistical evidence in favor of the latent class logit model.

I also compared the results of the mixed logit and latent class logit models with regard to preferences for future water services' heterogeneity using the statistical fit criteria. Since it is not possible to choose between the mixed logit model and the latent class logit model based on the goodness of fit as each model provides a different picture of how preferences vary across the population in this study I used both the models for drawing policy implications from each model.

To sum up, the estimated results for both the models are more or less consistent in that all the attributes are important influencers of households' preferences for fluoride safe water services and have consistent coefficient signs, in the Rift Valley region. In the mixed logit model, all attributes except the number of prior notification days, are significant in influencing the households' preferences for future demand for water services. Considering their estimated variances, all attributes exhibit the presence of heterogeneity among the households and hence the use of the mixed logit model as an appropriate estimation method is justified. The results of the mixed logit model show that households prefer the quality of water services being above WHO standards as far as fluoride concentrations are concerned at lower prices. To identify the most important attributes percentages of relative importance were calculated and accordingly the price was found to be the most important attribute followed by the quality of water services and duration of service interruptions. Therefore, water providers and policymakers can take into account these important attributes of future water services and look for mechanisms to provide fluoride tolerable levels of water at affordable price levels. Further, we can also find out the share of the population which prefers a given attribute from some threshold levels onwards or downwards since we can estimate the distribution of each parameter from the mixed logit model. For instance, 80 percent of the respondents' coefficient for duration of water service interruptions is below zero whereas 20 percent of the respondents' share of the coefficient for this attribute is above zero. Based on the percentage share of the coefficient the water provider can take a decision regarding the given attribute when providing water services in the area.

Though it is good to know individual level specific preferences, however, to make clear policy suggestions we need to consider heterogeneity preferences across the groups using the latent class logit model. Doing this my study found two clear latent groups of behavior in future water services' preferences. Their behavior was based on their past experiences and their location (whether they had a pipeline connection and whether they were living in a high concentration fluoride area or in a low fluoride concentration area). Accordingly one group of consumers is looking for the quality of water services (class 2) and another group is looking for availability of water services (class 1). By proposing scenarios the study conducted policy simulations for each scenario and the behavior was clearly observed in simulation results. Therefore, water providers and policymakers should address fluoride issues first for the people in class 2 since they want water quality that is above WHO standards. This group seems ready to cover the cost of service improvements since the results show that they are not price sensitive. On the other hand, for people in group 1, the water provider and policymakers should work on minimizing the frequency of water service interruptions, the length of the interruptions and earlier service notifications as these attributes are very important for this group. Overall acceptance is higher for water quality services above WHO standards with earlier service notification attributes (63 percent total acceptance rate).

5.3.4. Households' willingness to pay for fluoride safe water services: A comparison of CA and CVM

In this section the households' WTP is estimated using both an indirect survey (conjoint analysis) and a direct survey (CVM). Like Mogas et al., (2006) state it is advantageous to use both contingent valuation and choice modelling to estimate WTP and make appropriate policy recommendations. During the survey period, the contingent valuation for quality of water services at home and at the nearest public tab per jerican (equivalent to a 20 liter water container) was asked at the end of the questionnaire. The open ended contingent valuation questions asked were:

Q1: Suppose the local government wants to invest in water quality (fluoride level) and water supply infrastructure to be able to provide quality water which is drinkable from the tap to your home that is available 24 hours a day. If there is interruption due to some forced measures there will be prior notification via your mobile phone. But without collecting sufficient water fees from households like yours it is difficult to maintain sustainability of the water supply. Hence, what is the maximum amount of ETB that you will pay per jerry can (~20 liter water container), for such a fluoride safe water supply connection in addition to your current bill?

Q2: Suppose the local government wants to invest in water quality (fluoride level) and water supply infrastructure at the communal public tap that will be installed in your village close to your home (5 minutes' walk for a two-way trip) to ensure everybody has access to fluoride safe drinking water that is available 24 hours. If there are interruptions due to some forced measures there will be prior notification via your mobile phone. But without collecting sufficient water fees from households like yours it is difficult to maintain the sustainability of the water supply. Hence, what is the maximum amount of

ETB you will to pay per jerry can (~20 liter water container), for such communal fluoride safe water supply in addition to your current bill?

I used this open ended contingent valuation method questionnaire format and its possible drawbacks were avoided by placing the open ended questions in the last part of the survey, that is, after the respondents had become aware of the topic and the content of the questionnaire without significantly influencing the respondents' response bias. Further, the open ended contingent valuation survey is more efficient than a single dichotomous yes/ no choice survey as a closed ended question would be, 'would you willing to pay $m?' and this holds very less relevant information than a response to an open ended questions like 'How much are you willing to pay?'(Haab et al., 2003). However, an open ended CVM question format may also lead to overestimation or underestimation of WTP for the goods being valued unless given more attention to reduce the bias (Armbrecht, 2014; Nunes and Nijkamp, 2011).

In general, income compensating functions (Willig, 1976) could serve as a theoretical model for explaining households' willingness to pay model. Considering willingness to pay as a welfare measure, the income compensating function which includes arguments about the vector of respondents' characteristics can be referred to as the willingness to pay function (Kwak et al., 1994). Further, the WTP for improved quality of water will help in designing suitable policies for sustainability and cost effectiveness of fluoride safe public water supply (Gadgil, 1998). Applying the CV data we estimated the model using OLS and the censored econometrics model (Tobit).[28]

5.3.4.1. Estimation of the model

The dependent variable for the model is WTP which is continuous data but censored at zero; values less than zero or equal to zero are transformed to single value zero for people who have zero WTP or are not WTP for improvements in water services. In the statistical context, censoring means that the distribution of the underlined variable (WTP) may not be observed entirely and the unobservable portion of the distribution will be massed to a single value zero. In this case, the OLS coefficient's estimates will not be consistent and the WTP will be overestimated (Kwak et al., 1994). To overcome this inconsistency the Tobit model proposed by James Tobin (1958) and also by Amemiya (1984) is the best method which estimates parameter values using the maximum likelihood method (MLE). Therefore we apply Tobit censored econometrics, that is, fitting in cases where the WTP (dependent variable) has continuous, positive and non-zero values (Rodríguez-Tapia et al., 2017; Wooldridge 2015). The model is specified as:

Suppose the WTP for improved quality of water services for household i in the population is given by:

[28] Using open ended CV survey methods some respondents may respond by saying zero willingness to pay, others may respond with no willingness to pay and the remaining may give some positive number as willingness to pay. Hence, we need to use the censored Tobit model to address WTP estimation properly.

$$\text{WTP}^* = f(z_i, \text{q}_i, \varepsilon_i) \quad (5.3)$$

where, zi is a vector of household covariates, qi is water quality characteristics and ε_i is an error term element that may symbolize specification or measurement errors. Since there are people who have no WTP for improved water services in the survey sample to consider this reality the dependent variable is censored at zero and modelled as:

$$\begin{aligned} \text{WTP} &= f(z_i, \text{q}_i) + \varepsilon_i \; for \quad WTP^* > 0 \\ WTP &= 0 \; for \quad WTP^* \leq 0. \end{aligned} \quad (5.4)$$

Based on this behavioral model for a unit of the population, the parameter for the function of $f(z_i, \text{q}_i)$ and the distribution of ε_i is modelled as:

Suppose $\text{h}(\varepsilon_i)$ is the likelihood density function for ε_i, and the density for WTP for household with positive WTP for water service improvements, which is denoted $\text{h}^*(\text{WTP}_i / \text{WTP}_i^* > 0)$, is stated as a conditional probability of observing WTP_i provided WTP is greater than zero:

$$\text{h}^*(\text{WTP}_i / \text{WTP}_i^* > 0) = \frac{h(WTP_i - f(z_i, \text{q}_i))}{pr(f(z_i, \text{q}_i) + \varepsilon_i > 0)} \quad (5.5)$$

The denominator controls the density function for positive WTP to consider truncation by not observing zero WTP. The possibility of observing a household with zero WTP is $pr(f(z_i, \text{q}_i) + \varepsilon_i \leq 0)$. Accordingly, the study constructed the ith contribution to the probability function as the multiplication of the probability that WTP is equal to zero and the probability that WTP is positive times the density of the positive WTP (Haab et al., 2003):

$$\Pr(f(z_i, q_i) + \varepsilon_i \leq 0)^{1-I_i} . [\Pr(f(z_i, q_i) + \varepsilon_i > 0). \frac{h(WTP_i - f(z_i, q_i))}{pr(f(z_i, q_i) + \varepsilon_i > 0)} \qquad (5.6)$$

where, $I_i = 1$ when WTP is positive and 0 when WTP is zero. To make the estimation using the Tobit model we need to make assumptions about functional form $f(z_i, q_i)$ and the distribution of ε_i , $h(\varepsilon_i)$.

Let $f(z_i, q_i) = z_i\beta$ and $\varepsilon_i \sim N(0, \delta^2)$. The Tobit likelihood function is:

$$L(\beta, \delta / \text{WTP}, z) = \prod_{i=1}^{T} [1 - \Phi\left(\frac{z_i\beta}{\delta}\right)]^{1-I_i} . [\frac{1}{\delta}\phi\left(\frac{WTP_i - z_i\beta}{\delta}\right)]^{I_i} \qquad (5.7)$$

where, after rearrangement $\Pr(f(z_i, q_i) + \varepsilon_i \leq 0) = 1 - \Phi\left(\frac{z_i\beta}{\delta}\right)$

The log likelihood function for the Tobit model is:

$$\ln(L(\beta, \delta / \text{WTP}, z)) = \sum_{i=1}^{T} (1 - I_i) \ln[1 - \Phi\left(\frac{z_i\beta}{\delta}\right)] + I_i\{\ln[\phi\left(\frac{WTP_i - z_i\beta}{\delta}\right)] - \ln(\delta)\} \qquad (5.8)$$

The difference between the Tobit model and ordinary least squares (OLS) model is shown by noting that the Tobit model has an extra term $\sum_{i=1}^{T} (1 - I_i) \ln[1 - \Phi\left(\frac{z_i\beta}{\delta}\right)]$ from eq. 5.8.

Accordingly, using the individual covariates the Tobit model for WTP for improved quality of water services at home and at nearest public tap is modelled as:

$$\begin{aligned}
WTP^{*} = {} & \alpha_0 + \alpha_1 QUATT + \alpha_2 INFATT + \alpha_3 DISSATT + \alpha_4 SRCEW + \\
& \alpha_5 BOTL + \alpha_6 OWNHOUSE + \alpha_7 NCHL5YR + \alpha_8 AGE + \alpha_9 INCOME + \\
& \alpha_{10} BILL + \alpha_{11} VOLUMEW + \alpha_{12} MALE + \alpha_{13} EDUC + \\
& \alpha_{14} FAMSIZE + \alpha_{15} LOCATION + \varepsilon_i , \\
& \varepsilon_i / X_i \sim N(0, \delta^2)
\end{aligned} \qquad (5.9)$$

$$\text{WTP} = \max(0, \text{WTP}^{*})$$

$$WTP = WTP^{*} \; if \; stated \; WTP^{*} > 0$$

$$WTP = 0 \;\; if \; stated \;\; WTP^{*} \leq 0$$

Where,

WTP_{q*}	Household's willingness to pay for fluoride safe water connection per jerry can
$QUATT$	Respondents' perceptions about the quality of water services 1=strongly disagree, 2=disagree 3=neutral , 4=agree, 5=strongly agree
$INFATT$	Respondents' perceptions about prior information notification services 1=strongly disagree, 2=disagree 3=neutral , 4=agree, 5=strongly agree
$DISSATT$	Respondents' perceptions about dissatisfaction with current water services

	1=strongly disagree, 2=disagree 3=neutral , 4=agree, 5=strongly agree
SRCEW	Respondents' source of water supply, dummy variable 1 if has pipeline connection at home, 0 otherwise
BOTL	Monthly expenditure on bottled water
OWNHOUSE	Whether the respondents have their own house or not 1 if has own house, 0 if not
NCHL5YR	Number of children younger than 5 years in a family
AGE	Age of the respondents (household head) in years
INCOME	Monthly income of the household in ETB
BILL	Monthly water bill
VOLUMEW	The amount of water consumed per month in m^3
MALE	1 if the respondent is male, 0 otherwise
EDUC	1 if the respondent has formal education, 0 otherwise
FAMSIZE	Family size
LOCATION	1 if the respondents are from Adama and Lume, 0 otherwise
ε_i	Error terms assumed to be distributed IID and normal distribution

WTP^* is the latent dependent variable .From Eq. 5.9 it can be inferred that the observed variable WTP equals WTP^* when $WTP > 0$, but WTP become zero when $WTP^* \leq 0$. In the Tobit model we have to estimate the marginal effects of Xi (explanatory variables) from the change in WTP (Rodríguez-Tapia et al., 2017). The estimation results for both OLS and Tobit censored models are given in Table 5.25.

Table 5. 25 Estimation results using OLS, Tobit (MLE) model at home

	OLS		**TOBIT**		**Marginal effect of Tobit model**	
WTP*home	Coef.	t	Coef.	t	Dy/dx	x-mean
Constant	2.347	6.55	2.410	6.69	~	~
INFATT |	0.075**	2.4	0.084**	2.66	0.088	4.452
QUATT	0.333***	9.95	0.336***	9.98	0.331	4.433
DISSATT	0.301***	5.64	0.293***	5.47	0.302	4.882
SRCEW |	-0.239***	-4.33	-0.244***	-4.38	-0.240	-0.191
BOTL	0.001***	3.25	0.001***	3.5	0.001	31.624
OWNHOUS	0.282***	3.09	0.287***	3.12	0.266	0.961
NCHL5YR	0.055**	2.16	0.058**	2.31	0.056	0.639
AGE	-0.009***	-5.47	-0.009***	-5.55	-0.008	41.800
INCOME	0.162***	4.33	0.158***	4.21	0.158	7.318
BILL	-0.003**	-2.48	-0.002**	-2.37	-0.003	28.291
VOLUME	0.015**	2.46	0.015**	2.43	0.025	25.155
MALE	-0.051**	-2.15	-0.050**	-2.11	-0.052	0.664
EDUC	0.238***	6.3	0.233***	6.13	0.244	0.594
FAMSIZE	-0.022	-1.64	-0.027*	-1.98	-0.030	2.718
LOCATION dummy	-0.421***	-8.17	-0.412***	-7.95	-0.427	0.321
Sigma			1.289			
Prob > F	0.000					
LR chi2(16)			554.88			

It is estimated that the WTP for a fluoride safe drinking water connection is ETB 3.69 (US$ 0.13 cents) per jerry can at home with 24 hours availability.

Accordingly a household that consumes 2 m^3 water per month will pay US$ 13.45 (ETB 370). To compare this result with previous studies, Rodríguez-Tapia et al., (2017) estimated a total WTP for quality of water supply in Mexico City to be US$ 3.10 per home, bi-monthly.

The results of the estimated models show that perceptions about fluoride levels, prior information notification services and overall dissatisfaction rate positively influenced household WTP for fluoride safe drinking water connections. All the perception variables are statistically significant in influencing households' decision to pay.

In addition to factors of perception, the source of water supply has a strong influence on the respondents' WTP. For instance, households whose water source is through pipelines are less willing to pay for the improved quality of water services perhaps perceiving no significant difference in the quality as compared to people who depend open sources of water. Since a majority of people in the study area are not connected to private pipelines and mainly obtain water from open source like lakes, rivers and bore holes (private and common) and rarely from public taps they are more willing to pay compared to those who already have a connection at home.

Purchasing bottled water increases WTP by ETB 0.001 ($ US 0.00004) and incomes increase WTP by ETB 0.158 ($US 0.006) respectively. Another high impact social variable is the number of children less than 5 years in the family and whether the households have their own house or not. As a household has one more child in the family its WTP for fluoride safe drinking water per jerry can is 0.058 ETB ($US 0.002) and as a household owns a house its WTP for fluoride free water service connection increases by 0.287 ETB($ US 0.01).

Among the demographic variables age of the respondents, male head and family size have a negative impact on households' willingness to pay for fluoride safe drinking water at home. The implications of this are that older people are less educated in the Ethiopian context and hence less aware of the health impact of fluoride. As a matter of culture, females are responsible for fetching water and taking care of household activities so they value quality of water more than the men. The impact of family size on households' willingness to pay for fluoride safe water is insignificant and not different from zero in both the models. Another important variable is education which has a positive influence on households' WTP for fluoride safe water services. By considering the education variable as a dummy, those who attended formal schools are more willing to pay for fluoride safe water than those who do not have any formal schooling, assuming other things are constant. This implies that educated households are aware of the impact of fluoride on health and hence they value their own and their families' health more than illiterate households.

Concerning current water characteristics, the monthly bill had a negative impact on WTP for quality of water while the volume of water consumption had a positive impact on households WTP for quality water. Because households' incomes are limited a higher current bill will lead to less WTP for fluoride free water supply whereas the more the volume of water consumed by households the more WTP for fluoride safe water. These results are in line with Rodríguez-Tapia et al.'s, (2017) study in Mexico.

Location, which was categorized based on the fluoride concentration level, using a dummy variable the respondents from Adama and Lume had negative WTP for fluoride safe water as compared to Bora and Zuway Dugda *woredas*. These results make sense as far as the location is concerned since Bora and Zuway dugda have higher fluoride levels and severe victims of fluoride consumption. Hence, the residents are more WTP for safe water than their counterparts in the other *woredas* considered for the study.

The OLS and Tobit censored model estimation results following the same procedure for the model of WTP for the nearest public tab fluoride safe water are presented in Table 5.26.

Table 5. 26 Estimation results **using** OLS, Tobit model for WTP nearest public tap

	OLS		**TOBIT**		**Marginal effects of Tobit model**	
WTP nearest	Coef.	T	Coef.	t	dy/dx[29]	X-mean
Constant	0.920***	3.65	0.993***	3.92	~	~
INFATT |	0.026	1.43	0.028	1.55	0.028	4.452
QUATT	0.220***	11.31	0.222***	11.39	0.222	4.433
DISSATT	0.181***	5.85	0.178***	5.72	0.178	4.882

[29] (*) dy/dx is for discrete change of dummy variable from 0 to 1

SRCEW |	-0.098***	-3.07	-0.093**	-2.87	-0.093	0.191
BOTL	0.0003**	2.59	0.0003**	2.86	0.0003	31.624
OWNHOS	0.067	1.27	0.069	1.29	0.069	0.961
NCHL5Y	0.046***	3.14	0.047***	3.2	0.047	0.639
AGE	-0.007***	-7.15	-0.007***	-7.33	-0.007	41.800
INCOME	0.023	1.08	0.017	0.77	0.017	7.318
BILL	-0.001**	-2.1	-0.001*	-1.98	-0.001	28.291
VOLUME	-0.005	-1.22	-0.004	-1.02	-0.004	25.155
MALE	-0.052***	-3.81	-0.054***	-3.88	-0.054	0.664
EDUC	0.122***	5.54	0.124***	5.6	0.124	0.594
FAMSIZE	0.012	1.52	0.011	1.41	0.011	2.718
LOCATION dummy	-0.258***	-8.59	-0.255***	-8.44	-0.255	0.321
Sigma			0.748			
Prob > F	0.000					
LR chi2(16)			564.68			

The estimated WTP for fluoride safe water per jerry car from the nearest public tab is ETB 1.80 ($ US 0.065 cents). For households with 6 members who consume 6 jerry cans per week or 24 jerry cans per month (for drinking and cooking only) from the nearest public tab the WTP pay is ETB 43.20 ($US 1.6) and households who consume $2M^3$ per month have a WTP of ETB 180 ($US 6.55) only which is really affordable compared to current private vendor water bills and other opportunity costs.

The explanations for the explanatory variables are the same with model 1 and the results are also almost similar except the magnitudes and signs of some variables. For instance, perceptions of prior information notification about the water service are insignificant in influencing household WTP for fluoride safe water, and variables such as own house, income, family size and volume of water consumption are insignificant in influencing households' WTP for fluoride safe water from nearest public tap per jerry can. With regard to income effects, the results show that people with higher incomes do not necessarily have more WTP for public tap connections; instead it is poor household who prefer this source of water. This result is similar to Jonson's (2003) study in Sri Lanka where the poor households did not necessarily prefer private taps to public and mini-grid lines for water. Hundie's (2016) study in Ethiopia shows that the estimated mean WTP for improved water per jerry can (equivalent to 20 liters) was 94 cents in Jigjiga town that accounted for about 7.2 percent of the respondents' average income per year which is comparable to my study's results. My results show that households who get water from sources other than a pipeline have more WTP for improved water as compared to families whose source is pipelines.

5.3.4.2.Comparison of WTP results by methods

Focusing on the quality of water services since in the study area there is excess fluoride concentration in the underground water my study estimates the potential WTP to remove the fluoride problem. As estimated in the latent class logit model earlier, the mean WTP for fluoride safe water above and equal to WHO standards is ETB 159.24 ($US 5.8) and 75.37($US 2.75) in class 2 and insignificant in class 1. The comparison is presented by Figure 5.6.

Assuming a given household consumes $2m^3$ fluoride safe water per month (for drinking, cooking and washing) gets it either at home or from nearest public tap, the estimated mean WTP using the LCM analysis and the open ended CVM methods is quite comparable. Given the pipeline connection is at home, consumers' willingness to pay for quality water is a bit higher in the case of open ended CVM estimations compared to the latent class logit model. Although the means of valuation is different this means that in the latent class logit model the consumers value the quality of water service as part-worth in the level of other attributes whereas in the case of CVM, consumers value improved water services as a complete set of goods and services. In the latent class logit model (class 2) consumers have ETB 159.24 (US$ 5.80) MWTP per month for quality of water above WHO standards and ETB 75.37(US$2.75) for quality of water equal to WHO standards; in total they have MWTP about ETB 234.61(US$ 8.55) for quality equal to or above WHO standards.

On the other hand, by using CVM consumers' mean willingness to pay for fluoride safe water connected at home is ETB 370 (US$13.45) per month and that of WTP for the nearest public tab safe water is ETB 180 (US$ 6.55) per month. Comparisons of the mean willingness to pay are presented in Figure 5.6.

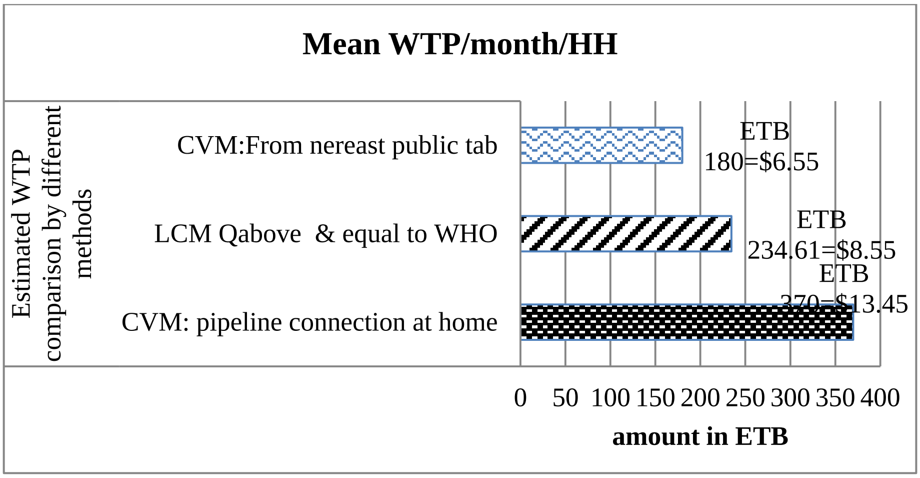


Figure 5. 6 Comparison of mean WTP for fluoride safe water service/month

5.3.5. Cost benefit analysis

In 2002-10 the Government of Ethiopia invested ETB 276.3 million (US $ 2.1 million) for water supply projects in five *woredas* in the Rift Valley region which is adjacent to my study area (Datturi et al., 2015). It was aimed that the water supply would cover about 827,000 residents in the area which is almost the same as the population in the *woredas* that my study focuses on (831,000 population) (CSA, 2013). In addition to the US$ 2.1 million initial investment (that includes cost of developing water sources, bone char to treat fluoride and all costs incurred in the setting up of the entire scheme, that is, water tanks, pipe lines, kiosks and water storage the estimated operational cost for a 20 year life span of the water supply scheme is calculated to be ETB 25.3 million (US $1.95 million) (Datturi et al., 2015). The estimated yearly operational costs include maintenance, electricity, chemicals, water care taker's salary and other miscellaneous expenses. Water was provided to the community after treatment of fluorides in community-based water taps. Considering the total investment and operational costs per m^3 of that project as a proxy cost for our study and adding the current inflation rate for calculating the total cost, we can do the cost benefit analysis. Therefore, if we calculate the total mean willingness to pay for the all households in the five woredas using the estimated monthly WTP of each household (Figure 5.6), and by comparing it with the initial investments and operation costs, we can verify the potential cost benefit analysis and estimate its potential for consumers in getting fluoride safe water. Hence, we considered aggregate mean WTP of all households living in the sampled *woredas* for this fluoride safe water supply project for a period of 20 years as the benefit of such a service in the benefit cost analysis estimation. The aggregated mean willingness to pay by assuming it as a sum of the present value of yearly mean WTP for 20 years, and adopting a 7 percent as annual discount rate[30] (Woo et al., 2017);

$$Total\,\mathrm{MWTP}_{allHH} = \sum_{t=1}^{20} \frac{anualMWTP_{allHH} / year}{(1+0.07)^{t-1}} \qquad (5.10)$$

where, the annual average WTP of all households is the product of individual average WTP estimated by each model times the number of households in the five *woredas* (CSA, 2013) times 12 months. The estimated results are given in Table 5.27.

[30] The National Bank of Ethiopia base money rate in April 2018 is used as an annual discount rate.

Table 5. 27 Average WTP for fluoride safe water supply in Ethiopia

Aggregate mean WTP	**Methods**	**Total amount in million ETB (US $)**
quality of water above WHO standard(<1.5 mg/l fluoride concentration)	LCM class	ETB 600.04 million (US$ 21.8 million)
quality of water equal to WHO standard (1.5mg/l fluoride concentration)		ETB 284 million (US$ 10.33 million)
both quality >=WHO standard (<=1.5 mg/l)		ETB 884.04 million (US$ 32.13 million)
Aggregate WTP for fluoride safe pipeline water connection at home	By CVM analysis	ETB 6971.1 million (US$ 253.5 million)
Aggregate WTP for fluoride safe nearest public tab water connection		ETB 3391.3 million (US$ 123.3 million)

*life span of water supply project is assumed to be 20 years.

It is estimated that the total investments and operational costs for the fluoride safe water supply project scheme was ETB 301.5 million (US$ 23.2 million) (Datturi et al., 2015). As I have calculated the total lifetime MWTP for fluoride safe water by CVM methods (Table 5.27) this is larger than the total cost of the project. Therefore, compared to the investments and operational costs, the supply of fluoride safe drinking water in the Rift Valley region is economically feasible since the residents' willingness to pay is sufficient enough to recover the investment and operational costs, given other things are constant. This result provides an answer to the analysis in Section 5.3.1, in which financial factors were discussed as the main constraints in the supply of safe water followed by the technical factors. The estimated aggregate present value of mean WTP using the latent class logit method (class 2) is about 32.13 million US dollars whereas using the contingent valuation method approach the total present value of mean WTP for a fluoride safe water connection at home is about US$ 253.5 million and for connection at the nearest public tap is about US$ 123.3 million; all these values are greater than the total cost of the clean water supply project assumed (US$ 23.2 million). The estimated value of WTP may be overestimated since consumers are valuing the quality of water services hypothetically. For instance, according to Datturi et al., (2015), the treated water tariff per meter cube in the adjacent woreda was ETB 22 ($US 0.8 cents) whereas the stated willingness to pay for one meter cube of fluoride safe water is about ETB 90 ($US 3.3). This difference can be because of different factors including biases such as strategic or response. Nonetheless, my results imply that there is huge potential willingness to pay if people are provided fluoride safe water services in the study area.

To sum up, it is possible to provide fluoride safe drinking water to Rift Valley's residents who are suffering from skeletal and dental fluorosis provided that there is a commitment from the *woreda*/regional water supply office. As explained in the cost benefit analysis there is huge potential WTP for safe water if the providers or any concerned body strategically designs the payment mechanism and scheme (through installments instead of one-time payment) to overcome the financial constraints which my study concludes are critical. However, supplier side problems are not limited only to financial problems but also involve technological constraints and institutional aspects. Therefore, my study concludes that the financial problems can be solved if there is a commitment to adopting new technology that monitors the fluoride level online and building institutional capacity. This is supported by the finding of mean WTP per household for fluoride safe water per month which ranges from a 3 percent share of income to 16 percent of the income. Using the latent class logit model the income share of the household WTP for quality of water services ranges from 3 percent to 7 percent whereas in the contingent valuation method the income share of households WTP for fluoride safe water per month ranges from 8 percent to 16 percent. This result is comparable to other studies such as Vásquez's (2009) study in Mexico which shows that households' median WTP for safe and reliable drinking water was greater than their current water bill at least by 45.6 percent and greater than 5.7 percent of the customers' median income which is greater than the proposed affordability threshold level which is 3 percent of household income (OECD, 2003). Gunatilake's (2012) study shows that households are WTP 3.6 percent of their incomes for water service improvement and Rodríguez-Tapia (2017) show that 0.22 percent of income consumers were WTP for quality of water services in Mexico city. Hensher (2005) shows that households are WTP 19 percent of their annual bills to receive prior notifications about water service interruptions and Lee (2014) estimated household WTP at about 18.2 percent of the current bill rate per cubic water consumption in Ulsan city in South Korea. González-Davila

(2013) show that household WTP for fluoride and arsenic removal was US$ 2.7 and 3.22 per month respectively in Mexico.

My results may imply consumers' eagerness and commitment to overcome the severity of the impact of fluoride which they have been experiencing for a long time in this study area. In addition, other factors which influence households' WTP were also explored, such as perceptions about the quality of water, degree of dissatisfaction, education, own house and number of children under 5 years all of which had a positive influence on households' WTP. Age of respondents, water bill, being male and location of the respondents (those in Adama and Lume) had a negative influence on households' willingness to pay for fluoride safe drinking water. Bottled water is 1,150 times more expensive than the current *woreda* water tariffs and to 200 times more expensive than the current stated household willingness to pay for 2m^3 of quality water.[31] This shows that households will be happy to adopt alternative forms of water purification or willing to pay for improved quality of water which involves lower cost, less time and is easier to get.

[31] 2 liters of bottled water cost ETB 15 ($US 0.55) and 2,000 liters cost ETB 15,000 (US$545) in January 2018.

Chapter 6. Conclusion and Policy Implications

6.1. Conclusion

WHO considers access to clean water a basic human right which is vital for human health including benefits ranging from avoiding costs and saving time to more intangible benefits such as convenience, well-being, dignity, privacy and safety (WHO, 2015). However, these rights and benefits are underserved particularly in developing countries where they could have more substantial benefits such as reducing the incidence of water-borne illnesses like cholera, diarrhea and dental fluorosis thus helping in reducing mortality and morbidity as well as reducing the number of working days lost and the expenditure incurred on importing expensive medicines. All this will finally improve the country's GDP. Further, the population of the Rift Valley region is overexposed to excess fluoride levels resulting in catastrophic health effects such as skeletal and dental fluorosis and damaged brain development. To understand the preference structure of the households in this region for bridging the perception gap between the water providers and consumers and providing concrete policy suggestions this study explored and identified constraint factors that bound water providers (using experts' judgment data) and the preference structure of consumers for fluoride safe water services in the study area. The study used Hensher (2015), Lee (2014) and Mogas's (2006) arguments to measure the economic benefits of households' water quality improvements using the mixed logit analysis and the contingent valuation methods. First, the study explored why the water providers fail to supply fluoride safe water services to households in the region. The results of the AHP analysis show that the bounding factors are not limited to financial aspects only but also involve technical and institutional factors which too act as constraints in the study area.

Using the conjoint experiment survey data my study also estimated the mixed logit and latent class logit models. The results from the mixed logit model show the presence of heterogeneity across respondents with additional price, the quality level of the water and the duration of service disconnections are the most important attributes in descending order. This implies that households prefer the quality of water to be above or equal to WHO standards, want service notifications before interruptions early, want mobile-based service notifications and want less frequent and smaller interruptions with lower service surcharge. The results of the latent class logit model show that the population of the Rift Valley region exhibits two kinds of behavior which are softly categorized into reliability seekers and quality seekers. The class 1 group of households needs to have minimum or no water service interruptions, smaller duration of interruptions, early service notifications and lower service charges whereas the households in class 2 want to get quality water that are above or equal to WHO standards (fluoride level < or = 1.5mg/l) regardless of service charges.

To understand the affordability of the preferred attributes with respect to future water service connections in the study area, the study studied households' WTP for fluoride safe water services using an open ended contingent valuation method. Using OLS and the censored Tobit models the estimated WTP for $2m^3$ of fluoride safe water connection in the home per month are \$13.70 and \$13.45 respectively and connected to the nearest public tap are \$6.84 and \$6.54 respectively. Considering households only as a source of funds, it is possible to provide fluoride safe water services (from the financial perspective) to the Rift Valley region since the aggregated total WTP is greater than the total water supply project's costs over the life span of 20 years, that is, it is economically feasible to do so, assuming that the other things are constant.

This study is thus expected to contribute to the empirical background on the use of stated preferences, a conjoint analysis and a contingent valuation analysis for fluoride safe water service connections from the consumers' perspective and the analytics hierarchy process method from the providers' side in the Rift Valley region to help draw policy measures for bridging unmet consumer demand.

6.2. Key findings and policy implications

A number of conclusions can be drawn from the analysis done in this study. From the mixed logit model's estimation, it is concluded that consumers in the Rift Valley would like to have connections to quality of water with fluoride safe levels either above WHO standards or equal to WHO standards (<=1.5 mg/l), want less water service interruptions, shorter duration of interruptions and want to receive notifications about services earlier.

Regarding the means of service communication, consumers prefer mobile-based service notifications and they dislike internet-based notifications compared to mass media which shows low internet penetration rates in the country. According to the International Telecommunication Union (2015) data report,[32] the internet penetration rate in Ethiopia is below that in many developing countries and accounts for only 15 percent of the total population. This figure confirms the findings of consumer preferences with regard to the means of information communication in the study area. As consumers prefer mobile-based services for service notifications, it would be good to work in parallel with internet service providers to facilitate penetration (widening the coverage of internet services) so that in the long run the internet-based platform service can become the preferred mode for receiving notifications.

The policy implications of this study are targeted at water providers – the government -- as a key stakeholder and responsible body for fluoride safe water supply in the study area. Accordingly, the following policy points are meant for the government and what it can do:

The government (water provider) needs to mobilize funds from households and from different donor agents including the World Bank. According to AHP’s results, financial factors are the main constraints that bind water providers’ in providing fluoride safe water services. Therefore, water providers need to look for financial sources which they can access. In the

[32] http://www.itu.int/net/pressoffice/press_releases/2015/17.aspx#.WxuJA-6FPIU.

Ethiopian context the source of finance for investments in water supply could be a loan from the World Bank and other lenders, from households, from public-private partnerships and loans from the government. So depending on convenience water providers should work on obtaining finances and in particular mobilize funds from household users and get loans from the World Bank and other donor agents. Households are also willing to pay more than a 75 percent surcharge in addition to their current bills if fluoride safe water is provided.

Another possible solution is that the water providers can raise revenue from water bills by controlling illegal connections, leakages and increasing tariff rates. According to observations during the survey there are illegal water connections and leakages with the result that much of the unmetered water is lost. In Ethiopia about 37 percent of water production is lost because of leakages which if managed properly can increase the water supply coverage (Desalegn, 2005). To increase revenues, water providers should control the illegal connections strictly (such as meter bypass, illegal connections, illegal reconnections, meter reversals and meter tampering) using strict regulations, incentives for informers and by adopting technology. Smart leakage detectors are available which can be installed along with the pipeline to detect where the leakage is and communicating this to the data center so that repairs can be done and leakages prevented. Therefore, water providers need to adopt leakage detector technology and online solutions to detect the leakages, create transparency and facilitate interoperability.

The government needs to work on reforms to bring in efficiency into the system. It can also invite private providers in the water supply sector. The private sector can easily be attracted because fluoride safe water supply is economically feasible according to the cost benefit analysis that I did. For instance, countries like England and Chile have fully privatized water sectors and France, USA, Cote d'ivore, South Africa, Malaysia, Colombia, Poland and Mexico are partially privatized with mixed ownership (Marin, 2009). By establishing strict regulations, inviting private water providers could be an alternative to improving service delivery.

The government needs to facilitate microcredit for the poor households for water supply connections.

This microcredit service should exclusively focus on giving loans for water supply connections to poor households which will enable it to make water and sanitation service coverage universal. According to the survey's results households need installment-based connection payment options rather than paying a lump sum amount for the connection. For the sake of universal safe water supply, it would be good if the government facilitates microcredit targeted at alleviating the problem of water supply connections and sanitation. For instance, households in countries such as Kenya, Uganda, Bangladesh and India have been benefiting from such water credit initiatives by institutions and NGOs since 2003 (Water.org, 2017).[33] Till 2011 these initiatives had helped 13 partner enterprises to reach 51,000 credits through water supply and sewage connections in Indonesia and in Vietnam. Hence, using the lessons

[33] https://water.org/siwi2017/.

learnt in other countries by different stakeholders should facilitate microcredit dedicated to water connections particularly for poor households who cannot afford to pay the initial connection costs.

The government also needs to consider sources of water supply for different population sizes. Since the population settlement patterns are scattered leading to inconvenience in providing public utilities on a large scale in the rural parts of Ethiopia, water providers should efficiently work on the sources of water supply. For very scattered populations water kiosks can be installed from drilled bore holes in the center of the community settlement, unless the government decides to work on settlement patterns of the population. For a large and densely populated area pipeline-based water supply distribution networks are efficient. Further, for large population sizes it would be better to supply water from safe sources than treating water which already has fluoride. By comparing the cost of supply from safe sources and the treatment costs of fluoride, the government should be able to minimize the cost of water supply.

The government also needs to adopt an online monitoring system. According to the results of the AHP analysis, technical and institutional and policy factors are the second and third main constraints that bound water providers in providing fluoride safe water services. Online technologies have advantages beyond ensuring the quality of water services, such as increasing service efficiency by increasing interoperability and transparency within institutions. By understanding these benefits, the government can also support internet service providers to expand their coverage to the Rift Valley region so that consumers adopt internet-based service communication which is more compatible with online-based fluoride monitoring and notifications. Hence, water providers need to adopt online technologies to control transparency issues, quality issues and interoperability issues and reduce inefficiency and corruption.

The government needs to install community-based fluoride safe public taps. According to the WTP analysis for the nearest public tap fluoride safe water service connection, households are ready to even WTP for them particularly the relatively poor households since they believe that they cannot afford to pay the connection fee so they would like to pay more for safe water services from the nearest public tap. Hence, the government should provide community-based fluoride safe water public taps that can be used as a good intervention for tackling the problem of providing clean water at least in the short run.

Creating public private partnerships for service delivery is another viable option for the government. The government can still have the ownership and can outsource some service delivery for some duration of time. However, if the government wants to fully privatize the water supply service sector, there are good lessons from England and Chile and some other cities in America which can be examined. Public private partnerships are common forms in which the private sector can participate in the water supply sector (Marin, 2009).

There are different modes of PPP in the water service sector such as a management contracts under which the private player is responsible for operating the system, a lease contract under which the private player takes resources on lease and receives a share of the revenue and public private mix ownership in which the government has a minority share while the management is in the hands of the water supply company and a concession which shows and dictates the private player as running the entire system it makes the investments.

Accordingly for instance, in Kenya the local water utility created a public private partnership with those who have private bore holes in the community by transferring them to networks of water kiosks in the community (Njeru et al., 2014). The local public water supply company was invested in rehabilitating and equipping the fragmented private bore holes, constructing storage, pipeline distribution and a network of water kiosks. This can be a good lesson for Ethiopia since both countries similar situations with regard to the fluoride problem. In this way the local government in the Rift Valley region (at kebele level) can also intervene and supply reliable and affordable water services through a network of water kiosks and community taps beside creating employment for kiosk operators, reducing school dropout rates because of water vending or water collecting and or water borne disease and increase the overall social welfare. Creating public private partnerships is a typical solution which is mostly overlooked by local governments.

Another policy suggestion is adopting water service interruption notification systems. Water providers need to adopt water service notification systems which automatically enable them to notify the households in advance about service outages. To identify the means of service notifications the study studied households' preferences for different means of service notifications. A majority of the households would like to receive notifications through mobile phones (either voice call, or text messages) compared to mass media and they do not like internet-based notifications (email, website, social media) because of low internet coverage in the Rift Valley region. For instance, in Asheville in the US, the water provider company has a 'delt-alert customer notification call system' which automatically notifies customers by phone, email or text message within an affected area in addition to issuing a press release. The delt-alert call system uses a mapping interface system in conjunction with registered phone, email, and text users to pick out a certain area or street where an inconvenience may occur and then makes the call to registered users in that area. For scheduled water interruptions the city's water provider notifies its customers at least four business days in advance.[34] In Korea water is supplied by K Water in the whole country and if there is any interruption a notification is sent via media outlets, including emails and phones.[35] In North Carolina (USA), New Castle City (UK) and in Cambridge (USA) too water notifications for service interruptions are delivered to registered households via emails and local mass media if the disconnection is going to impact a large area. In Zambia particularly in Lusaka, the water and sewerage company provides interruption notifications on the company's website and through

[34] http://www.ashevillenc.gov/departments/water/default.htm.
[35] http://english.kwater.or.kr/eng/main.do?s_mid=4.

social media including Facebook.[36] However, in my study area it is difficult to target the customers using internet-based services. Hence, it will be better to send interruption notifications using mobile-based text messaging at least in the short run.

[36] https://www.facebook.com/lusakawater/.

6.3. Limitation and future research

My study was aimed to understand consumer preferences and WTP for fluoride safe water services and identifying the main challenges that bind providers in supplying fluoride safe water services in the Rift Valley region. It focused on fluoride level monitoring aspects. However, knowing the level of fluoride is not a guarantee of safe drinking water supply. What is needed for this is working on appropriate technologies. Hence, it is suggested that fluoride removal technology preferences and other related matters should be taken up by future research studies. Another limitation of this research is that it mainly focuses on the fluoride problem in the Rift Valley region and does not include the general water quality levels and hence its findings can only be applied to fluoride prevalent areas in developing countries.

Further, there should be good ICT infrastructure for water providers to install online-based quality monitoring systems and for giving prior information to users so that they have the freedom to choose either internet-based services or mobile-based services. Ethio telecom (a single telecom and IS) provider in Ethiopia needs to deploy infrastructure in every location to complement other development projects such as fluoride safe water supply projects provided that consumers have the potential to pay the costs of service improvement. Therefore, the government's policy concerning ICT service providers can be another topic for potential research in Ethiopia.

Another shortcoming of my study arises from the nature of the data and the methodological point of view as the preference data for estimating consumer preferences for future water services was collected through interview methods using hypothetically constructed choice sets/alternatives. As a result, the stated preferences may at times not reflect the actual behavior. The situation of the respondent during the interview period (in a hurry, not stable, not in a good mood), the understanding levels of the respondents, their ranking abilities, clarification abilities of the interviewer and other related aspects make the data quality uncontrollable and it may also have biases.

Further, my study could not include more than six attributes in the choice experiment of the survey. The respondents may face difficulties in clearly and consistently identifying their preferred alternatives over repeated choice sets. To avoid these kinds of problems, the study trade off additional important attributes in this study such as ownership of water providers whether it could be either public or private or public private partnership or others too. Hence I suggest potential researcher to work on developing other ways of capturing more attributes as much as possible in the future study

Another possible limitation of my study is the single source of data that fails to represent and provide universal implications. There are many countries vulnerable to excess fluoride including Ethiopia's neighbors such as Kenya, Tanzania and Malawi and other countries in the Middle East. However, the results of my study may not help in generating policy implication for these countries since their households may have their own unique preference structures thus leading to different policy implications. Therefore I suggest other potential researcher to consider different countries realities and conduct survey to generalize in the future.

The open ended contingent valuation survey also has its own drawbacks. Although it provides a simple direct valuation of fluoride safe water services, the respondents may not have a frame of reference to respond accurately because consumers value attributes of the goods more than the goods per se. Hence, the WTP data may be subject to overestimated or underestimated results compared to other dichotomous choice formats (Bateman et al., 2001).

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Appendix

Annex 1-map of Ethiopia with survey sites

Annex II- Household preference Survey Questionnaire

Survey questioniare for future water service connection in the Rift Valley Region in Ethiopia, December 2017-january 2018.

Introduction

Good morning/afternoon/evening. My name is --------------- and I am carrying out a research survey on household preference for fluoride safe water service connection in the central rift valley rigion of Ethiopia, conducted by Birku Reta for his PhD thesis under the supervision of Professor Jongsu Lee. Thank you for your participation in the survey in advance.

Respondents address Survey date: ---------------------------------, Time--------------------------------- Region/ town/city: --------------------------- Kebele: ___________________________ Enumerator name:___________________

The purpose of the study is mainly to explore the household preference structure for the fluoride safe water service connection in the central Rift Valley Region of Ethiopia. The result of the study will be used for policy suggestion with regard to future water supply in the underlined study area. The information received from this survey and the outcome will be kept strictly confidential and used only for the academic purposes which will be reflected as the policy suggestion paper for the Government of Ethiopia and policy advocates.

The interview may take 20 minutes!

Q1.Have you or any family member or relatives, been working in water or electricity provider company? *If yes drop this respondent, if no proceed to Q2.*

Yes ☐ No: ☐

Q2. Would you agree to participate in the interview? ***If yes proceed to section I, if no change the respondent.***

Yes ☐ No: ☐

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Section 1: Future water service improvement and connection survey

Part I: Information about respondent experience related to current water services supply

1. Do you have water pipeline service connection at your house? **If no go to next [2-5], if yes jump to Q.no. 6.**
   Yes ☐ No: ☐
2. Do you want to be connected to pipeline water at your yard/house?
   Yes ☐ No: ☐
3. What is the main reason for you not having connected to private water tap yet? If your reason **is *b* proceed to Qno.4, if not jump to Q no.5**
   1. I have requested for connection and waiting for it ☐
   2. Initial connection cost is unaffordable to me ☐
   3. No water supply coverage in my area ☐
   4. I am satisfied with my current source of water supply ☐
   5. Monthly bill is too high ☐
   6. Others ☐
4. Would you be connected to the pipeline if the initial connection charge is to be paid off in monthly installments based along with your monthly bill?
   Yes ☐ No: ☐
5. Which of the following source of water supply you are currently using? **Multiple answers possible. Then proceed to Q no.6**
   1. from public tap_____________
   2. from private borehole_________
   3. from common tube well or borehole________
   4. from open springs ________
   5. from open river/lakes_______
   6. From private vendors________
   7. Other source___________
6. Approximately how much is your your monthly water bill and amount of water your household consume in m^3

Amount in birr per month	Volume of water consumed in m^3

7. For those who are connected to pipeline, is water is available all the time? **If no proceed to Q[8-14], if yes jump to Qno.16.**
   Yes ☐ No: ☐
8. How often it goes away (outage) per month?
   Once ☐ three times ☐ five times ☐ >/=seven times ☐
9. How long you wait to get water back when it outage once on average?
   <1 hr ☐ [1-12] hr ☐ (12-24) hr ☐ > =24 hr ☐
10. Is there any official time schedule for water service outage period? **If no proceed to Q[11-14], if yes go to Qno. 15**
    Yes ☐ No: ☐

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11. Do you receive prior notification before water service is disconnected? *If yes proceed to Q 12, if no go to Qno. 13*

Yes ☐ No: ☐

12. By what means you usually receive information of water service disconnection? **Go to 15**.

Mobile based ☐ internet based ☐ mass media based ☐ other ☐

13. Do you want to get prior notification for water service outage? ***If yes proceed to Q14, if no go to Q15.***

Yes ☐ No: ☐

14. By what means you would like to receive prior information of water service disconnection?

Mobile based ☐ internet based ☐ mass media based ☐ other ☐

15. Do you think existing drinking water supply has an excess fluoride problem? **If yes proceed to Q[16-18], if no go to Qno.19.**

Yes ☐ No: ☐

16. Do you treat to remove fluoride from the water before you drink?

Yes ☐ No: ☐

17. Have you/your family member ever suffered from dental or skeletal fluorosis or any other disease because of excess fluoride take up?

Yes ☐ No: ☐

18. Do you want to get defluoridated water supply?

Yes ☐ No: ☐

19. Have you ever used bottled water for drinking purpose at home perceiving tap water has no drinkable level of quality? Yes ☐ No ☐

If yes how much bottle (of 1litter) on average your household members consume per month? ___

How much birr you spend to buy this bottled water/month?______

20. If fluoride free and quality water is provided to your household (private tap), what is the maximum amount of birr you are WTP/jerican (20 liters) in addition to your current bill? ____

What if quality of water is provided at the nearest public tap (5 minutes' double trip walk)? How much WTP/jerican? _____

What is the maximum munities/hrs, you would like to tolerate to fetch fluoride free water? _____

21. Do you use internet services? *If yes proceed to Q[21-22], if no go to part II.*

Yes ☐ No: ☐

22. Where do you use internet services most of the time? Multiple answers possible

At home ☐ internet café ☐ workplace ☐ other place ☐

23. What type of internet service you are using or connected to? Multiple answer possible

Mobile data ☐ other wireless ☐ wired internet ☐

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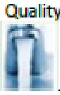
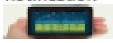
Part II: Rank-based Conjoint experiment Survey for water service improvement

Suppose the government(water provider)want to invest on water quality(fluoride monitoring) and water supply infrastructure so that you can able to connected to safe water services that is drinkable just from the tap at your home. It is projected that if households' preferences are identified and enough funds can be raised, the projects can be implemented quickly to provide households with improved water service as described above. The municipal government will try its best to keep a low water tariff in achieving the goals. However, without knowing users preferences and collecting sufficient water fees from households like yours, the water supply quality (fluoride safe) and quantity improvements may not be secured and hence the projects may not be implemented. Now you will be asked to rank the set of services based on your preference. There are **SIX** service sets each with **FOUR** alternative services. Keep in mind that each service are different at least in some attribute level and hence considering your most liked combination of attribute level please rank each services in all service set. For your understanding here below is a short description of attributes and their levels

Attribute picture/	Levels	Description
Quality of water supply 	Above WHO standard Equal WHO standard Below WHO standard	This attribute measure the extent of fluoride free drinking water supply according to WHO standards (maximum 1.5 mg/L).
	Once a month Once in 2 months Once in 3 months	Number of times water is unavailable per months
	1hr 12 hr 24hr	length of time that water is unavailable each time that it goes off in hour on average
No. of days of prior notification 	1day 4day 7 day	Length of days that prior service interruption notification is received by users
Means of information notification   	Mobile based Internet based Mass media based	Means of information delivery for notification of service interruption. Mobile based means it can be through voice call or SMS text. Internet based means it can be through email, or different social media such as Facebook, WhatsApp, twitter etc. and Mass media includes local tv channel, radio or personal announcement
Additional price to current bill/month 	**Same level** **+ 25%** **+ 50%**	Additional payment household WTP for service improvement per month

Please rank the service that you are most likely preferred (1st) to least likely preferred including current status.

Service Rank set 1

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notification	Means of information notification	Additional price	Rank(1st ,2nd ,3rd , 4th)
Service 1	Above WHO standards	once in 3 months	24 hour	7 days	massmedia based	+ 25%	
Service 2	Equal WHO standards	once in 2 months	1 hour	1 day	massmedia based	+ 25%	
Service 3	Below WHO standards	once a month	1 hour	1 day	mobile based	same level	
Status quo							

Service Rank set 2

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notificatio	Means of informatio notification	Additional price	Rank
Service 1	Below WHO standards	once in 3 months	12 hour	4 days	mobile based	same level	
Service 2	Above WHO standard	once in 3 months	24 hour	1 day	mobile based	+ 50%	
Service 3	Equal WHO standards	once a month	1 hour	4 days	internet based	+ 25%	
Status quo							

Service Rank set 3

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notificatio	Means of information notification	Additional price	Rank
Service 1	Above WHO standards	once in 3 months	1 hour	4 days	massmedia based	+ 50%	
Service 2	Below WHO standard	once a month	12 hour	7 days	mobile based	+ 25%	
Service 3	Equal WHO standards	once a month	24 hour	7 days	internet based	+ 50%	
Status quo							

Service Rank set 4

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notification	Means of information notification	Additional price	Rank
Service 1	Above WHO standard	Once in 2 months	12 hour	4 days	Internet based	+ 50%	
Service 2	Equal WHO standards	once a month	12 hour	1 day	massmedia based	+ 50%	
Service 3	Below WHO standards	once in 2 months	24 hour	1 day	internet based	same level	
Status quo							

Service Rank set 5

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notification	Means of information notification	Additional price	Rank
Service 1	Equal WHO standards	once in 2 months	1 hour	7 days	mobile based	+ 50%	
Service 2	Below WHO standard	once a month	24 hour	4 days	massmedia based	same level	
Service 3	Above WHO standards	once in 2 months	24 hour	4 days	mobile based	+ 25%	
Status quo							

Service Rank set 6

services	Quality of water	Frequency of water outage	Duration of water outage	No. of days of prior notification	Means of information notification	Additional price	Rank
Service 1	Above WHO standards	once in 3 months	12 hour	1 day	internet based	+ 25%	
Service 2	Equal WHO standard	once in 3 months	1 hour	7 days	internet based	same level	
Service 3	Below WHO standards	once in 2 months	12 hour	7 days	massmedia based	same level	
Status quo							

Part III: Psychographic Information for water service improvement

This part of survey is used for internal consistency checks points for above discrete choice experiment rank survey. It enables to ensure that respondents were engaging in the exercise and taking it seriously. Now I will ask you some few questions to measure the extent you agree or disagree, with the following sentences.

1. I prefer to pay more tariff than facing frequent interruption of water services				
Strongly agree	Agree	Neutral	disagree	Strongly disagree
❺	❹	❸	❷	❶
2. I value quality of water more than 24hr/7day availability of water supply				
❺	❹	❸	❷	❶
3. I believe that I should get early prior notification of interruption so as to able to store water				
❺	❹	❸	❷	❶
4. I feel comfortable to receive prior notification by mobile phone(call or SMS) than by internet means (email, social media)				
❺	❹	❸	❷	❶
5. I prefer to receive interruption notification of water service by internet means than mass media				
❺	❹	❸	❷	❶
6. I am WTP some money to remove fluoride from drinking water				
❺	❹	❸	❷	❶
7. Overall, I am not satisfied with existing drinking water service				
❺	❹	❸	❷	❶

Section 2: Respondent socio demographic information

24. How old are you in years? ☐
25. Gender?
    Male ☐ Female ☐
26. What is your education level?

    Illiterate ☐ Primary (8th) ☐ High school (up to12th ☐ Dibloma ☐ >=degree ☐

27. What is your marital status? If single jump to Q21, If not single proceed to Q20.
    Single ☐ Married ☐ Divorced ☐ widowed ☐

28. Could you tell me about your family size by gender and age including you and other family member who live with you at least for >= 6 months?

	e.g. 3 (5, 32, 40 years)	No.of family members who are students. E.g. 2
Number of male with age		
Number of female with age		

29. What is your occupation?
    Gov't/private hired ☐ own business ☐ farmer ☐ unemployed ☐ others ☐
30. If you are gov't or private employee, what is your job position at work place? ___________
31. Do you have own house?
    Yes ☐ No ☐
32. Which type of house you own/or living in?
    madeof wood/metal sheet roof ☐ Grass roof ☐ Villas ☐ Apartments ☐
    Condominium ☐
33. How much is your family income per month in '000 birr? ___________

Thank you very much for devoting your precious time!!!

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Annex III- Water providers' expert judgement survey questionnaire

Water service providers' expert judgement survey in the Rift Valley Region of Ethiopia

Dear Respondent!

We are carrying out this research to identify major factors that hinder the supply of fluoride safe water supply to the people of the rift valley region of Ethiopia. After rigorous discussion, we have identified major domains and barriers that hinder fluoride safe water supply and looking your opinion on this regard. With your experiences on water supply staff, ICT, water engineers, active involvement on Policy level, you are chosen as an expert for this study. This questionnaire includes pairwise comparison between the barriers that influence the overall decision of fluoride free water supply project in your woreda dwellers. The response of this questionnaire will comply with academic confidential norms. It will be utilized only for academic purpose and as policy implication for the stakeholders of fluoride safe water supply in the rift valley region of Ethiopia.

You are request to read thoroughly the following instructions before filling questionnaire

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Email: birku@snu.ac.kr; ***Mobile phone*** *+251-9-1153-6221*

Researcher: Birku Reta

Advisor Prof: Jongsu Lee (PhD)

Seoul National University, Seoul, Korea.

The questionnaire is divided into two parts; first part is pair wise comparison between the criteria and subcritera presented. And the last section is about your general information

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Part 1

We have structured the possible barriers to supply fluoride safe water supply to the 'woreda' dwellers. The top level "Fluoride safe water supply" is the goal of the set of the comparison from supply perspective. We have categorized into four different factors which are further subcategorized to second level. Kindly look at the hierarchical decision tree which we are using for the comparison of factors and sub factors in this section. Please refer the following table to scale while comparing two factors or sub factors. For the comparison of alternatives, we have selected two alternatives which are categorized as online quality (fluoride) detection vs off line (lab based) quality detection of water supply.

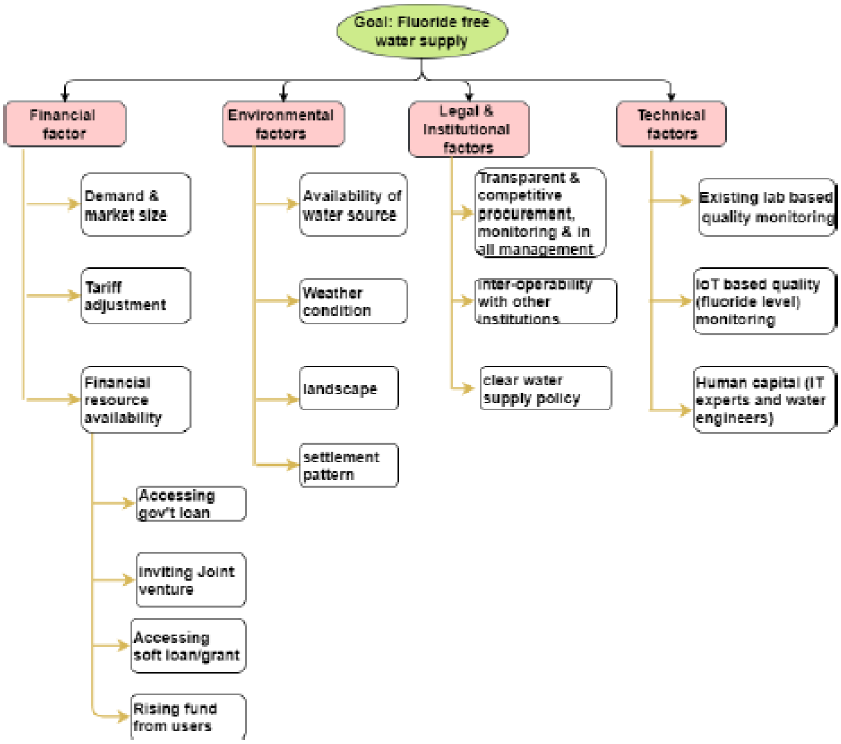

Fig: Hierarchical structure of decision criteria and sub criteria

Tabular based descriptive factors affecting fluoride safe water supply in rift valley region

Goal: fluoride free& sufficient water supply		
Criteria /factors	Sub factors	Explanation
Financial factor	Financial related criteria for clean and sufficient water supply	
	Demand and market size	Market size and users ability to pay for service matters to supply clean and sufficient water
	Tariff adjustment	Possibility to adjust tariff based on agreement because of during rainy excess fluoride problem and during drought need to find another source of water
	Financial resource availability	Availability of budget/finance is key important factor to provide fluoride safe water in Ethiopia.
	Getting govt loan	Possibility of getting enough loans from government determines quality of water supply.
	Accessing soft loan/grant	Possibility to get Soft loan or grant through bilateral/multilateral/ development agencies
	Inviting joint venture	Creating public private joint venture for fluoride safe water supply
	Rising fund from users	Mobilizing fund from intended fluoride safe water users
Environmental factor	Considering environmental factors is important to identify degrees of challenge to provide fluoride safe and sufficient water supply	
	Availability of sufficient water source	How nearby availability of abundant water or absence of water source impacts supply of fluoride safe water. (psychical availability)
	Weather condition	How fluctuating weather condition impacts provisions of fluoride safe water supply (drought, rainy season etc)
	Landscape	How landscape (i.e. mountain or plain) has an impact on supply of fluoride safe water to the woreda dwellers.
	Settlement pattern	How population settlement pattern (i.e. scattered vs densely) has an impact to provide fluoride safe water.
Legal & institutional factors	Strong policy and committed institutions determines the quality (fluoride safe) and enough water supplies to the citizens.	
	Transparent &competitive procurement	How transparency and procurement issues easy fluoride safe water supply or not in Ethiopian context
	Inter-operability with other institutions	How difficult or easy it is to have good inter-operability with other institutions (land management, telecommunication etc) to provide fluoride safe water supply
	Clear water supply policy	Whether the water supply policy is full cost recovery or partial cost recovery, impact it has on fluoride safe water supply
Technical factor	ICT and IoT technologies are growing fast enabling connecting cyber world with physical world given that able and capable to use them	

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	Existing lab based quality monitoring	How existing lab based water quality monitoring is dependable to provide fluoride free water?
	Online quality monitoring using IoT technologies	How online quality monitoring using IoT technologies are difficult or easy ?
	Human capital (IT expert and water engineers)	How getting appropriate expertise has an impact on fluoride free water supply?

Comparison scale and their definition

Intensity of Importance	Definition	Explanation
1	Equal importance (EI)	Two activities considered equally important
3	Moderate importance of one over another (MI)	One activity is marginally favored over another
5	Essential or strong importance (SI)	One activity is strongly favored over another
7	Very strong importance(VSI)	One activity is very strongly favored and its dominance is demonstrated in practice
9	Extreme importance(ExI)	The evidence favoring one activity over another is of the highest possible order
2, 4, 6, 8		Intermediate values between two adja-cent judgments

<u>**For example:**</u>

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Factor A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor B
Environment					❺													Financial
Environment																		Technical
Environment																		Institutional
Financial														❻				Technical
Financial																		Institutional
Technical																		Institutional

As above example response, Box 5 in left side is marked because environment factor is strongly important than Financial factors. To compare environmental factor and financial factor we may need to refer factors, subfactors in the decision hierarchy shown above. In the second comparison set, box 6 is marked in right side which means technical factor is higher than strongly important and lower than very strongly important than financial factor.

1. Please input your judgmental scale which influences more on "the provision of fluoride safe quality water supply for your woreda residents" using scale 1 to 9 (refer comparison scale table).

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Factor A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Factor B
Financial factors																		Environmental factor
Financial factors																		Technical factor
Financial factors																		Institutional factor
Environmental factor																		Technical factor
Environmental factor																		Institutional factor
Technical factors																		Institutional factor

2. **Please input your judgmental scale which is more important for "Financial Factor" for fluoride safe water supply, using above mentioned scale 1 to 9.**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Market size and Demand																		Tariff adjustment
Market size and Demand																		Financial Resource access ability
Tariff adjustment																		Financial Resource access ability

2.1. **Please input your judgmental scale which is difficult for "Financial Resource Accessibility" for fluoride safe water supply under financial factor using above mentioned scale 1 to 9.**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Getting govt Loan																		Accessing Soft loan/ Grant
Getting govt Loan																		Inviting joint venture
Getting govt Loan																		Rising fund from users
Accessing Soft loan/ Grant																		Inviting joint venture
Accessing Soft loan/ Grant																		Rising fund from users
Inviting joint venture																		Rising fund from users

3. **Please input your judgmental scale which influences more on "Environmental factor" concerning fluoride safe water supply in your woreda, using above mentioned scale 1 to 9.**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Availability of source of water																		Weather condition
Availability of source of water																		Landscape
Availability of source of water																		Settlement pattern
Weather conditions																		Landscape
Weather conditions																		Settlement pattern
Landscape																		Settlement pattern

4. **Please input your judgmental scale which influences more on "legal & Institutional factors "in order to supply fluoride safe water for woreda residents using above mentioned scale 1 to 9.**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Transparent & competitive procurement, monitoring																		Inter-operability with other institution
Transparent & competitive procurement, monitoring																		Clear water supply policy
Inter-operability with other institution																		Clear water supply policy

5. **Please input your judgmental scale concerning "Technical factor" which you think would be more important to ensure provision of fluoride safe water service, using above mentioned scale**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Offline (Existing lab based quality monitoring)																		Online IoT based quality monitoring
Offline (Existing lab based quality monitoring)																		Human capital
Online IoT based quality monitoring																		Human capital

6. **Rate the means of fluoride monitoring pairwise comparison based on 1 to 9 scale according to each questions below**

Scale	ExI		VSI		SI		MI		EI		MI		SI		VSI		ExI	
Project A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Project B
6.1	Which quality monitoring mechanism is more suitable for "different source points of water supply" to supply fluoride free water?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.2.	Which quality monitoring mechanism is more suitable for "changing weather condition "environment?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.3.	Which quality monitoring mechanism is more guarantees for" large market size and high demand customers" for fluoride free water supply?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.4.	Which quality monitoring means is suitable for real time fluoride level detection and guides determining "tariff adjustment "if necessary?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.5.	Which quality monitoring mechanisms require more" financial resource availability" to enable to supply clean water?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.6.	Which quality monitoring mechanism needs more "transparency and competitive procurement" to enable to supply quality and adequate water?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.7	Which quality monitoring mechanism needs to have strong "inter-operability with other institutions "to smooth and increase fluoride free water supply?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)
6.8	Which quality monitoring mechanism need to have "more IT skilled experts and water engineers" to provide fluoride free water?																	
Online IoT based fluoride detection (monitoring)																		Off line, lab based fluoride detection (monitoring)

Section 2: General Information

7. City/woreda name: _______________

8. Gender: Male ☐ Female ☐

9. Age: ________

10. Education: PhD ☐ Master's Degree ☐ Bachelor's Degree ☐ Diploma /technical ☐

11. Education background type: IT/Computer ☐ water engineering ☐ other engineering ☐ business field ☐ other ☐

12. Your Position in your Organization: ____________________

13. Working Experience: _______________in years

14. Contact email or phone address:

Thank you very much for devoting your precious time!

초 록

청정 수도 공급 정책 및 계획에 있어 불소 안전 수돗물 공급자들의 문제점과 불소 안전 수도 서비스에 대한 대중의 선호를 이해하는 것이 중요하다. 본 연구의 목적은 열곡 지대 거주자들의 불소 안전 수도 서비스 속성에 대한 선호 구조, 지불의사액과 하수도 공급자의 제약들을 파악하는 것에 있다. 본 연구는 과량의 불소 농도 지역에서 불소 안전 수도 서비스 공급에 대한 학계와 정책 입안자 모두에게 통찰력을 제공한다. 본 연구는 열곡 지대 거주자들의 선호도를 파악함에 있어 직접 설문 방법과 간접 설문 방법을 모두 사용하였다. 무작위 효용 이론을 바탕으로 에티오피아의 중앙 열곡 지역인 Adama, Lume, Bora, Zuway dugda 및 Adami Tulu & Jido kombolcha woredas 에서 표본을 추출하여 혼합 및 잠재 계층 로짓 모델을 사용하여 분석했다. 보상 잉여 힉스주의 이론을 사용한 censored Tobit 모델을 추정하여 평균 지불의사액을 산정하고 연구 지역의 불소 안전 수도 공급 프로젝트에 대한 비용 편익 분석을 수행하였다. 수집된 데이터는 3 가지 다른 방법론을 통해 분석되었다.

첫번째 부분에서는 불소 안전 수돗물 공급 업체들의 제약 조건들을 파악하기 위한 연구로 분석 계층 프로세스(AHP) 방법과 전문가 쌍방향 평가 데이터를 활용하였으며 제약 조건 유형 중에서 재무적 요인, 기술적 요인, 제도적 요인 순으로 중요하게 도출되었다. 또한, 불소 안전

수돗물 공급 업체들은 높은 초기 비용과 무관하게 온라인 기반 불소 함량 모니터링을 선호하는 것을 알 수 있었다.

두번째 부분에서는 미래 수도 서비스에 대한 소비자 선호를 파악하기 위해 혼합로짓모형을 적용하여 선호도의 이질성을 포착하였으며, 잠재계층로짓 모형을 사용하여 가구 단위 이질성을 포착하였다. 속성들로는 불소 함량 (WHO 표준을 기준인 1.5mg / l 을 사용), 용수 중단 빈도, 중단 기간, 중단 사전 통지 일 수, 통지 방식과 서비스 개선을 위한 추가 비용을 사용하여 분석하였다. 두 모형의 결과는 각 속성과 영향의 방향이 일치하였는데, 중단 빈도, 중단 기간과 인터넷 기반 통지 시스템은 음의 한계 효용을 보였으며, 불소 함량, 사전 통지 일 수, 모바일 기반 통지 시스템은 양의 한계 효용을 보였다. 모형 별 상대 중요도는 다르게 나타났는데, 추가 서비스 비용을 제외하고 혼합로짓모형에서는 WHO 기준 이상의 불소 함량 수질이 가장 중요한 반면, 잠재 계층 로짓 모형에서는 WHO 수준의 불소 함량 수질이 가장 중요한 것으로 나타났다.

세번째 부분에서는 선호 특성의 경제성을 파악하기 위해 잠재 계층 로짓 모형을 활용하여 평균 지불의사액을 추정하고 토빗 모델을 사용한 조건부 가치 평가 방법을 사용하여 소비자의 불소 안전 수도 공급 서비스에 대한 지불의사액을 조사했다. 인근 에티오피아 정부의 수도 공급 비용을 연구 지역에 불소 안전 수도 공급 비용에 대한 대용 값으로 활용하여 비용 편익 분석을 수행하였다. 분석 결과, 가구들의 불소 안전

수돗물에 대한 지불의사액은 자신 수입의 3%에서 16%에 달하였다. 이에 따른 정책적 함의는 다음과 같다; (1) 정부는 불소 안전 수돗물 공급을 위해 세계 은행을 포함한 외부 기금을 동원할 필요가 있으며, 가정은 불소 안전 수돗물에 대해 현재 요금 수준의 최대 75%를 추가로 지불할 수 있음을 감안해야 할 것이다. (2) 수도 공급 업체가 불법 연결, 누출 및 관세율 인상을 통제함으로서 수도 요금을 인상해야 한다. 현재 생산된 수돗물 중에서 37% 수준이 누수되고 있어 강력한 규제의 도입, 고발 제도와 더불어 누수 감지 기술을 도입해야 한다. (3) 정부는 급수 부문을 민영화 하기를 권한다. 비용 편익 분석에 따르면 민간 부문에서 진행하여도 충분한 사업성을 확보할 수 있으며, 영국과 칠레는 수도 사업이 완전히 민영화되어 있다. (4) 정부는 수질을 보장하기 위해 온라인 모니터링 시스템을 채택하기를 권한다. 온라인 모니터링 시스템은 투명성과 더불어 다른 기관들과의 상호 운용성을 제공한다. (5) 정부는 지역 사회 기반의 불소 안전 공공 수도꼭지를 설치해야한다. 이것은 가계가 가장 가까운 공용 수도꼭지에서 불소 안전 수도 서비스에 대해 지불 의사가 충분하기 때문에 실행 가능하다. (6) 정부는 공공 서비스 공급 방식에 있어 민간 파트너십 방식 또한 허용해야한다. 이는 파트너십의 양상과 관계 없이 미국, 남아프리카, 말레이시아, 프랑스, 케냐 등 많은 국가에서 성공적으로 실행된 바 있다. 따라서 에티오피아 정부는 국가 상황과 편의에 따라 보편적인 안전 수도 공급 범위와 수도 부문 목표인 GTP -II 를 달성하기 위해 공공 서비스 공급 방식에 있어

민간 파트너십 방식을 차용해야 한다. (7) 또 다른 정책적 함의는 저소득층 가구가 수도 공급 연결을 위한 소액 대출을 용이하게 해야한다는 것이다. 가구는 초기 연결 비용에 대해 일시불 비용보다 할부 기준 지불이 필요하기 때문에 특히 저소득층 가구에 대한 소액 대출이 매우 생산적이다. 인도, 방글라데시, 케냐, 우간다 및 베트남과 같은 국가는 이러한 방식을 채택하고 있다. (8) 또 다른 권고는 정부가 급수원을 결정함에 있어 인구 규모를 고려해야한다는 것이다. 흩어져있는 시골 지역 주민들에게는 지역 공동체의 중심에 시추공을 제공하는 것이, 인구 밀집 지역 주민들에게는 파이프 라인 기반의 수돗물 공급이 효율적이다. 안전한 공급원과 수처리도 함께 고려해야 한다. (9) 마지막으로 수도 공급 업체는 중단 발생시 거주자들에게 자동으로 통지하는 수도 중단 통지 시스템을 채택해야 한다. Asheville 시의 자동 통지 시스템 사례 연구를 보면 지역 가정들은 모바일 기반 서비스 통지 (음성 통화, SMS 및 MM)를 선호함을 알 수 있다.

주요어: 불소 안전 수도 서비스, 이산 선택 모형, 지불의사액, 계층 분석법, ICT 적용, 에티오피아 열곡 지역

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