zef
Center for
Development Research
University of Bonn

ZEF-Discussion Papers on
Development Policy No. 220

Muhammed A. Usman, Nicolas Gerber, and Evita H. Pangaribowo

Determinants of Household Drinking Water Quality in Rural Ethiopia

Bonn, July 2016

The **CENTER FOR DEVELOPMENT RESEARCH (ZEF)** was established in 1995 as an international, interdisciplinary research institute at the University of Bonn. Research and teaching at ZEF address political, economic and ecological development problems. ZEF closely cooperates with national and international partners in research and development organizations. For information, see: www.zef.de.

ZEF – Discussion Papers on Development Policy are intended to stimulate discussion among researchers, practitioners and policy makers on current and emerging development issues. Each paper has been exposed to an internal discussion within the Center for Development Research (ZEF) and an external review. The papers mostly reflect work in progress.

Muhammed A. Usman, Nicolas Gerber and Evita H. Pangaribowo, Determinants of Household Drinking Water Quality in Rural Ethiopia, ZEF – Discussion Papers on Development Policy No. 220, Center for Development Research, Bonn, July 2016, pp. 33.

ISSN: 1436-9931

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Straße 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
www.zef.de

The author[s]:
Muhammed Abdella Usman, Center for Development Research (ZEF), University of Bonn
Contact: mabdella@uni-bonn.de
Nicolas Gerber, Center for Development Research (ZEF), University of Bonn
Contact: ngerber@uni-bonn.de
Evita Hanie Pangaribowo, Dept. of Environmental Geography, Gadjah Mada University
Contact: evitahp@ugm.ac.id

Acknowledgements

This work is supported by the Bill and Melinda Gates Foundation, under the project "WATSAN-AGICULTURE – guiding pro-poor investments in the nexus among domestic water quality and quantity, sanitation and hygiene, and agriculture from the bottom-up." We are grateful to Joachim von Braun for his continuous support and advice. We would also like to acknowledge the support from the Center for Development Research (ZEF), the Ethiopian Economics Association (EEA), the Welthungerhilfe and the Organization for Rehabilitation and Development in Amhara (ORDA) during our field research in Ethiopia. We are also grateful to the members of the AG-WATSAN project for their valuable comments and suggestions at several of our project seminars and workshops. Many thanks go to Samantha Antonini for her review and suggestion on the earlier version of this paper and to the data collectors for their hard work during the household survey.

Abstract

Safe and adequate water supply is a vital element to preserve human health; however, access to clean water is limited in many developing countries. Furthermore, improved water sources are often contaminated with fecal matters and consumption of unsafe water poses a great public health risk. This study seeks to identify determinants of microbial contamination of household drinking water under multiple-use water systems in rural areas of Fogera and Mecha districts of Ethiopia. In this analysis, a random sample of 454 households was surveyed from February to March 2014, and water samples from community sources and storage containers were collected and tested for fecal contamination. The number of *Escherichia coli* (*E.coli*) colony forming units per 100ml (cfu/100ml) water was used as an indicator of fecal contamination. The results show that 50% of households used protected water sources, 38% used unprotected wells/ spring and 12% used surface water sources. However, water microbiological tests demonstrated that 58% of household storage water samples and 74% of water sources were contaminated with *E.coli*. After controlling for household sanitary factors, high level of *E.coli* bacteria colonies were observed in unprotected water compared to surface water and protected wells/springs sources. To ensure the quality and safety of water stored in the household, our findings suggest that point-of-use water treatment, safe water handling and storage, proper hygiene practices such as washing hands after critical times and proper disposal of household garbage should be promoted. On-site water wells should be properly designed to prevent seepage from unhygienic household pit latrine. Furthermore, community water sources should be adequately protected and sanitary measures should be undertaken regularly to reduce contamination from human and animal waste.

Keywords: drinking water quality; water source; Escherichia coli; sanitation and hygiene; rural Ethiopia.

JEL classification: I10, Q25, Q53

Content

1. Introduction 1
2. Context and Related Literature 5
3. Methods and Data 9
 3.1 Description of the Study Areas 9
 3.2 Sampling Design and Household Data Collection 10
 3.3 Microbial Quality of Drinking Water Samples 11
 3.4 Data 12
  3.4.1 Summary Statistics 12
  3.4.2 Empirical Estimations 15
4. Empirical Results and Discussion 16
 4.1 Bivariate Analysis of Determinants of Storage Water Quality 16
 4.2 Multivariate Analysis of Determinants of Storage Water Quality 19
 4.3 Limitation of the Study 25
5. Conclusions and Recommendations 27
References 29

1. Introduction

Lack of access to safe and adequate water supply and the health risks associated with water-related diseases are major public health problems in many developing countries. Today, more than 700 million people, who mostly living in the developing countries, are without access to improved and adequate water (WHO/UNICEF 2014).[1] More than 1.5 million children under the age of five die of diarrheal diseases every year (WHO/UNICEF 2009). Unsafe drinking water is considered to be one of the major causes of diarrhea (Zwane & Kremer 2007). Increasing the provision of improved drinking water plays an important role in the fighting against diarrheal diseases for young children in developing countries.

Figure 1 presents the coverage of access to improved water supply in Ethiopia. It is estimated that about 57% of households have access to an improved drinking water source, with a higher proportion among urban residents (93%) than among rural residents (49%). There is a big disparity between urban and rural households in terms of access and types of services. Moreover, as access to improved sanitation facilities are very limited in rural areas, majority of households defecate in the bush or open fields (WHO/UNICEF 2015). Furthermore, including drinking water safety or quality criteria in the WHO/UNICEF Joint Monitoring Programme (JMP) definition of access to improved drinking water, the reported figures would be substantially lower in both urban and rural Ethiopia because water collected from improved sources are often re-contaminated during collection, transportation and storage (Wright et al. 2004). Consequently, the current definition used by the JMP is likely to lead to substantial over estimation of the number of population who have access to improved water sources in many developing countries (Bain et al. 2014; Godfrey et al. 2011). In rural Ethiopia, hand-pump water sources are also often broken and non-functional due to poor maintenances and repairs (MoWE 2007). This would further reduce the actual number of households reported to have access to an improved water source.

[1] The classification of both improved/unimproved water -and –sanitation facility types are presented in Table 1.

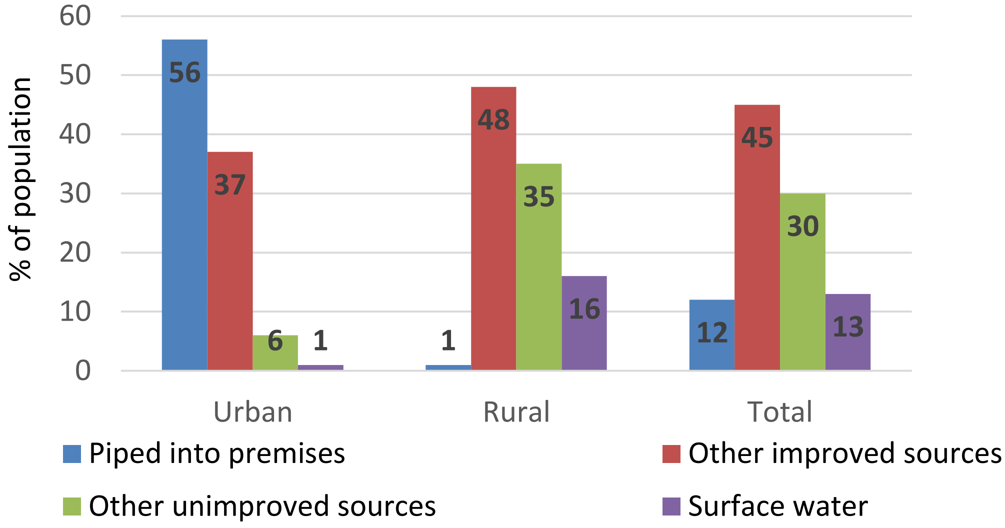

Figure 1: Percentage of population by type of drinking water source in Ethiopia, 2015

Source: Authors' compilation using the WHO/UNICEF Joint Monitoring Programme (JMP) dataset

Ethiopia is the water tower of East Africa, yet in most parts of the country water is still as inaccessible as it is precious. Moreover, water quality is poor and often contaminated by human and animal feces. As a result of limited improved water availability, most rural population relies on unimproved water sources. People use unprotected springs, shallow wells, irrigation water from canals and rivers as a source of water for domestic uses which are easily polluted by human and animal feces. Unimproved sanitation habits and open defecation practices exacerbate the problem.[2] Often shallow and unprotected community water source points are subject to gross contamination when rain water washes wastes from surrounding areas into the sources. The situation is much worse where drinking water sources are shared with livestock.

Unsafe and inadequate water supply together with poor sanitary conditions result in higher rates of morbidity and mortality particularly in rural areas of the country (Begashaw 2003). During the dry season, most of the traditional water sources are placed under pressure as shallow wells, springs and several other recurrent sources of water shrink-up. Moreover, due to long distance and queues, rural households can only collect few liters of water for drinking and cooking (Sutton *et al.* 2012). Limited availability of water may also prevent basic personal hygiene practices.

There are various chemical, physiological and microbiological standards for a water supply to be qualified and acceptable for drinking. While water contamination can have various origins, this study primarily focuses on *Escherichia coli* (*E.coli*) bacteria – one of the most

[2] Open defecation is defined as defecation in fields, behind bushes, forests, in roadside ditches, bodies of water or other open spaces.

common indicator for microbial water quality studies. This bacteria comes only from human and animal excreta. Human feces are the primary source of pathogens that cause waterborne diseases such as diarrhea. According to the WHO drinking water quality guideline, *E.coli* bacteria as a microbial water quality indicator should be zero per 100 ml for the water to be considered safe for drinking (WHO/UNICEF 2010a). A single gram of human feces can contain 10 million viruses, one million bacteria, 1,000 parasite cysts and 100 parasite eggs (UNICEF 2000). These pathogens can transfer from an infected host to a new one via various routes. They can also easily get into water supply sources where sanitation facilities are inadequate and open defecation is widespread. In rural areas, water source contamination is more pronounced because most water supply sources are inadequately protected (Butterworth *et al.* 2013) and improved latrines are very limited. However, removing human excreta safely and cleaning hands with soaps after contact with fecal material substantially reduces the transmission of pathogen agents (Curtis & Cairncross 2003).

Determining the public health risk associated with drinking water quality is very important. To determine the health risk, the WHO recommends a routine monitoring of drinking water quality but this is generally not feasible in the context of rural Ethiopia, because either the analytical tools often do not exist or the tests are expensive and complicated to perform (WHO/UNICEF 2010a). As the problem of point-of-use (POU) water quality is complex, subjective judgments about storage water quality based on the types of sources are often misleading in the absence of household intervention to improve water quality at the POU.

This paper aims to identify the factors that influence the quality of drinking water stored in the households[3] in Fogera and Mecha districts, Ethiopia. It investigates the quality of storage drinking water and community water sources at a large scale in multiple-use water systems of rural Ethiopia where drinking water supply and sanitation infrastructures are very limited. This paper has two major contributions. First, existing studies that examine the determinants of storage water quality and its relationship with rural water supply sources and household's sanitary behaviors are quite limited: they primarily focus on the impact of water source types on storage water quality and ignore hygiene- and sanitation-related factors (Amenu *et al.* 2014; Yasin *et al.* 2015). Second, determinants of domestic water quality under multiple-use water systems is under researched (Scheelbeek 2005; Sutton *et al.* 2011). Irrigation agriculture has a complex interaction with domestic water in rural areas. For instance, small-scale irrigation may provide multiple water use such as drinking, cooking, bathing among others. Moreover, we could able to perform the water quality testing on the field immediately after collecting water samples from household's storage which is uncommon in rural areas. This type of work is therefore crucial to enhance the understanding the determinants of the microbial quality of storage water in rural households of Ethiopia and

[3] Hereafter storage water.

might thus help policy makers to design the right intervention to improve access to safe drinking water in rural areas.

The paper is structured as follows: the next Section review the related literatures, while Section 3 presents the methods and data used in the empirical estimation. Section 4 presents the empirical results and discusses them in detail. The last Section concludes the paper with some recommendations.

2. Context and Related Literature

Ethiopia has made remarkable progress to improve the water and sanitation (WASH) situation of the country by adopting the Universal Access Plan (UAP) in 2005. It aims to provide access to safe drinking water for all rural and urban population of the country before the end of 2015 (MoWE 2006). This was a very ambitious target to be realized. Ethiopia's UAP defines the minimum standards for rural population as at least 15 liters of water for everyone per day within 1.5 km of their home. Although the government is playing a key role in the rural water supply schemes, the role of non-governmental organizations (NGOs) and its development partners have been crucial since the government does not have the financial resources and/or the technical capacity to undertake this radical and ambitious move alone.

To increase access to safe drinking water in rural areas and to provide 15 liters of water per day for everyone within 1.5 km radius, several on-spot springs protection, normal hand dug wells, and hand dug wells with pump ropes have be constructed in many rural areas (MoWE 2006). However, most of these water supply points fail to function just after their installation. As a result, sustainability issues become a major challenge in the provision of safe water supply in rural areas. For instance, a survey of water source points in rural Ethiopia found that 29% of hand-pumps and 33% of mechanized boreholes were not functioning mainly because of maintenance problems (UNDP 2006). The 2012 National Water Inventory (NWI) report also indicates that more than 93,000 water schemes across the country were non-functional. To make the matter worse, most of the existing community water sources often contaminated with fecal materials and pose high public health risk (Amenu et al. 2014; Atnafu 2006; Jano 2007; Tsega *et al.* 2014).

The WHO/UNICEF JMP for water supply and sanitation defines access to drinking water and sanitation in terms of the types of technology and levels of service provided. The WHO sets five basic indicators for a safe water supply such as water quality, quantity, cost or affordability, continuity and coverage or accessibility. Table 1 shows the current WHO/UNICEF JMP classification of improved or unimproved water and sanitation technologies. However, this definition of access to 'improved' water source does not consider the safety or quality of the water; consequently, it does reliably predict neither the microbiological nor the physiological quality of the water being consumed. As this approach can be highly misleading, it is argued that inclusion of water safety parameter will further reduce the coverage level of improved water sources reported by JMP due to the high risk of microbiological contamination (Bain et al. 2014; Godfrey et al. 2011).

Table 1: JMP Classification of drinking water source types and sanitation facilities

Category	Types drinking-waters sources	Types of sanitation facilities
Improved	Use of the following sources: Piped water into dwelling, yard or plot, Public tap or standpipe, Tube-well or borehole, Protected dug wells, Protected spring and Rainwater collection	Use of the following facilities: Flush or pour-flush to piped sewer system or septic tank or pit latrine, ventilated improved pit (VIP) latrine, pit latrine with slab and composting toilet
Unimproved	Use of the following sources: Unprotected dug wells, Unprotected spring, Cart with small tank or drum, Tanker truck-provided water [a], Surface water (river, dam, lake, pond, stream, canal, irrigation channel) and Bottles water [b]	Use of the following facilities: Flush or pour-flush to elsewhere (that is not piped sewer system, septic tank or pit latrine), pit latrine without slab/open pit, bucket, hanging toilet or hanging latrine, shared facilities of any type and no facilities, bush or field

[a] Normally considered to be "unimproved" because of concerns about the quantity of supplied water.
[b] Considered to be "unimproved" because of concerns about access to adequate amount of water, about inadequate treatment, or about transportation of the water in inappropriate containers.
Source*:* WHO/UNICEF (2010b).

The figures presented in Table 2 provide some evidence on the status of microbial water quality in Ethiopia at the national level. The WHO/UNICEF report presented in Table 2 shows that, of the 1602 water samples analyzed for thermotolerant coliforms (TTC), 1153 of 1602 (72%) samples met both the national standard and the WHO guideline value of <1 cfu/100 ml water. However, 7% had counts of 1−10 cfu/100 ml water, and another 14% had counts of 11−100 cfu/100 ml water. Overall, 7% of all samples had counts >100 cfu/100 ml water. The proportion of 11−100 cfu/100 ml and >100 cfu/100 ml water count is significantly higher for protected springs and protected dug wells but it is lower for utility piped supplies because they are better protected than other water source points. Moreover, utility piped supplies are often chlorinated which protects the water from microbial contamination (WHO/UNICEF 2010a).

Table 2: Compliance of drinking water sources in Ethiopia for thermotolerant coliforms [a]

Count category (cfu/100 ml)	Utility piped supplies	Boreholes	Protected springs	Protected dug wells	Total
	Prop. (%)	Prop (%)	Prop. (%)	Prop. (%)	Prop. (%)
<1	87.7	67.9	43.3	54.8	72.0
1-10	4.2	9.9	10.0	11.0	6.9
11-100	6.4	16.9	29.2	21.3	14.3
>100	1.8	6.2	17.6	12.9	6.8
Sources sampled (n)	**838**	**290**	**319**	**155**	**1 602**

[a] cfu = colony-forming unit. Prop.=proportion of water samples showing corresponding count category.
Source: Adopted from WHO/UNICEF (2010a, p.21).

There are few studies in Ethiopia that examine the chemical and microbial quality of drinking water. Existing studies related the water quality aspects with seasonality, type of water sources, and storage behavior. Amenu et al. (2014) investigated the microbial water quality of rural households in Lemu and Siraro districts of Oromia Regional State, Ethiopia. A total of 233 water samples collected from household's drinking water (126 collected during dry and 107 samples collected in wet seasons) were analyzed. The study finds that 54.9% of the samples were contaminated with E.coli; however, the concentration of E.coli was much higher during the wet season than the dry season.

Other water quality assessments based on water sources typology indicated that the quality of drinking water is highly influenced by water source types. In particular, (Haylamicheal & Moges 2012) examined the physiochemical and microbial quality of the water for 28 randomly selected community water sources (14 on-spot springs and 14 dug wells fitted with hand pump) in Wondogenet district of southern Ethiopia. The study found that water quality met the WHO drinking water guidelines in terms of pH, temperature, fluoride, chloride, and turbidity but not the guidelines for total and fecal coliforms. Of the total sample, 25% of water sources were contaminated with E.coli while more than 85% the samples were contaminated with total coliforms.

In addition to types of water sources, existing studies also emphasized the role of storage behavior on water quality at the POU (Clasen & Bastable 2003; Crampton & Aid, 2005; Rufener et al. 2010; Baker et al., 2013). Among the earlier studies on water quality, Clasen and Bastable (2003) report that 92.2% of storage drinking water were contaminated with fecal matters, and using the case of Bamoko, Mali, Baker et al. (2013), the quality of drinking water was highly affected by household storage behavior even though most of the households had access to piped tap water, mainly due to lower concentration of free residual chlorine below the required level during the storage period.

Studies show that water collection container and water handling practices also affect household water quality (Crampton & Aid 2005; Eshcol et al. 2009). A study that aims to examine the linkage between water handling practice and microbial water quality in Addis Ababa, Ethiopia, finds that 34% of the samples were contaminated with fecal coliforms out of the 127 total water samples tested (Crampton & Aid 2005). POU water samples were more contaminated with fecal bacteria (37%, n=54) than water samples from sources (33%, n=72). Moreover, the study has also showed that 'dip' methods of water storage such as bucket and ensera is more prone to frequent contamination but contamination level is lower as compared with 'pour' methods of water storage such as jerrycan and jug. Narrow mouthed storage containers are the safest method of water storage but it may be often difficult to properly clean them after emptying. They usually store bacteria in the 'biofilm' and allow micro-organism to grow on their surface. Crampton and Aid (2005) therefore suggest that "either a covered bucket with a floating cup used simply to decant water into another glass for consumption; or a large yet handheld jug with a lid which can be raised for cleaning” could be a better solution.

Generally, the microbial quality of drinking water substantially deteriorates along the chain from source to mouth after collection from improved sources (Clasen & Bastable 2003; Rufener et al. 2010; Wright et al. 2004). Clasen and Bastable (2003) examined the level of thermotolerant coliforms (TTC) for 100 storage drinking water samples and 20 water source points from which the households draw their drinking water in the Kailahun district of Sierra Leone. The authors find higher TTC loads both at the point of unimproved sources and at household storage. Moreover, 92.9% of water samples from storage were contaminated with fecal matters although there was no detectable fecal coliforms per 100 ml water samples from improved water sources. Rufener et al. (2010) found similar results in Bolivia. The authors analyzed 347 water samples taken from different water source points, transport vessels, treated water and drinking water cups from 81 households, and the findings indicate that fecal contamination (E.coli) of drinking water considerably higher along the chain from the water sources to the drinking cups. Further, Wright et al. (2004) arrived at the same conclusion after systematically reviewing studies on microbial contamination of water between source and point-of-use. Above all, existing empirical results suggest that, since water quality is often compromised during household collection, transportation and storage, water quality protection at the POU should be as highly emphasized as at the point of source.

3. Methods and Data

3.1 Description of the Study Areas

This study was carried out in Fogera and Mecha *woreda* (district) of Amhara National Regional State (ANRS) located in Northwest Ethiopia. Wereta and Merawi are the respective administrative towns of Fogera and Mecha districts, and are situated 615 km and 523 km from Addis Ababa, respectively. Mecha is one of the district in the West Gojjam Zone whereas Fogera is part of the South Gondar Zone administrative. Merawi is located 34 km from Bahir Dar city – the capital city of ANRS, and Wereta is located 59 km to the east of Bahir Dar. As of July 2012, the population of Mecha and Fogera district is estimated to be 334, 789 (with an area of 1,481.64 sq. km) and 264, 512 (with an area of 1,111.43 sq. km) respectively (CSA 2013).

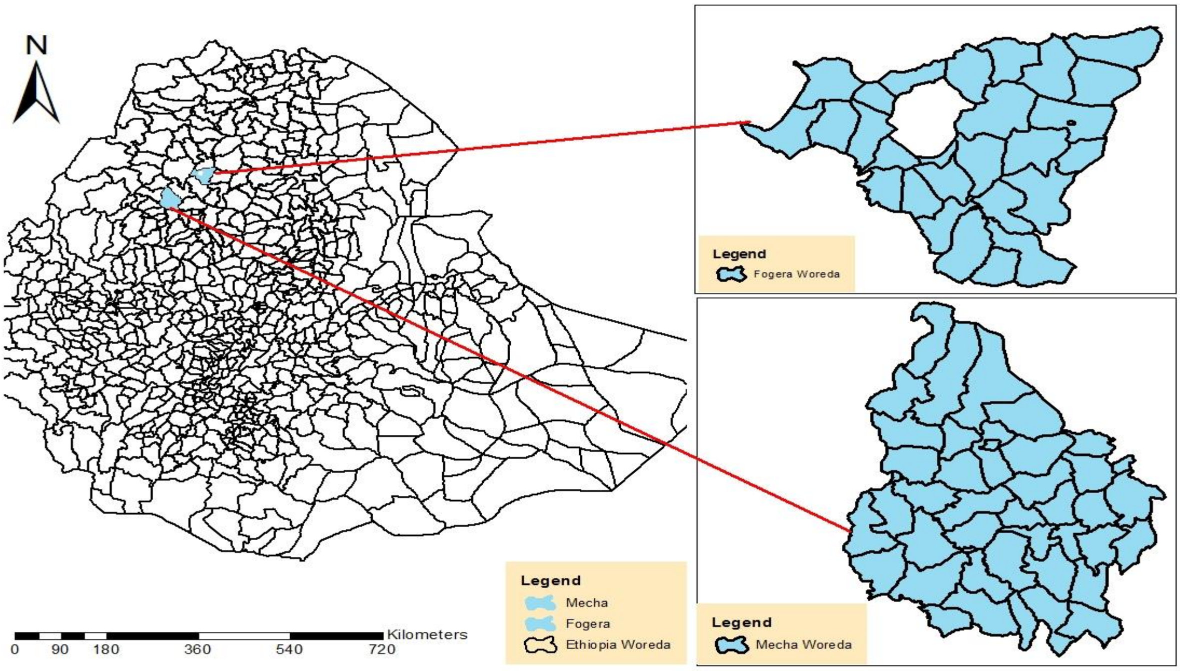

Figure 2: Map of the study areas

The provision of safe and adequate drinking water in rural Ethiopia is far behind the desired service levels. For instance, access to safe drinking water in Fogera district is estimated to be 69.9% (Stel & Abate 2014); however, some community water sources failed to operate regularly due to poor maintenances. Only 35% of the rural population of Mecha district have access to improved water sources (Beyene 2012), and most water sources do not provide sufficient water.

The coverage of simple pit latrine in the study areas is also very low. In some cases, households with a simple pit latrine do not use it frequently and prefer to defecate in the open. The government together with local and international development partners are striving to help the rural communities to improve access to clean water and adopt good hygiene behaviors and sanitation practices.

3.2 Sampling Design and Household Data Collection

Fogera and Mecha districts were purposely selected from the ANRS based on access to improved drinking water and sanitation coverage, prevalence of waterborne and water-related diseases and small-scale irrigation schemes. These districts were identified because the existing coverage of improved water supply and sanitation infrastructure is among the lowest, the prevalence of waterborne and water-washed diseases are the primary health problems of the inhabitants and small scale irrigation adoption is very common. Administratively, regions in Ethiopia are divided into zones, which are subdivided into administrative units called *woreda* (district). Each district is further subdivided into the lowest administrative unit, called kebele. Based on the above selection criterion and accessibility, a total of 20 kebeles were identified, 11 kebeles from Fogera, and the remaining 9 kebeles from Mecha district.

A stratified two-stage cluster sample design was used to select the sample households. In the first stage, 61 villages/clusters were selected randomly from the 20 selected kebeles. As the villages had different sizes, the probability of selecting a village within each kebele proportional to the village size (PPS). Moreover, the sample villages were selected independently in each sampling stratum i.e. kebele. Among the 61 villages, 39(64%) are in Fogera district and 22 (36%) are in Mecha district. Subsequently, in the second stage, 454 agricultural households were selected based on a systematic random sampling (SRS) method. Of all the 454 households selected from 61 villages, 277 are in Fogera and 177 are in Mecha district. The lowest administrative division of the region (i.e. kebele) is used to form the first level of stratification.. [4]

We used structured questionnaires to collect a range of information. The household questionnaire was used to list all the usual members of the selected households and basic characteristics of each person listed such as age, sex, education, relationship to the head of the household and other household level information. We also collected information on characteristics of housing, water supply sources, continuity of water supply and seasonal change, water treatment and storage, toilet facility, waste management, and hygiene behavior and knowledge of the primary caretaker of the household.

Storage water sample collection

In addition to water sample quality testing from household storage, information about how households handle and store their drinking water, and any additional water treatment

[4] A household is a group of people who live together and take food from the same plate, and someone who has lived in the household at least six months. Moreover, the questionnaires were translated into Amharic language – the mother tough language of the study areas, in parallel to the English language.

behavior were recorded. Drinking water samples were collected to analyze the microbiological quality of the water for a random sample of 454 households using a portable water test kit (a product of Wagtech *WTD*, UK) in the field. Using a membrane filtration technique, the test kit detects the presence of the *E.coli* bacteria which indicates a recent fecal contamination of the water.[5] Storage water samples were kept into a coded glass bottles which were properly sterilized using autoclaves in the local health centers at a temperature of 121 degree Celsius for 30 minutes.[6] Water sample tests from household's storage were conducted between February and March 2014 − which is between the end of winter (Bega) and the beginning of spring (Tseday) seasons in Ethiopia and considered as a dry period.

Community water sources samples

In addition to storage water samples, 61 water sources were tested for the presence of *E.coli*. These water sources were selected based on the number of households they serve. Typically, these water source points serve many households of the villagers. Inaccessibility and resource constraints were the major factors that hindered the uptake of water samples from all community sources.

3.3 Microbial Quality of Drinking Water Samples

There are different microbiological indicators of drinking water quality. Several studies used total coliforms, fecal thermotolerant coliforms and *E.coli* bacteria to analyze microbial water quality. In this study we analyzed the level of *E.coli* bacteria in the water sample because testing for all known pathogens is a complicated and expensive process in the study areas. Besides, *E.coli* bacteria are considered as the best microbial quality indicator of drinking water for public health protection (Edberg *et al.* 2000).[7]

Coliform bacteria are grouped into two categories. Total and fecal coliforms based on their origins and characteristics. Total coliforms are a group of bacteria widely found in the environment such as in water and soils as well as in human and animal feces; while, fecal coliforms are found only in animal and human feces. They are often used to detect and estimate the level of fecal contamination of water; however, they are not often considered as dangerous to human health but used to indicate the presence of a health risk. For instance, the presence of fecal coliforms and *E.coli* in drinking water indicates recent contamination of water by human or animal feces and may indicate the possible presence of

---

[5] According to the WHO/UNICEF drinking water guidelines, the number of fecal coliform bacteria (*E.coli*) in drinking water samples ideally should be zero. Therefore, in a sample volume of 100 ml water, a count of zero *E.coli* cfu is an indicative a microbiologically safe water supply. If the count exceeds 1 *E.coli* bacteria cfu per 100 ml water, contamination is indicated and appropriate action is urgently required.

[6] Enumerators asked household members (usually an adult woman) the following question, "could you please give me some water for drinking" so that their behavior would not be altered.

[7] The identification of *E.coli* bacteria from contaminated water is not complicated and the results are obtained relatively quickly and cheaply, even though they are only an indicator of fecal contamination.

other diseases causing organisms (pathogens) such as certain bacteria, viruses or parasites. These pathogens can cause diarrhea, cramps, nausea, and headache and therefore may pose a special health risk mainly for infants and children.[8]

Water samples were collected from household storage in each selected household and the collected water samples immediately were placed into the portable test kit on-site for incubation.[9] The bacteria colonies allowed to culture on Membrane Lauryl Sulphate Broth (MLSB) media which are specifically formulated to facilitate the growth of *E.coli* bacteria and prevent the growth of other micro-organism. Because bacteria are very small they should be grown on nutrient plates so that they can multiply rapidly and become visible for enumeration. *E.coli* concentrations are reported as colony forming units per 100 ml of water sample (cfu/100 ml water).

Immediately after the water samples were collected, the growth pads dispensed into a sterile petri-dish and a dissolved media solution was poured over the growth pad. Then the water sample was filtered through the membrane and when all the 100 ml water has been filtered, we placed the membrane on top of the pad which has been saturated with the MLSB media. In the next stage, we replaced the petri-dish lid and label with sample identification number and time, and placed the petri-dish into the petri-dish rack. Finally, we placed the filled rack into the incubator and incubate the samples between 20 to 24 hours at a temperature of 44 degree Celsius. Upon completion of the incubation period, we enumerated the number of *E.coli* (cfu/100 ml water). In a membrane filtration method, accurate enumeration of bacteria colony is difficult when the fecal coliform bacteria counts are greater than 200 cfu/100 ml water.[10]

3.4 Data

3.4.1 Summary Statistics

The descriptive statistics about the respondent's background characteristics and socio-demographic variables are presented in Table 3. Out of the 454 surveyed households, 289 households belong to Fogera and 185 households belong to Mecha district. The survey finds that average household size is about 6 persons per household which is higher than the reported mean household size of 5 in rural areas by Central Statistical Agency of Ethiopia (CSA and ICF International 2012). The survey finds that literacy level (for reading and writing in the local language) is 9% for primary caretakers and 46% for household heads. Among the

[8] http://water.epa.gov/drink/contaminants/#five (accessed on March 01, 2015).

[9] It is normally recommended that the time between water sample collection and analysis not to exceed 6 hours and it is one of the strength of this work that we could able to perform the test on the field immediately after collecting the samples from household storage.

[10] The optimum volume of sample is that which will allow the most accurate enumeration of bacteria. This is achieved when the number of fecal coliform colonies on the membrane following incubation is in the range of 20−200, and more than 200 colonies are difficult to count.

respondents, a few are completed primary school, which indicates that majority of the respondents in this study are illiterate.

Based on the JMP classification; the data in Table 3 showed that 50% of the households get their drinking water from improved water sources such as protected wells/springs, about 37% obtain water from unprotected wells/springs and the remaining 13% of the households depend on surface water sources. The proportion of households having improved water source is similar to the WHO/UNICEF 2015 progress report; however the use of surface water is relatively lower in our sample (WHO/UNICEF 2015) (12% compared to 16%). On the other hand, the WHO/UNICEF 2015 report indicated that 28% of rural Ethiopian households have access to improved sanitation facility but our result shows that access to this service is non-existent in the study areas which is quite surprising. However, 42% the households reported that they have a simple pit latrine but people may not use it frequently. Many of these latrines were constructed in response to a push by the local governments. It is not uncommon for most women to go to the bush/open field early in the morning and late in the night for defecation. The survey also revealed that more than 76% of the primary caretakers defecate without a toilet before the survey. Open defecation is a norm and practiced by most rural households. More than 57% of households in the study areas practice open defecation which is much higher than the rural national average open defecation rate of 43% (WHO/UNICEF 2014). The study also found that only 5% of the households have access to protected drinking water source in their own yard or premises, and more than 84% of households on average spend about 25 minutes for one round water collection trip (Table 3). Moreover, about 34% of the households need round trip of 30 minutes or more to obtain drinking water from the sources. This suggests that the proportion of households that spend more than 30 minutes for a round trip for water collection are lower than what is indicated by the CSA and ICF international report (CSA & ICF International 2012) (34% compared to 62%). Further, although half of surveyed households get their drinking water from unimproved source, the proportion of households applying any form of water treatment is very low (8%). This indicates that there is a lack of awareness of the need to treat household drinking water among rural households.

Table 3: Descriptive analysis - household and community characteristics

Variables	N	Mean	SD	Min	Max
<u>**Demographic characteristics**</u>					
Household head age	454	37.72	8.64	18	70
Household head literacy	454	0.44	0.49	0	1
Primary caretaker age	453	30.33	6.64	16	48
Primary caretaker literacy	453	0.09	0.29	0	1
Highest education completed in a household	454	3.50	3.05	0	15
Adult women	454	1.22	0.49	0	3
Household size	454	5.98	1.77	2	10
Under-five children	454	1.24	0.45	1	3
Household density	454	3.30	1.27	1	9
<u>**Housing and household possessions**</u>					
Roofing materials					
Corrugated iron sheet	454	0.91	0.28	0	1
Thatch	454	0.09	0.28	0	1
<u>**Water sources, sanitation and hygiene**</u>					
Primary drinking water sources					
Private-protected dug wells	454	0.05	0.22	0	1
Shared-protected dug wells/spring	454	0.44	0.50	0	1
Unprotected dug wells/spring	454	0.39	0.49	0	1
Surface water	454	0.12	0.32	0	1
Minutes to water sources [a]	383	24.18	14.19	3	75
Water quality [b]	454	0.42	0.49	0	1
Household water purification/treatment	454	0.08	0.27	0	1
Water collection container (1= Jerrycan)	454	0.83	0.37	0	1
Pit latrine (1=yes)	454	0.42	0.49	0	1
Safe stool disposal (1=yes)	454	0.32	0.21	0	1
Handwashing with soap (1=yes)	454	0.27	0.45	0	1
<u>**Garbage disposal**</u>					
Dugout/burning	454	0.11	0.31	0	1
Throw-away in the yard	454	0.54	0.50	0	1
Through away outside the yard	454	0.13	0.34	0	1
Used as a fertilizer	454	0.22	0.42	0	1
<u>**Agriculture**</u>					
Irrigation (1=yes)	454	0.66	0.47	0	1
Livestock units	454	3.97	1.87	0	8
<u>**Community Characteristics**</u>					
Water user association (1= yes)	454	0.29	0.46	0	1
Distance to the nearest health center	20	4.97	4.09	0	12

Note: [a] the mean is calculated for households whose water sources are not in their own yard/premise.
[b] the percentage indicates the number of households with no detectable *E.coli* (cfu/100 ml) water.

3.4.2 Empirical Estimations

This paper assesses the factors influencing storage water quality in rural areas of Fogera and Mecha districts, Northern Ethiopia. To examine the determinants of microbial quality of storage drinking water, socio-demographics, water sources, as well as collection, storage, sanitary and waste disposal behaviors were assessed using simple chi-square analysis followed by a multivariate regression analysis. Admittedly, due to the collinearity among the variables and the cross-sectional nature of the data, our analysis is constrained to make any causal interpretation of the results. Rather, it investigates the degree of correlation between the microbial quality of storage water and socio-demographic, water sources, and sanitary factors.

In the multivariate analysis of factors affecting storage water quality was examined using two different measurement specifications for the dependent variable. First, the dependent variable indicates the number of *E.coli* (cfu/100 ml water). We transformed the dependent variable (*E.coli* counts) into the inverse hyperbolic sine (IHS) which is defined as: $ihs(y) = \log(y + sqrt(y^2 + 1)$ where *Y* is the number of *E.coli* and estimated using ordinary least squares (OLS).[11]This transformation is an alternative to log transformation when the dependent variable takes on zero values (MacKinnon & Magee 1990) and we interpret the coefficients of the explanatory variables same as the log transformation. Second, we also measured the dependent variable as a binary outcome which indicates the presence or absence of *E.coli* bacteria colony, that is, y is equal to 0 if *E.coli* is less than 1 and y is equal to 1 if *E.coli* is greater than or equal to 1, and estimated using maximum likelihood estimator in the subsequent analysis.

[11] The reason for this transformation is that we cannot take the normal log of y as we have many observations with zero value, and the distribution of *E.coli* is positively skewed because coliforms naturally grow exponentially.

4. Empirical Results and Discussion

4.1 Bivariate Analysis of Determinants of Storage Water Quality

The bivariate analysis helps to examine if there is statistically significant relationships between storage water quality and variables of water sources and household characteristics. More than 58% of storage drinking water samples were contaminated with *E.coli.*[12] This result is not surprising when compared to earlier findings elsewhere in Ethiopia. For instance, a study in Kersa district of Eastern Ethiopia found that more than 78% of sampled household's storage water were contaminated with *E.coli* (Mengistie *et al.* 2013; Tsega *et al*. 2014). In the bivariate analysis, water quality indicator is measured as a dummy variable (the variable is equal to 1 if there is 1 or more *E.coli* cfu/100ml water sample, otherwise 0).

Water sources, handling and collection and storage water quality

The relationships between water sources, collection and handling practices and storage water quality have been presented in Table 4. The results show that types of water sources, water collection containers and garbage disposal patterns have statistically significant influence on storage water quality. Households who had so called 'improved' water sources showed much better microbial water quality than households who had either unprotected dug wells/springs or surface water sources. The result in Table 4 also shows a significant association between the types of water collection containers and storage water quality (p=0.000). Household water treatment practice do not have significant influence on storage water quality. Moreover, the proportion of households with contaminated water with *E.coli* was slightly lower among households who had simple pit latrine than those who did not have (p=0.022). Similarly, households in which the primary caretaker washes her hands with soap had better storage water quality than households who did not. Safe disposal of household's garbage have influence on household water quality (p=0.000). Although higher percentage of non-irrigator households had better water quality than irrigator households, the relationship is not statistically significant.

[12] The presence of *E.coli* bacteria colony units on storage drinking water of the surveyed households ranged from 0 to 195 (cfu/100 ml) water sample.

Table 4: Bivariate analysis showing the link between water sources, collection or handling and storage water quality

Variables	N	Water quality (%)		Chi-squared (χ2)	P-values
		Contaminated	Uncontaminated		
Water sources					
Private protected dug wells	23	43.48	56.52	41.640	0.000
Shared protected dug well/spring	202	43.07	56.93		
Unprotected dug wells/spring	176	72.16	27.84		
Surface water	53	75.47	24.54		
Water collection container					
Jerrycan	379	62.01	37.99	14.014	0.000
Clay-pot (*ensera*)	75	38.01	61.33		
Household water treatment					
Yes	35	71.43	28.57	2.748	0.097
No	419	57.04	42.96		
Handwashing with soap					
Yes	124	47.58	52.42	7.831	0.005
No	330	62.12	37.88		
Household sanitation facilities					
Pit latrine	189	51.85	48.15	5.277	0.022
No facility (open field/bush)	265	62.54	37.36		
Garbage disposal					
Dugout/burning	49	16.33	83.67	59.309	0.000
Throw-away in the yard	245	71.43	28.57		
Through away outside the yard	59	42.37	57.63		
Used as a fertilizer	101	55.45	44.55		
Irrigation					
Yes	302	58.94	41.06	0.232	0.630
No	152	56.58	43.42		

Note: [a] pouring the waste into a pit (soak away) is considered as safe while throw onto the compound or on the street is considered as unsafe methods of waste disposal.

Community water sources quality

Of the total 61 community water source samples tested, 73.77% of the total samples were contaminated with *E.coli*. Of the water samples collected, 58.62% of protected dug wells/springs, 84.62% of unprotected wells/springs and 100% of surface water sources were contaminated with *E.coli*. Forty-eight percent of the samples were from protected wells/spring while the remaining were from unprotected wells/springs and surface water (Table 5). Protected wells/spring has lower *E.coli* concentration (cfu/100 ml) than unprotected wells/springs and surface water sources. The finding is evident that most communal water sources are of unacceptable microbial quality for household consumption unless water is made safer. The presence of rampant drinking water contamination both at the source and point-of-use, therefore, pose high risk of public health problem from water-related diseases.

Table 5: Community water source sample test results

Source type	N	Contaminated water sources		Mean E.coli per 100 ml
		Column percentage	Row percentage	
Protected well or spring	29	37.78	58.62	6.83
Unprotected well or spring	26	48.89	84.62	34.46
Surface water	6	13.33	100	61.33
Total sample	**61**	**100**		

Source: Authors estimates using survey data

In many developing countries, particularly in sub-Saharan region, women and girls bear the burden of water fetching for household uses, and often needs to travel more than half an hour round trip (WHO/UNICEF 2010b). Figure 3 shows which household members usually collect water for households whose primary drinking water is not on premises or own yard. Often females are more responsible for household water collection than other household members in the study areas. For instance, adult women are approximately ten times more likely to collect water for household consumption than adult men. This result is consistent with a recent finding from the Demographic and Health Survey (DHS) report (CSA and ICF International 2012). As the time burden of domestic water collection is primarily borne by adult women and school-age female children, it has other implications – such as gender equality, social empowerment and school attendance – especially for girls. Therefore, the provision of clean and adequate water supply and sanitation facilities foremost benefits women and children – because it reduces the burden of travelling long distances to fetch water, which in turn increases their time to participate in community activities.

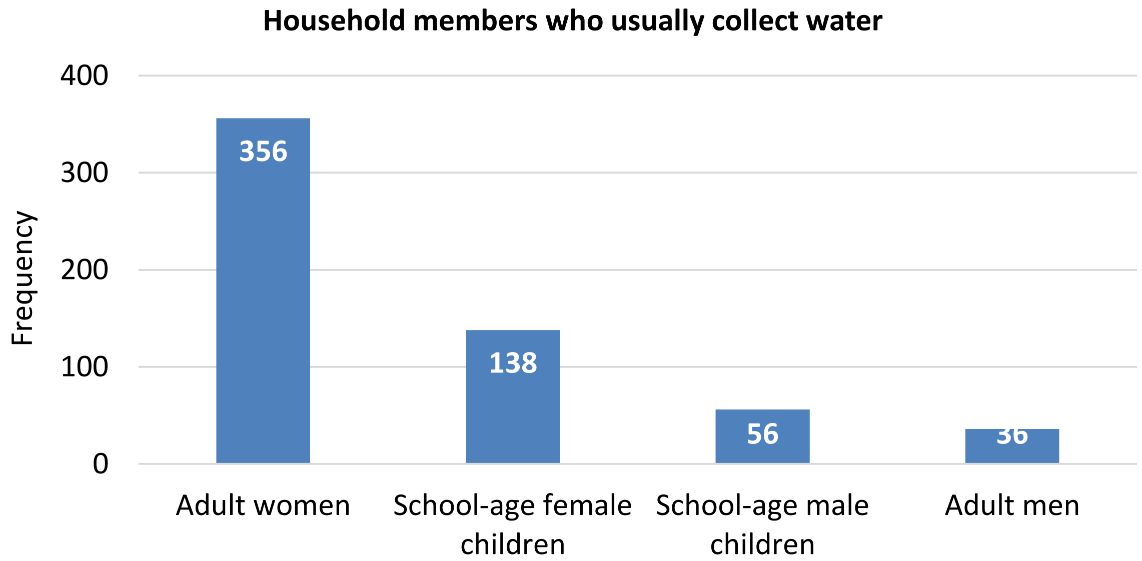

Figure 3: Household members who usually collect water when water source is not on premises

Source: Authors' computation using survey data

4.2 Multivariate Analysis of Determinants of Storage Water Quality

This section discusses the empirical results from the multivariate regression in detail. The ordinary least squares (OLS) results are presented in Table 6 while the logistic estimated odds ratios are presented in Table 7. The OLS model was used to determine the factors associated with the natural logarithm of *E.coli* water quality measures, that is, the intensity of fecal contamination. On the other hand, the logistic regression was used to estimate the odds of unsafe water quality, that is, the binary outcome of potable or not potable water (is equal to 1 if there is at least 1 or more *E.coli* cfu per 100 ml water, otherwise 0). For both types of regression analysis, we estimated different model specifications in stages to allow for inferences about the potential confounding of some of the relationships.

The OLS regression results presented in Table 6 show that types of primary water sources influence storage water quality. Household storage water from protected wells/spring had lower E.coli (cfu/100 ml water) compared to unprotected wells/springs and surface water sources – implying that water from unprotected wells/spring and surface water sources had significantly higher level of E.coli than protected sources (columns 2 Table 6). It has been shown that simple spring protection significantly improves the microbial quality of both point of source (POS) as well as POU water (Kremer et al. 2009). This association remains significant after further adjustment for household demographic characteristics. However, the pattern of relationship between water sources and E.coli level of storage water does not remain same after controlling for sanitary characteristics. The result suggests that water from unprotected wells/spring had higher level of E.coli than other alternative water sources, and there is no statistically significant difference between water from protected and surface water sources (columns 3 Table 6). Similarly, the results from the logistic regression estimates presented in Table 7, suggest that water from surface water is 3.7 times more likely to be contaminated with fecal materials compared to protected wells/springs, however, this odds disappear after controlling for sanitary factors (columns 3, Table 7). On the other hand, water from unprotected sources is 1.9 – 3.6 times more likely to be contaminated than protected sources.

The time to walk to a water source is highly positively associated with the level of *E.coli*. Traveling long distance to collect water increases the risks of the water to be contaminated. This relationship remains strong after controlling for household demographic and sanitary characteristics. Available evidence indicated that water collected from improved sources may be re-contaminated during collection, transportation and storage (Wright *et al.* 2004). There is a strong association between household water collection container vessels and the level of *E.coli* even after adjusting for household's socio-demographic and sanitary characteristics. Households who use jerrycan container for water collection activities had higher *E.coli* level than households using *ensera.* In rural Ethiopia, it is found that more than 95% of households do not adequately and regularly clean their water jerrycan containers (Kinfegabriel 2014).

Regarding household demographic characteristics, household level of education, as expected, negatively affects storage water quality. Further, household density is strongly positively associated with storage water level of *E.coli* across all model specifications. On the other hand, household size is negatively correlated with storage water quality after adjusting for sanitary factors which contradicts our prior expectation. However, the influence of this variable seems statically insignificant in the logistic regression (Table 7). The proportion of adult female household members negatively influence storage water quality but the association vanishes after controlling for household sanitary conditions. Our study also indicates that household's methods of garbage disposal patterns are highly positively associated with storage water level of *E.coli*.

In the third model specification, although the relationship between latrine and level of *E.coli* is not statistically significant, it is positively associated with the level of *E.coli* when we introduce the interaction terms between latrine and water source location. This implies that availability of pit latrine may increase the risk of fecal contamination of storage water if a water source is located on premises. This seems intuitive if ground water sources are inadequately protected and/or located close to a pit latrine. Further, our results also suggest that handwashing with soap is negatively associated with storage water quality, and similar result is shown in the logistic regression, that is, hand washing with soap is associated with lower odds of storage water contamination than who does not.

Majority of households practice mixed farming and most often livestock is living together with human beings. In general, more livestock unit means more crowded living conditions in rural areas. The negative relationship is expected and the effect is relatively large. Households engaged in irrigation agriculture had also low storage water quality. As irrigation agriculture has complex interactions with drinking water, household water can easily become affected through irrigation agriculture practices or through multiple water use. The existence of water user association (WUA) in the community is also associated with better storage water quality. Finally, the r-squared for the OLS regression is modest for a cross-sectional study and it ranges from 0.17 to 0.45 when we adjusted for socio-demographic and sanitary characteristics.

Table 6: Estimates from OLS regression predicting the natural log of *E.coli*

VARIABLES	(1) Model	se	(2) Model	se	(3) Model	se
Primary water source						
Protected well/spring (reference)						
Unprotected well/spring	1.040***	0.186	1.066***	0.165	0.315**	0.155
Surface water	1.190***	0.261	1.154***	0.237	0.235	0.233
Minutes to water source (*1 = less than 30 minutes*)	-1.061***	0.242	-0.975***	0.224	-0.911***	0.220
Container (*1=Jerry can*)	1.197***	0.198	1.150***	0.192	1.086***	0.186
Highest education completed			-0.084**	0.034	-0.051*	0.026
Household size			-0.089	0.072	-0.120**	0.056
Household density			0.401***	0.082	0.351***	0.066
Proportion of adult female			-2.015*	1.159	-0.176	0.859
Garbage disposal						
Dugout/burning (reference)						
Throw in the yard					1.516***	0.223
Throw away outside the yard					0.568*	0.301
Used as fertilizer					0.872***	0.246
Handwashing with soap					-0.611***	0.162
Livestock units					0.166***	0.040
Irrigation farming (*1=yes*)					0.439***	0.137
Water use group (*1=yes*)					-1.419***	0.177
Pit latrine (*1=yes*)					-0.510**	0.243
Water source location (*1 = on premises*)					-0.446**	-0.037
Pit latrine X water source location					0.567**	0.267
Constant	1.520***	0.281	1.415**	0.548	0.206	0.525
Observations	454		454		454	
R-squared	0.17		0.25		0.45	
Model F-test	35.28		35.18		68.18	
Model p-value	0.000		0.000		0.000	

Robust standard errors adjusted for clustering at the village level;
Significance *** p<0.01, ** p<0.05, * p<0.1

In most of the cases, the two regression tables produce similar results with expected signs. For instance, across all model specifications, time to water sources and household level of education are significantly associated with lower odds of fecal contamination while water collection jerrycan, household density and garbage disposal patterns are significantly associated with higher odds of fecal contamination (Table 7). Moreover, households who keep livestock is associated with 28 percentage point increase in the odds of contaminating their storage water. However, contrary to the OLS regression results presented in Table 6, some of the variables such as irrigation practice, latrine presence and water source location, which influence storage water quality at different levels, do not have a significant influence on the odds of storage water contamination.

Our results generally indicate a common problem of poor storage water quality in the rural areas of Fogera and Mecha district with more than 58% of the households having at least one *E.coli* per 100 ml water. Our results further suggest that storage water quality is strongly associated with water source, water collection time and containers, existence of WUA in the village, household demographic structures and households overall sanitary characteristics. Our findings are also consistent with other studies that demonstrate substantial levels of fecal contamination of storage water after collection from improved sources that are less prone to high level of fecal contamination (Wright et al. 2004). Existing underdeveloped rural water infrastructure couples with poor household water quality and lack of key hygiene practices pose substantial risk from waterborne infectious diseases in the country.

Table 7: Estimates from Logistic regression predicting E.coli contamination (1 if *E.coli* >= 1)

VARIABLES	(1) Model	se	(2) Model	se	(3) Model	se
Primary water source						
Protected well/spring (reference)						
Unprotected well/spring	3.246***	0.717	3.626***	0.764	1.889**	0.532
Surface water	3.693***	1.277	3.709***	1.234	1.111	0.419
Water collection time (*1= less than 30 minutes*)	0.387***	0.116	0.399***	0.124	0.372**	0.155
Container (*1=Jerry can*)	2.635***	0.759	2.715***	0.773	3.570***	1.291
Highest education completed			0.898***	0.036	0.899***	0.036
Household size			0.940	0.085	0.878	0.085
Household density			1.429***	0.165	1.490***	0.175
Proportion of adult female			0.113	0.173	0.533	0.850
Garbage disposal						
Dugout/burning (reference)						
Throw in the yard					14.948***	8.001
Throw away outside the yard					2.972*	1.797
Used as fertilizer					5.845***	3.341
Handwashing with soap					0.373***	0.112
Livestock units					1.288***	0.096
Irrigation farming (*1=yes*)					1.507	0.407
Water use group (*1=yes*)					0.146***	0.051
Pit latrine (*1=yes*)					0.847	0.234
Water source location (*1= on premises*)					0.607	0.244
Pit latrine X water source location					1.418	0.768
Constant	0.795	0.277	0.776	0.567	0.089**	0.093
Observations	454		454		454	
Pseudo R-squared	0.10		0.15		0.35	
Model Chi2	55.79		105.13		185.81	
Model p-value	0.000		0.000		0.000	

Robust standard errors adjusted for clustering at the village level;
Significance *** p<0.01, ** p<0.05, * p<0.1
Coefficients are odds ratio (OR)

In general, rural water supply infrastructure often does not guarantee the basic safe water supply indicators defined by the WHO such as water quality, quantity, continuity and coverage or accessibility. It has been estimated that 33% of rural water supply schemes are non-functional at any time (MoWE 2007). A recent survey of 57 diverse water source schemes also showed that 38.6% of the systems were non-functional on the day of the visit (Welle & Williams 2014). For instance, a community has to wait may be for more than a month to get a broken hand pumps repaired. As a result of the intermittent and unreliable water supply, most households are forced to collect water from other unimproved water sources as people generally prefer the taste of spring water than constructed wells in the study areas (Beyene 2012). Besides, water from spring sources require less waiting time than water from constructed wells.

In the bivariate analysis the influence of household water treatment practice on storage water quality is not strong (Table 4). As we have discussed earlier, the weak relationship between household water treatment practice and storage water quality is because of lack of regular use of any form of water treatment in our sample households. For instance, among the households who use some form of water treatment, more than 81% of these households applying chlorine-based methods, of which 72% households use this method during the month before the survey. None of the respondents reported regularly treating their household drinking water. However, we observed that *E.coli* levels are significantly lower for households practicing any water treatment methods compared to households who did not. The empirical evidence that household water treatment and safe storage (HWTS) practice in improving the microbiological quality of drinking water is well documented (for example; see Clasen 2015; Fewtrell *et al.* 2005; Mengistie et al. 2013; Mintz *et al.* 1995). Largely, the habit of treating water before drinking is critically slim in both urban and rural households. Because there is also a lack of awareness about domestic water quality and its health consequences, people often perceive that clean water is ‘clean’. For instance, nationally, about 87% of urban households and 91% of rural households do not practice any form of household water treatment (CSA and ICF International 2012).

The types of household storage container can also influence household water quality (Levy *et al.* 2008). In this study, types of water collection container significantly associated with the quality of water consumed by the household. More than 83% of the household identified jerrycan as a favorite container for hauling and storing their drinking water; and only 24% of households had separate water storage containers. Our result shows that jerrycan increases the risk of storage water contamination, and this is mainly due to inadequate cleaning. Although jerrycan container has an advantage of being narrow-mouthed, rural households do not properly clean it. It is very difficult to clean its inside part with simple washing. A study in rural Ethiopia reported that more than 95% of households do not adequately and regularly clean their water container or jerrycan (Kinfegabriel 2014). Previous studies elsewhere showing that storage container characteristics such as narrow versus wide mouth and covered versus uncovered, are key factors in determining storage water quality (Mintz *et al*. 1995). It is believed that water pouring is safer than dipping but this research questioned if narrow necked container such as jerrycan is the safest methods of water storage. Households opt to store water for future use when water supply is unreliable and intermittent. However, Brick *et al.* (2004) suggest that drinking water contamination will also be higher if water is stored for longer period.

Our results also highlighted that increased water collection time increases the risk of storage water contamination. This is in line with studies showing that the microbiological quality of water obtained from improved sources significantly deteriorates during collection and transportation (Wright et al. 2004). Moreover, water collection time determines the quantity of water a given household can collect and consume (Cairncross 1987), which is a critical determinant of key hygiene practices (Cairncross 1997; Curtis *et al.* 2000; Gilman *et al.* 1993). On the other hand, more time allocation for household water collection may allow households to collect sufficient water and to maintain key hygiene practices such as washing hands at critical times which can influence storage water quality (Curtis *et al*. 2000). Hands may come into contact with feces as a result of multiple factors and pose potential risk of contaminating household water during water handling (Trevett *et al.* 2005). Therefore, proper hygiene practice can reduce storage water contamination.

Household demographic variables particularly household density is a strong predictor of storage water quality. It can be argued that crowded living conditions might influence the overall hygiene and sanitation environment that probably increase the risk of storage water contamination. Unlike in the logistic regressions, we are puzzled by the negative association between household size and storage water quality in the OLS regression result. It is a common understanding that the level of *E.coli* in storage water expected to positively correlate due to possible contacts from the many hands to water containers.

On the other hand, pit latrine availability increases the level of *E.coli* on storage water for households who use wells water sources in their own premises. Megha *et al.* (2015) showed that the microbiological quality of ground water deteriorate where pit latrines are placed close to the source. Our result showed that households having a pit latrine and using own wells located in premises have high levels of *E.coli* on storage water. In addition to the type of well, the risk of water quality problems with groundwater supplies is directly related with how close it is to potential sources of contamination, that is, the risk of contamination decreases as the distance between the well and potential contamination sources increases. Therefore, source water contamination from own latrine could be one possible channels for high contamination of storage water. Moreover, as private-wells are often shallow and inadequately protected compared to communal hand dug wells, this might increase risks of contamination from household waste water, animal droppings, flood-washed wastes, dirty well surroundings and water-drawing buckets. Although the sign is positive, this relationship is not statistically significant in the logistic regression.

In rural areas, agriculture and livestock rearing, which are the primary sources of livelihood, have complex interactions with household water quality. Most households keep livestock and often livestock is living together with human beings which can increase the risk of household water contamination. The negative relationship is expected and the effect is also relatively large. Further, households engaged in irrigation agriculture had also lower water quality. Where access to improved drinking water is limited, households opt to use irrigation water for domestic purpose which is often of poor quality. A significant portion of households reported that they directly withdraw water from irrigation sources for household consumption. Although irrigation water increases water availability for domestic purpose, it might increase the risk of storage water contamination. Similarly, household members working on an irrigation field may come into contact with domestic water and contaminate if proper personal hygiene and handwashing is lacking.

Another interesting finding is that the existence of WUA in a village influences the quality of storage water quality. Households belong to a community in which there is a WUA reported better storage water quality. This association is consistently statistically significant across all model specifications. The WUA is primarily responsible in monitoring and supervising and handling conflicts among household users of community water sources. The influence of WUA on storage water quality could be via improving the protection of water sources from external contamination. Basically, WUA were instituted in many villages for governing rural water supplies when a new water source point was constructed (Tilahun *et al.* 2013).

Generally, increasing the provision of rural water supply is the agenda of both the regional government and other development partners, yet, most rural households had to travel long distance which may not even guarantee them to get improved water sources. Moreover, widespread household water contamination in rural areas of the countries undermined the progress that has been made in terms of increasing access to improved water supply in rural areas. Today, lack of access to clean and adequate drinking water and poor sanitary environment is a critical public health problem in Ethiopia, contributing to about 70% of the diarrheal diseases burden in the country (FMoH 2005). Unsafe water is not just dirty; it can be deadly if people drinks it without any treatment. Therefore, any intervention that aiming at increasing access to safe and clean rural water supply should be complimented by large-scale household intervention such as safe water storage, POU water treatment to make water safer.

4.3 Limitation of the Study

One of possible drawback of this study is that we use only a one-time water sample test results. This does not allow us to capture the seasonal impacts on groundwater quality. Although one-time sampling information is very useful, high level of *E.coli* may be a one-time event occurrence. Moreover, since all our sampled households entirely rely on non-piped water supply sources, seasonal changes could likely affect water quality in the household which might have also influence the level of water quality measured. Conducting subsequent water sample testing over time could provide a more representative water quality indicator.

Further, we could not test for all known pathogens that pose a health risk because it is both complicated and expensive in the field. Lastly, the study could have been improved if water samples could have been taken from all available community water sources and matching with household water sample test results. Moreover, additional sanitary inspection of water sources should have been carried out to better understand determinates of water quality at the point of source. Hence, inadequate protection, poor site location and unhygienic practices such as washing, bathing, keeping and watering animals around the sources might deteriorate the water quality. We recommend that the focus of future research should be assessing seasonal changes in water sources and how it impacts storage water quality under multiuse water sources. Further, it should focus on exploring on how individual level of behaviors related to WASH affects both source and POU water.

5. Conclusions and Recommendations

Most of the health problems of children in Ethiopia are communicable diseases due to unsafe drinking water sources, improper water handling practices and poor sanitation facilities. The fact that, about 74% and 58% of the water sample from sources and household storage were positive for E.coli bacteria shown that majority of the rural population is at high risk of waterborne diseases. About 50% the surveyed households get their water from protected or 'improved' water sources; however, more than 42% of these households' storage drinking water was contaminated with fecal materials. The findings indicated the rampant drinking water problems both at POS and POU in rural areas of Ethiopia. The situation is almost similar in many other rural areas of the country (Mengistie et al. 2013, Tsega et al. 2014). Further Wright et al. (2004) showed that microbiological quality of drinking water significantly decline after collection from acceptable quality of water sources. It is widely believed that POU water treatment and safe water storage are more effective ways, and should be a focus of intervention to ensure the quality of water being consumed (Clasen & Bastable 2003; Gundry et al. 2004).

The study suggests that there is a need to promote water safety along the POS to POU to advance the Sustainable Development Goals (SDG6) of ensuring access to clean water for everyone. Therefore, a number of intervention that can be implemented to address the problem of poor water quality until the long term goal of providing clean and safe water supplies for all Ethiopian rural households can be achieved. In addition to expanding the WASH infrastructures to increase access for the unserved population, the following recommendations are made to improve the overall situation of poor water quality both at the POS and POU. First, available water source points should be adequately protected. Most communal water sources considered to be 'improved' and widely considered to provide safe water showed the presence of E.coli which is not in compliance with both the national and the WHO guideline standards. Moreover, private-well water sources should not be developed close to household's latrine to prevent potential seepage. The quality of well water often is directly related to the care taken in well construction. Many of the private-water sources in the study areas are bucket wells and they are often shallow and under-protected and can be easily contaminated by latrine, animal droppings, dirty ropes and buckets and households waste. Therefore, one should plan carefully before choosing the site to minimize the risk exposure from external contamination as its location determines the quality of the water obtained. Second, promoting household water treatment methods and products to make water safer would be a worthy intervention to improved drinking water quality, given that most households draw their drinking water from unimproved or unprotected sources. However, there is a lack of awareness of the need to treat drinking water among households, as our empirical findings show. Household water treatment and safe storage (HWTS), such as boiling, filtering, or chlorinating water at home, are effective in improving the quality of storage water (Clasen 2015). Therefore, promoting HWTS and the health risks of drinking contaminated water may bring significant progress in the provision of clean and safe water. Third, as most of households use jerrycan for water collection and storage, either providing safer and convenient storage containers or promoting how to clean it properly would avoid substantial risk of water contamination. Moreover, since adult women are disproportionately responsible for household water collection, targeting adult women in any hygiene education intervention on handwashing and key hygiene practices may improve storage water quality. Fourth, ad hoc water quality testing and quality control mechanisms for rural water supply systems need to be in place to ensure safety of drinking water supplies. Determining the public health risk associated with drinking water quality is very useful; however, in practice monitoring of pathogens is generally not carried out either systematically or regularly. Once the water supply infrastructure is in place, systematically well planned and designed sanitary management needed to ensure safe drinking water. Finally, building the capacity of WUA and providing them training in water source protection, environmental sanitation and systems operation and maintenance. The provision of drinking water in rural areas through communal water scheme is the conventional way and this is the only existing alternative to increase access to clean water. Therefore, supporting WUA to enable them to repair and manage available water sources is critical in the provision of sustainable water supply. Additionally, variations in community and household behavioral and sanitary factors are key determinants of household storage water quality. Unsafe sanitation habits, inadequate garbage disposal and open defecation (the default option for those without access to pit latrines) could be the primary causes of drinking water contamination. Further, keeping livestock units separately from household dwellings and out of the water source catchment areas can improve water quality. Therefore, without proper waste disposal and sanitation facilities, water source points are highly prone to gross contamination from human and animal feces which are the primary sources of diseases-causing pathogens. Generally, the association between improved water supply and safe household water seems too simplistic, and a mix of instruments needed to address the complex problem of drinking water safety and to make progressive improvements in the next decade in terms of other aspects the SDG6 indicator as well.

References

Amenu, K., Spengler, M., André, M., & Valle Zárate, A. (2014). Microbial Quality of Water in Rural Households of Ethiopia: Implications for Milk Safety and Public Health. *Journal of Health, Population, and Nutrition, 32*(2), 190-197.

Atnafu, M. (2006). *Assessment of Bacteriological Quality of Drinking Water Supply at the sources and Point of Use at Home in Worebabu District, South Wollo.* M. Sc Thesis. Addis Ababa University, Addis Ababa. 34-57.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. *PLoS Med, 11*(5), e1001644. doi: 10.1371/journal.pmed.1001644

Begashaw, G. (2003). Community health, water supply and sanitation. *Integrated water and land management research and capacity building priorities for Ethiopia*, 98.

Beyene, H. A. (2012). *Factors Affecting the Sustainability of Rural Water Supply Systems: The Case of Mecha Woreda, Amhara Region, Ethiopia.* Cornell University.

Brick, T., Primrose, B., Chandrasekhar, R., Roy, S., Muliyil, J., & Kang, G. (2004). Water contamination in urban south India: household storage practices and their implications for water safety and enteric infections. *International Journal of Hygiene and Environmental Health, 207*(5), 473-480.

Butterworth, J., Sutton, S., & Mekonta, L. (2013). Self-supply as a complementary water services delivery model in Ethiopia. *Water Alternatives, 6*(3), 405.

Cairncross, S. (1987). Water, Women and Children. In J. Pickford & B. Leedham (Eds.), *The Benefit of Water Supply*: Developing World Water II, London: Grosvener.

Cairncross, S. (1997). More water: better health. *People and the Planet, 6*(3), 10-11.

Clasen, T. (2015). Household Water Treatment and Safe Storage to Prevent Diarrheal Disease in Developing Countries. *Current Environmental Health Reports*, 1-6. doi: 10.1007/s40572-014-0033-9

Clasen, T., & Bastable, A. (2003). Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *J Water Health, 1*, 109-115.

Crampton, J., & Aid, W. (2005). Maintaining clean water: contamination during water collection and storage in Addis Ababa.

CSA. (2013). Population projection of Ethiopia for all regions at wereda level from 2014 – 2017. Addis Ababa, Ethiopia.

CSA and ICF International. (2012). *Ethiopia Demographic and Health Survey 2011*. Addis Ababa, Ethiopia and Calverton, Maryland, USA: Central Statistical Agency (CSA) and ICF International.

Curtis, V., & Cairncross, S. (2003). Effect of washing hands with soap on diarrhoea risk in the community: a systematic review. *The Lancet infectious diseases, 3*(5), 275-281. doi: http://dx.doi.org/10.1016/S1473-3099(03)00606-6

Curtis, V., Cairncross, S., & Yonli, R. (2000). Review: Domestic hygiene and diarrhoea – pinpointing the problem. *Tropical Medicine & International Health, 5*(1), 22-32. doi: 10.1046/j.1365-3156.2000.00512.x

Edberg, S. C., Rice, E. W., Karlin, R. J., & Allen, M. J. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology, 88*(S1), 106S-116S. doi: 10.1111/j.1365-2672.2000.tb05338.x

Eshcol, J., Mahapatra, P., & Keshapagu, S. (2009). Is fecal contamination of drinking water after collection associated with household water handling and hygiene practices? A study of urban slum households in Hyderabad, India. Journal of water and health, 7(1), 145-154.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford Jr, J. M. (2005). Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet Infectious Diseases, 5*(1), 42-52. doi: http://dx.doi.org/10.1016/S1473-3099(04)01253-8

FMoH. (2005). National hygiene and sanitation strategy *To enable 100% adoption of improved hygiene and sanitation*. Addis Ababa, Ethiopia: Federal Democratic Republic of Ethiopia Ministry of Health (FMoH).

Gilman, R. H., Marquis, G. S., Ventura, G., Campos, M., Spira, W., & Diaz, F. (1993). Water cost and availability: key determinants of family hygiene in a Peruvian shantytown. *American Journal of Public Health, 83*(11), 1554-1558.

Godfrey, S., Labhasetwar, P., Wate, S., & Pimpalkar, S. (2011). How safe are the global water coverage figures? Case study from Madhya Pradesh, India. *Environmental Monitoring and Assessment, 176*(1-4), 561-574. doi: 10.1007/s10661-010-1604-3

Gundry, S., Conroy, R., & Wright, J. (2004). A systematic review of the health outcomes related to household water quality in developing countries. *J. Water Health, 2*(1), 1-13.

Haylamicheal, D., & Moges, A. (2012). Assessing water quality of rural water supply schemes as a measure of service delivery sustainability: A case study of WondoGenet district, Southern Ethiopia. *African Journal of Environmental Science and Technology, 6*(5), 229-236.

Jano, M. (2007). *Assessment of Physicochemical and microbiological Quality of rural Drinking water supply at the source in Menge Woreda, Benshangul Gumuz Regional state, Ethiopia.* M. Sc Thesis. Addis Ababa University, Addis Ababa.

Kinfegabriel, T. (2014). *Welthungerhilfe Ethiopia WASH Sector Experience. A presentation at WATSAN Agriculture Workshop Organized by Center for Development Research (ZEF) of University of Bonn, Germany, 8-9 September*.

Kremer, M., Leino, J., Miguel, E., & Zwane, A. P. (2009). Spring cleaning: rural water impacts, valuation and property rights institutions: National Bureau of Economic Research.

Levy, K., Nelson, K. L., Hubbard, A., & Eisenberg, J. N. (2008). Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Environ Health Perspect, 116*(11), 1533-1540.

MacKinnon, J. G., & Magee, L. (1990). Transforming the dependent variable in regression models. *International Economic Review*, 315-339.

Megha, P. U., Kavya, P., Murugan, S., & Harikumar, P. S. (2015). Sanitation Mapping of Groundwater Contamination in a Rural Village of India. *Journal of Environmental Protection, Vol.06No.01*, 11. doi: 10.4236/jep.2015.61005

Mengistie, B., Berhane, Y., & Worku, A. (2013). Household Water Chlorination Reduces Incidence of Diarrhea among Under-Five Children in Rural Ethiopia: A Cluster Randomized Controlled Trial. *PLoS ONE, 8*(10), e77887. doi: 10.1371/journal.pone.0077887

Mintz, E. D., Reiff, F. M., & Tauxe, R. V. (1995). Safe water treatment and storage in the home: a practical new strategy to prevent waterborne disease. *The Journal of the*

American Medical Association, 273(12), 948-953. doi: doi:10.1001/jama.1995.03520360062040

MoWE. (2006). Universal Access Program for water Supply and Sanitatio Addis Ababa, Ethiopia: Ministry of Water and Energy.

MoWE. (2007). Water sector development programme (WSDP) reports. Addis Ababa, Ethiopia: Ministry of Water and Energy (MoWE).

Rufener, S., Mäusezahl, D., Mosler, H.-J., & Weingartner, R. (2010). Quality of Drinking-water at Source and Point-of-consumption—Drinking Cup As a High Potential Recontamination Risk: A Field Study in Bolivia. *Journal of Health, Population, and Nutrition, 28*(1), 34-41.

Scheelbeek, P. (2005). *Two Containers a Day: The Search for proper Water Sources in Eastern Ethiopia. Water Quality and Sanitation in the Lege Dini Watershed Area, Ethiopia. MSc Thesis in Irrigation and Water Engineering.* Wageningen University, the Netherlands.

Stel, N., & Abate, F. M. (2014). Between Control and Cooperation: Multi-Stakeholder Service Provision and the Legitimacy of State Institutions in Ethiopia's Amhara National Regional State. *European Journal of Development Research, 26*(5), 743-760.

Sutton, S., Butterworth, J., & Mekonta, L. (2012). *A hidden resource: household-led rural water supply in Ethiopia*: IRC International Water and Sanitation Centre, The Netherlands.

Sutton, S., Mamo, E., Butterworth, J., & Dimtse, D. (2011). Towards the Ethiopian goal of universal access to rural water: understanding the potential contribution of self supply: RiPPLE Working Paper.

Tilahun, S. A., Tigabu, A. D., Tarekegne, T. M., Addisie, M. B., Beyene, H. A., Alemeyehu, Z. A., . . . Steenhuis, T. S. (2013). Factors in the suboptimum performance of rural water supply systems in the Ethiopian highlands. Retrieved from http://hdl.handle.net/10568/34247 (Accessed 15 March 2015)

Trevett, A. F., Carter, R. C., & Tyrrel, S. F. (2005). Mechanisms leading to post - supply water quality deterioration in rural Honduran communities. *International Journal of Hygiene and Environmental Health, 208*(3), 153-161. doi: http://dx.doi.org/10.1016/j.ijheh.2005.01.024

Tsega, N., Sahile, S., Kibret, M., & Abera, B. (2014). Bacteriological and physico-chemical quality of drinking water sources in a rural community of Ethiopia. *African health sciences, 13*(4), 1156-1161.

UNDP. (2006). *Human Development Report 2006-Beyond scarcity: Power, poverty and the global water crisis*. New York: USA: Palgrave Macmillian.

UNICEF. (2000). Sanitation for all: Promoting dignity and human rights. *UNICEF, New York*.

Welle, K., & Williams, J. (2014). Monitoring and addressing governance factors affecting rural water supply sustainability. Regional approach paper based on Global Water Initiative East Africa Governance-into-Functionality monitoring of water schemes implemented in Ethiopia, Tanzania and Uganda. GWI East Africa.

WHO/UNICEF. (2009). Diarrhoea: Why children are Still Dying and what can be done: World Health Organization (WHO) and United Nations Children's Fund (UNICEF).

WHO/UNICEF. (2010a). Rapid Assessment of Drinking Water Quality in the Federal Republic of Ethiopia: Country Report, World Health Organization (WHO), Federal Ministry of Health (FMoH), Ethiopian Health & Nutrition Research Institute (EHNRI) and United Nations Children's Fund (UNICEF).

WHO/UNICEF. (2010b). Progress on Sanitation and Drinking-Water, 2010 Update. Available at: http://whqlibdoc.who.int/publications/2010/9789241563956_eng_full_text.pdf.

WHO/UNICEF. (2014). Progress on Drinking Water and Sanitation: 2014 Update. New York, NY, USA, United Nations Children’s Fund (UNICEF); Geneva, Switzerland, World Health Organization (WHO)

WHO/UNICEF. (2015). Progress on Drinking Water and Sanitation: 2014 Update and MDG Assessment. New York, NY, USA, United Nations Children’s Fund (UNICEF); Geneva, Switzerland, World Health Organization (WHO)

Wright, J., Gundry, S., & Conroy, R. (2004). Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical medicine & international health, 9*(1), 106-117. doi: 10.1046/j.1365-3156.2003.01160.x

Yasin, M., Ketema, T., & Bacha, K. (2015). Physico-chemical and bacteriological quality of drinking water of different sources, Jimma zone, Southwest Ethiopia. *BMC research notes, 8*(1), 541.

Zwane, A. P., & Kremer, M. (2007). What Works in Fighting Diarrheal Diseases in Developing Countries? A Critical Review. *The World Bank Research Observer, 22*(1), 1-24. doi: 10.1093/wbro/lkm002