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Abstract

In rural areas access to improved water supply is inadequate; consequently, most households rely on unimproved water sources, including unprotected wells/springs, streams, and surface water, which are easily polluted by human and animal feces. Moreover, irrigated agriculture has complex interactions with water supply and sanitation (WATSAN) services as separate sources of water for drinking and for agricultural use do not exist in several areas. For this analysis, a household survey has been conducted in rural areas of Fogera and Mecha districts of Ethiopia between February and June 2014. A sample of 454 agricultural households was randomly selected using a stratified two-stage cluster sampling method.

The survey collected a range of information including anthropometric measures for under-five children to examine child nutritional status. In addition, assessment of the microbial quality of stored drinking water and community water sources were undertaken. The number of *Escherichia coli* (*E.coli*) colony-forming units per 100ml water was used as an indicator of fecal contamination, and the results demonstrate that 58 percent of household stored water samples and 74 percent of water sources were contaminated with *E.coli*. Our results also show that uncontaminated household storage water and safe child stool disposal decrease incidence of child diarrhea by 15 and 23 percentage points, respectively. In contrast, neighborhood concentration of pit latrine increases the incidence of child diarrhea by 13 percentage points. The latter result casts serious doubt on the assumed health and social benefits of moving from open to fixed-location defecation. Creating open defecation free communities in rural areas is not enough to achieve the desired health benefits of sanitation. To protect rural households from the risk of contracting communicable diseases, existing pit latrines should be upgraded to make them safer to use –fly-proofed and hygienic.

Using anthropometric measures of under-five children, our results show that WATSAN services are strongly associated with improved weight-for-age z-score but its correlation with height-for-age z-score is not statistically significant at any of the conventional levels. Dietary diversity of child feeding practice and health indicator variables, such as number of antenatal care visits and delivery with a health professional, turn out to be strong predictors of both nutritional outcome measures. On the other hand, although the domestic use of irrigation water significantly increases household's overall morbidity status except for diarrhea, it substantially reduces the burden of time spend on water collection for women. Recognizing the multiple-use of water resources in rural areas where access to improved water supply is inadequate or where there is only one water source for all household needs would be vital to design the right intervention. Promoting improved WATSAN from 'farm to fork' through water source protection, appropriate water-lifting technologies, ensuring households do not use irrigation runoff for drinking, and adopting household water treatment and safe storage to reduce microbiological contamination so that the health risks associated with domestic use of irrigation water may be minimized.

Zusammenfassung

In ländlichen Gebieten ist der Zugang zu einer verbesserten Wasserversorgung unzureichend. Infolgedessen sind die meisten Haushalte auf Wasser aus hygienisch bedenklichen Quellen, einschließlich ungeschützten Brunnen/Quellen, Strömen und Oberflächenwasser, die leicht durch menschliche und tierische Fäkalien verschmutzt werden, angewiesen. Darüber hinaus bestehen komplexe Wechselwirkungen zwischen der bewässerten Landwirtschaft und der Wasserversorgung und Abwasserentsorgung (WATSAN), da getrennte Wasserquellen für Trink- und Landwirtschaftszwecke in mehreren Regionen nicht existieren. Für diese Analyse wurde in den ländlichen Gebieten der Bezirke Fogera und Mecha in Äthiopien zwischen Februar und Juni 2014 eine Haushaltsbefragung durchgeführt. Eine Stichprobe von 454 landwirtschaftlichen Haushalten wurde nach dem Zufallsprinzip mittels einer Klumpenstichprobe (zweistufig, geschichtet) ausgewählt.

Mittels einer Umfrage wurde eine Reihe von Informationen gesammelt, einschließlich anthropometrischer Messungen für Kinder unter fünf Jahren um deren Ernährungsstatus zu prüfen. Zusätzlich wurde eine Bewertung der mikrobiellen Qualität des gespeicherten Trinkwassers und der gemeinschaftlichen Wasserquellen vorgenommen. Die Anzahl der *Escherichia coli* (*E.coli*) koloniebildenden Einheiten pro 100ml Wasser wurde als ein Indikator für die fäkale Verunreinigung verwendet. Die Ergebnisse zeigen auf, dass 58 Prozent der Haushaltswasserproben und 74 Prozent der Wasserquellen mit *E.coli* kontaminiert waren. Unsere Ergebnisse zeigen zudem, dass unkontaminiertes Haushaltswasser und eine sichere Fäkalienentsorgung bei Kindern das Auftreten von Kinderdurchfall um jeweils 15 beziehungsweise 23 Prozentpunkte verringern. Im Gegensatz dazu erhöht die Konzentration von Grubenlatrinen in der Nachbarschaft die Häufigkeit von Durchfall bei Kindern um 13 Prozentpunkte. Das letztgenannte Ergebnis führt zu ernsthaften Zweifeln an den bislang angenommenen gesundheitlichen und sozialen Vorteilen des Umstiegs von öffentlicher zu stationärer Defäkation. Die Errichtung von Gemeinschaften in ländlichen Gebieten in denen Stuhlgang nicht mehr in der Öffentlichkeit praktiziert wird, reicht nicht aus um die gewünschten gesundheitlichen Vorteile von Sanitärmaßnahmen zu erreichen. Um ländliche Haushalte vor dem Risiko der Ansteckung übertragbarer Krankheiten zu schützen, sollten bestehende Grubenlatrinen ausgebaut werden, um sie sicherer zu machen – geschützt vor Fliegen und hygienisch.

Die Ergebnisse der anthropometrischen Messungen von Kindern unter fünf Jahren zeigen, dass WATSAN-Dienstleistungen stark mit einem verbesserten „weight-for-age“-Standardisierung verbunden sind, jedoch ist ihre Korrelation mit der „height-for-age“-Standardisierung nicht statistisch signifikant. Eine ausgewogene Kinderernährung und Gesundheitsindikatoren, wie zum Beispiel die Anzahl der vorgeburtlichen Betreuungsbesuche und die von medizinisch betreuten Geburten, erweisen sich als starke Einflusswerte für beide Indikatoren des Ernährungszustands. Obwohl die Morbidität, außer für Durchfall, durch die häusliche Benutzung von Bewässerungswasser insgesamt signifikant erhöht wird, wird auf der anderen Seite die Last der Frauen hinsichtlich Zeit, die für die Wassersammlung gebraucht wird, erheblich reduziert. In Anbetracht der Mehrfachnutzung der Wasserressourcen in ländlichen Gebieten, in denen der Zugang zu einer verbesserten Wasserversorgung nicht ausreichend ist oder nur eine Wasserquelle für alle Haushaltsbedürfnisse vorhanden ist, wäre es entscheidend, die richtige Maßnahme durchzuführen. Das beinhaltet die Förderung von verbesserter Wasser – und Sanitärversorgung auf dem Feld und den Haushalten durch den Schutz von Wasserquellen, geeignete Wasserförderungstechnologien, das Sicherstellen, dass private Haushalte nicht den Abfluss von Bewässerungswasser zum Trinken verwenden und die Übernahme von „Household water treatment and safe storage“-Methoden zur Verringerung der mikrobiologischen Kontamination. Mit dem Ziel, die Gesundheitsrisiken im Zusammenhang mit der häuslichen Nutzung von Bewässerungswasser, zu minimieren.

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List of Acronyms

ANRS	Amhara National Regional State
AG-WATSAN	Agriculture-Water and Sanitation
ATE/ATT	Average Treatment Effect / Average Treatment on the Treated
CSA	Central Statistical Agency
DHS	Demographic and Health Survey
EEA	Ethiopian Economics Association
GPS	Global Positioning System
HEW	Health Extension Worker
HWTS	Household Water Treatment and Safe Storage
L/p/c/d	Liter Per Capita Per Day
MLSB	Membrane Lauryl Sulphate Broth
ORDA	Organization for Rehabilitation and Development in Amhara
WHO	World Health Organization
UNICEF	United Nations Children's Fund
FMoH	Federal Ministry of Health
POS	Point-of-Source
POU	Point-of-Use
PSU	Primary Sampling Unit
SDGs	Sustainable Development Goals
SSU	Secondary Sampling Unit
WASH	Water, Sanitation and Hygiene
WASTAN	Water and Sanitation
WUA	Water User Association
OLS	Ordinary Least Squares
CLTS	Community-Led Total Sanitation
MoWE	Ministry of Water and Energy
SSI	Small-scale Irrigation
ZEF	Center for Development Research, University of Bonn

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1. General Introduction

Worldwide more than 3.4 million people die of diseases related to water, sanitation and hygiene (WASH) (Prüss-Üstün *et al.* 2008). More than 90 percent of diarrheal deaths under the age of five years are in developing countries (UN Water 2008a). As a result of lack of access to improved drinking water supply and sanitation (WATSAN),[1] inadequate hygiene practices and malnutrition, diarrhea is more prevalent in many developing countries. It is the second leading causes of death among under-five children globally, which kills more children than malaria, AIDS, and measles combined (WHO/UNICEF 2009). In most cases, these deaths could have been prevented by providing safe drinking water, basic sanitation facilities, and promoting proper hygiene practices.

As reported by the WHO/UNICEF Joint Monitoring Programme (JMP), which monitors progress on the water and sanitation targets, 2.5 billion people—over one-third of the world population—lack access to improved sanitation facilities, of which a billion people practice open defecation, and over 780 million people—80 percent of these people live in rural areas—worldwide lack access to improved drinking water sources (WHO/UNICEF 2014).[2] Most of the unserved population lives in sub-Saharan Africa and southeastern Asian regions.

The problems of inadequate WASH services are complex and multifaceted. Globally, due to WASH-related diseases alone, 5.5 billion productive days and 443 million school days are lost every year (Fewtrell *et al.* 2007; UNDP 2006). Studies also show that provision of sanitation facilities at school increase girl's school enrollment rates by over 15 percent (IRC 2007; UN Water 2008b). It is estimated that improving WASH services could prevent nearly 10 percent of the burden of disease and about 6 percent of all deaths globally (Prüss-Üstün *et al.* 2008).

Improved WATSAN services together with proper hygiene practices can have significant health impacts on the population by reducing the incidence of a variety of water-related diseases. A wide range of empirical studies show that improvement in WATSAN service affect health outcomes, as measured by less diarrhea, improved child growth, reduction in parasitic and worm infections, skin diseases, trachoma, and lower rates of morbidity and mortality (Checkley *et al.* 2004; Esrey 1996; Esrey *et al.* 1991; Fenn *et al.* 2012; Günther & Fink 2010; Jalan & Ravallion 2003). In addition to improving human health by putting a barrier for the transmission of waterborne and other infectious diseases, improved WATSAN services can transform the lives of

[1] WHO/UNICEF JMP for WATSAN defines an improved drinking water supply refer to sources that are adequately protected from external contamination, especially from the contamination with fecal matter, but are not necessarily free from pathogens or safe for drinking. Similarly, an improved sanitation facility is one that hygienically separates human feces from human contacts.

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

many disadvantaged people in developing countries through various channels. Because investments in WATSAN infrastructures generate a wide-ranging economic benefit.

1.1 Background Information

The coverage of improved WATSAN infrastructure in Ethiopia is one of the lowest in the world. Table 1-1 presents the coverage of access to improved WATSAN services in Ethiopia between 1990 and 2015. About 57 percent of the population has access to improved drinking water sources, while these numbers drop sharply in rural areas; and 58 percent of the population lacks access to basic sanitation facilities, and nearly 30 million people—29 percent of the total population—practicing open defecation (WHO/UNICEF 2015). These figures conceal various inequalities between rural and urban areas in terms of access and service levels. The impacts of inadequate WATSAN services on the country's GDP is expected to be substantial.

Contaminated drinking water and unsafe sanitation practices contribute significantly to the high incidence of diarrheal disease in rural Ethiopia (Usman *et al.* 2016). Repeated diarrhea episodes and parasites infection also increase children's risk of slow physical and mental development, and poor school performance (Lorntz *et al.* 2006). The problem of child undernutrition and substandard child growth attainment in the country is among the highest in the world. It is estimated that 44 percent of under-five children are stunted, and 21 percent of children are severely stunted (CSA & ICF International 2012). The proportion of child malnutrition is even much higher in rural areas. For instance, the prevalence of child stunting (low height-for-age), which often used as an indicator of chronic malnutrition), is over 50 percent in rural areas. As the government had made swift measures to improve child malnutrition, the incidence of child stunting has dramatically declined from 67 percent in 1992 to 44 percent in 2012 (UNICEF 2013). Until these days, however, malnutrition and child mortality remain a great public health problem.

Table 1-1: Estimated drinking water and sanitation coverage 2015 update in percentage

Service types		Year					
		1990	1995	2000	2005	2010	2015
Water supply	Total improved	13	19	29	38	48	57
	Piped onto premises	1	2	4	6	9	12
	Other improved	12	17	25	32	39	45
	Other unimproved	39	38	35	34	32	30
	Surface water	48	43	36	28	20	13
Sanitation	Improved	3	3	9	15	22	28
	Shared	4	4	6	9	11	14
	Other unimproved	1	2	9	16	23	29
	Open defecation	92	91	76	60	44	29

Source: Author's compilation using WHO/UNICEF JMP 2015 data.

It is understood that one of the health benefits from improved water supply happens through better water quality—which reduces the ingestion of pathogens, which in turn reduces diarrhea incidence and other intestinal parasites. On the other hand, providing means of safe excreta disposal reduces the number of pathogens in the environment, which improves nutrient absorption and diseases resistance. The provision of hygiene education, in addition to the physical intervention, helps ensure that people preserve their health by washing hands with soaps properly, removing feces safely, and store water more carefully (Bosch *et al.* 2002). It is also argued that hygiene promotion and point-of-use (POU) water treatments are more effective and sustainable to reduce diarrheal diseases; however, this long-held consensus is now challenged by a recent review analysis by Waddington and Snilstveit (2009) and suggesting that "sanitation 'hardware' interventions are highly effective and sustainable in reducing diarrheal morbidity." Provision of improved WATSAN services together with proper hygiene practices, therefore, will significantly improve the country's overall health, socioeconomic conditions, and quality of life at large.

The government has made considerable efforts to improve the WATSAN situations of the country by adopting the Universal Access Program (UAP) to provide access to safe drinking water for all urban and rural population. To this end, it made major reforms by decentralizing service delivery responsibilities to the *woredas*[3] (districts) level and strengthening their capacity. The government also adopts the Community-Led Total Sanitation (CLTS) approach to eradicating open defecation practices in peri-urban and rural communities. The CLTS approach becomes highly promising in influencing communal sanitation behaviors to stop open defecation, to construct their own pit latrine, and to adopt proper hygiene practices. There are, however, significant challenges to sustain the process and to keep up its momentum. Raising the level of awareness to change people's attitudes and practices are important for the CLTS to be effective over time. For instance, if a minority in a given community continues to defecate in the open, everyone in the community is at risk of infections. The government and the international organizations are playing a key role in the CLTS in making a progress in the provision of WATSAN services in many rural communities.

Agriculture is one of the primary sources of livelihoods for the vast majority of Ethiopian rural households. Rain-fed subsistence agriculture dominates in the country but low and erratic rainfall limits productivity and food security and resulting in an incidence of drought every 4-5 years (Osman & Sauerborn 2002). Accordingly, small-scale irrigation (SSI) has been identified as a key poverty reduction strategy because it is expected to increase productivity through the use of available water resources. Irrigation is little developed and agricultural use of groundwater is low in the country. Since access to improved water supply in rural areas is inadequate, separate water sources for domestic purposes and agricultural uses do not exist in several areas. Consequently,

[3] Woreda is the third lowest administrative unit in the country.

in such rural settings, drinking water supply and sanitation has complex interactions with agriculture. Irrigated farming system is not well developed in the country, and such multiple-use of water systems create competition for water between domestic and productive uses. This is the central theme of this thesis, which makes it different from the pool of existing empirical studies.

Although there is a trade-off in the domestic use of irrigation water, availability of irrigation water may increase the amount of water for domestic uses. Where water is scarce, irrigation increases water availability for domestic uses with the potential health benefits and saving time and energy. On the other hand, using poor quality of irrigation water for domestic purposes may be harmful to health. The threshold level of water quality which is acceptable for production activities may not be acceptable for drinking or domestic uses. Moreover, the quality and quantity of ground water for domestic uses may be affected by irrigation activities by reducing the quality and availability of water within irrigated areas (Horgby & Larson 2013; van Der Hoek *et al.* 1999). Irrigated agriculture may also increase food availability and dietary diversity to enhance improved nutrition (Burney *et al.* 2013; Namara *et al.* 2005). In such a complex environment, an integrated approach may be crucial to enhance improved WASH, efficient water use, and sustainable food production. Improved health and nutrition may be ensured simultaneously by exploring available opportunities to optimize the synergies and to reduce the tradeoff between WATSAN and irrigated agriculture.

Considering the limited studies on the linkage between agriculture and WATSAN, this research aims to shed more light on the agriculture-WATSAN nexus issues. Using a primary household survey data, this study investigates the impacts of rural WATSAN services on child health outcomes and the linkage between agriculture and WATSAN under multiple-use water systems. The research findings bring a better understanding of the complex interactions between WASH and irrigated agriculture under multiple-use water systems. This would provide necessary inputs for policy makers and practitioners to design evidence-based policies/interventions regarding the sector, which allows for effective investments and sustainable provision of improved WATSAN and SSI infrastructures. It also serves as a guidance on how future investments should be channeled to maximize the benefits of improved WATSAN services and small-scale agriculture in support of improved health and nutrition outcomes.

1.2 Motivation and Problem Statement

Diseases caused by poor WATSAN services are major health problems in Ethiopia. It is understood that most of the deadly diseases caused by poor WATSAN services are largely preventable. The WATSAN problem is substantial in the country, and its WATSAN coverage is rated among the lowest in the world—even by sub-Saharan African standards (WHO/UNICEF 2012). This shows the need for improvement to avoid water-related diseases that cost many lives. It is estimated that below 8 percent of the population in Ethiopia following the safe drinking of water chain from source to mouth (Federal Ministry of Health (FMoH) 2011). In another report, the FMoH (2005) indicates that 70 percent of the diarrheal diseases and 60 percent of the country's disease burden are mainly attributed to poor WASH. This suggests that inadequate WATSAN services and poor hygiene practices cause thousands of the country's poor people to die from preventable diseases every year, which undoubtedly hampers the socioeconomic development of the country.

The FMoH estimates that the top 10 causes of mortality account for 74 percent of all deaths in the country. Many Ethiopians face high morbidity and mortality with a growing prevalence of communicable diseases mainly attributed to potentially preventable infectious diseases and nutritional deficiencies. Although largely preventable, childhood and maternal illnesses and communicable diseases are major causes of death in the country. Since access to improved drinking water—both in terms of quality and quantity—is inadequate in rural areas, women and children have to travel many hours to collect water far from home, and that may not even provide safe water. Traveling long distance for water collection mean little is available for proper hygiene because availability is limited. Such conditions and poor access to improved drinking water sources make them more susceptible to the spread of infectious diseases.

Poor WATSAN services can affect the growth and development of young children. Acute and chronic diarrhea has a significant impact on child growth outcomes. Repeated diarrhea episodes sap the nutritional status of children and reduce the availability of nutrients by decreasing the body's capacity to absorb nutrients which led to stunting (reduced child growth rate), impaired physical growth, and cognitive development (UNICEF 2013; Humphrey 2009). Moreover, malnourished children have lower resistance to diseases, and they are more likely to suffer from subsequent diarrhea and other infections (UNICEF 2013). For instance, severely undernourished child is almost 10 times higher than average to die from diarrhea (Black *et al.* 2008). This vicious cycle has a strong negative influence on child growth and development.

To address the problem of access to improved WATSAN services in the country, the sector got an eye from the government of Ethiopia (GoE) and international development partners. They have been working to increase access to WATSAN services at household, community and in many public areas, and to bring about basic hygiene behavioral changes; including hand washing with soap at critical times, and safe water handling and treatment. Despite all this progress, many Ethiopians still lack clean drinking water and basic sanitation facilities. The widespread open defecation practices and frequent outbreaks of diseases due to inadequate WASH services remain to be major challenges of the country. To substantially reduce the spread of communicable diseases in the country, still much work needs to be done in the WASH sector.

The provision of improved WATSAN services and proper hygiene practices are of crucial importance in the prevention of waterborne diseases, including diarrhea (Usman *et al.* 2016). It is estimated that improved water supply can result in an average reduction in cases of diarrheal morbidity over 24 percent; improved sanitation facility reduces by 33 percent; and proper hygiene practices, such as handwashing with soap at critical times, have been found to reduce diarrheal incidence by more than 40 percent (WHO/UNICEF 2009). Investments in WATSAN infrastructures generally result in higher economic returns, which contribute to overall economic growth—particularly in developing countries. Depending on the region, US$1 invested in WATSAN would give an economic return of between US$3 and US$34 (Hutton & Haller 2004). It is also argued that "people without access to water supply and sanitation are […] caught in a vicious cycle in which lack of access leads to poverty which in turn prevents people from having the ability to gain access to services. Lack of access to water and sanitation is thus both a cause and an effect of inequality, poverty, and underdevelopment" (Brocklehurst 2011, p.6).

On the other hand, in rural Ethiopia, SSI has a complex interaction with rural drinking water supply, which is far below the desired services levels (Butterworth *et al.* 2013; Scheelbeek 2005). Irrigated agriculture and WASH services are interconnected, and they can have different implication on health and nutrition outcomes. The following Figure 1-1 shows the conceptual linkage between agriculture, nutrition, and health. This conceptual framework is discussed in detail in section 5.2. Irrigation can impact health and nutrition outcomes through several pathways. It can influence health negatively through increased malaria incidence. For instance, certain agricultural development practices aimed at increasing productivity to ensure food security, such as water harvesting techniques, irrigation canals, ponds, tanks and/or dams, can actually exacerbate the incidence of diseases and create suitable conditions for the propagations of waterborne diseases-vectors such as mosquitoes transmitting malaria (Amacher *et al.* 2004; Asayehegn 2012; Asenso-Okyere *et al.* 2012; Ersado 2005; Hawkes & Ruel 2006; Keiser *et al.* 2005; Kibret *et al.* 2010; Kibret *et al.* 2009). Irrigated agriculture also influences health through other channels. Irrigation often increases household's income which allows them to access improved health care service. In addition, domestic water quality and quantity might be affected by irrigation practice. Irrigation water is often used for non-agricultural purposes, including domestic uses such as for food preparation, gardening, laundering and personal hygiene. Irrigation water can also be the sources of drinking water in developing countries where improved drinking water supply is inadequate (van Der Hoek *et al.* 2001; van Der Hoek *et al.* 1999). Although, in most cases, the level of water quality for irrigation may not be acceptable for domestic consumption, van der Hoek *et al.* (2002) argue that water quantity is more important than water quality as it reduces the prevalence of hygiene related diseases.

Although there is a growing understanding in the literature that agriculture, nutrition, and health—especially through WATSAN—are strongly linked, determining those linkages in their dynamic, trade-offs and interactions between them remain to be a challenge for policy-makers and development practitioners and has to be examined properly. Any development projects in developing countries that attempt to address agricultural and nutritional issues are less likely to meet their targets unless the role of WATSAN services in improving health and nutritional outcomes have been recognized and properly addressed.

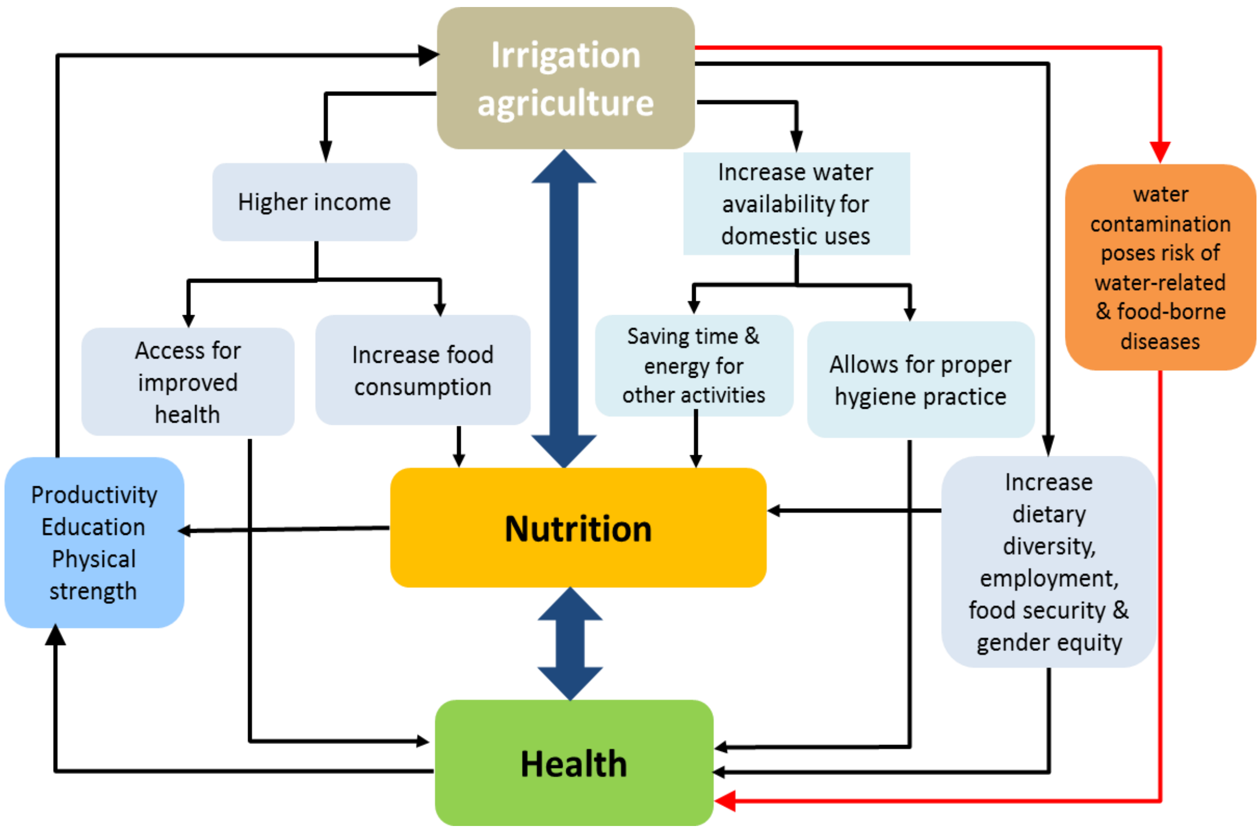

Figure 1-1: The linkage between agriculture and nutrition and health

Source: Author's own illustration.

1.3 Objectives

Given the discussion in the previous sections, this thesis addresses the research question, "how water, sanitation, and agriculture are linked, and what are their implication for health and nutritional outcomes in rural Ethiopia?" More specifically, this study has the following four specific research objectives:

(i) To examine the key drivers of household drinking water quality in rural areas.

This objective examines the primary factors that influence household storage water quality. Here, we tried to investigate the influence of socio-demographic, types of water sources, water collection vessels, sanitary and community characteristics on stored household drinking water quality. The outcome variable is the count of *E.coli* colony-coliform units per 100ml (CFU/100ml) water, and a binary variable based on contaminated and uncontaminated storage water quality.

(ii) To assess the impacts of drinking water quality and sanitation practice on childhood diarrhea in the study areas.

This objective investigates the impacts of quality of stored drinking water and household sanitation and hygiene behavior on diarrhea prevalence among under-five children in the study districts. We used instrumental variable approach to address this research question. In addition, it examines the longitudinal diarrhea prevalence on under-five children using longitudinal data. We followed under-five children of the same households biweekly visiting them for a period of 12 weeks to record the prevalence of diarrheal and other infectious diseases.

(iii) To study the linkages between rural water supply, sanitation, and agriculture, and their impacts on health outcomes.

This is the principal theme of this thesis and focuses on the linkage between irrigated agriculture and WASH, as well as their impacts on household's health outcomes and storage water quality. Health was measured as the prevalence of diarrhea (diarrhea and cholera diseases symptoms), water-related diseases (skin-itching, typhoid fever, giardiasis, and trachoma), and overall morbidity status (excluding injuries, chronic and other unknown diseases symptoms) in the preceding two months before the survey. In this section, we primarily focus on non-preschool household members. The analysis is based on both individual and household level information. In the empirical analysis, we focused on diarrheal diseases, but interested readers can find the estimation results for the other health outcome measures in Appendix A.

(iv) To investigate the association between households water quality and sanitation practices and children's growth outcomes.

The nutrition outcome analysis focuses on underweight and stunting for under-five children. We use anthropometric measures of weight and height to calculate weight-for-age, height-for-age, and weight-for-height -z-scores to determine whether a child is underweight, stunted and/or wasted, respectively, using the new WHO 2006 reference group.

1.4 Significance of the Study

The findings of the research, in addition to filling the research gap in the empirical literature, it would provide key inputs for policy makers and development practitioners to design evidence-based WATSAN interventions and to make informed decisions. Such interventions would likely be effective and sustainable to ensure quality provision of WATSAN services through the full engagement of all relevant actors. Building the capacities of rural communities to maintain and manage their WATSAN environment by themselves can be instrumental in improving their well-being and lives at large. It also helps to identify investment priorities at the interface of agriculture-WATSAN nexus for better health and nutrition outcomes for key players of the sector such as the regional government, local and international developmental partners. Unlike many existing empirical studies in this area, this study is a first-attempt to holistically investigating the linkage among agriculture, WATSAN, and health using econometric methods. Mostly, existing empirical works focus on the relationship either between WATSAN and health or irrigation and health while isolating the complex interaction between agriculture and WATSAN in rural settings. Furthermore, due to its interdisciplinary nature, this research is in the frontiers of the ZEF research themes, and it could provide some insights for future research on many development aspects such as water resources management, reducing extreme poverty and hunger, promoting gender equality and empowerment, improving maternal health, and reducing child morbidity and mortality through combating waterborne diseases.

1.5 Organization of the Thesis

This thesis has seven chapters. Chapter 1 provides a general background information, and it briefly discusses the problems, research objectives and its contribution to the wider empirical literature. Following the preceding introductory discussions, chapter 2 provides a detail description of the study areas, data collection process, the design of the household survey, and the water and anthropometric measurements during the field work. Chapter 3 presents an empirical study on the key drivers of household storage water quality. It examines the primary factors affecting the microbial quality (*Escherichia coli* bacteria (CFU/100ml water sample)) of stored household drinking water. It employs simple ordinary least squares (OLS) and logistic model estimation. Chapter 4 investigates the impacts of storage water quality and household sanitation practices on diarrhea among under-five children. The prevalence of diarrhea is a self-reported prevalence by the primary caretaker of the child in the preceding two weeks before the survey. Methodologically, an instrumental variable (two-stage least square) estimator and recursive bivariate probit methods have been used. In this chapter, we briefly examine the longitudinal prevalence of diarrhea using a longitudinal data collected from the same households during the follow-up survey for a period of 12 weeks. We also examine a cost-benefit analysis for an improved water supply in the study areas.

Chapter 5 addresses the research question on the linkage between domestic water supply and irrigation and their implications on health outcomes and domestic water quality/quantity. This chapter exclusively focuses on non-preschool household members. Although diarrhea is a measure of our primary interest outcome variable, other health outcome indicators, such as other water-related and general morbidity status, have also been investigated, particularly in the descriptive analysis section. Also, the unit of analysis focuses on both household and individual level for a more robust relationship. Chapter 6 studies the determinants of child growth outcome. Based on the anthropometric measures of weight and height, it primarily focuses on underweight and stunting. Finally, chapter 7 presents the major findings of the study, with potential policy implications and suggestions for further research directions.

2. Data Collection and Survey Descriptions

2.1 Description of the Study Areas

The overarching objective of this study is to investigate the complex interactions and linkage between irrigated agriculture and WASH to provide a set of evidence-based recommendations. In doing so, it identifies investment priorities and policies to improve the WATSAN environment of rural communities, which in turn improves health and nutrition outcomes. It is conducted as part of a broader thematic area of "guiding pro-poor investments in the nexus among 'domestic water quality and quantity', 'sanitation and hygiene' and agriculture from the bottom-up (AG-WATSAN Nexus)." The project has been undertaking in Ethiopia, Ghana, India, and Bangladesh where access to WASH is seriously lacking. Considering the central theme of the project, the study sites were identified based on *ex-ante* information on access to improved WATSAN, the prevalence of waterborne and water-washed diseases, and the practice of irrigated agriculture by taking into account the multiple-use of water resources. In addition, different stakeholders in government and non-government organization (NGOs), which are closely working in the WASH sector, were consulted during the hotspot mapping process.

To identify suitable areas for this study, the above *ex-ante* information was factored in the hotspot mapping process. Following that line, five districts in the Amhara and Oromia regions were identified and two of them were visited. Discussion with experts from government and NGOs working in the sector were made to learn more on the suitability of identified districts. Succeeding survey field assessment, Fogera and Mecha districts were identified because existing coverage of improved WATSAN infrastructure is among the lowest, the prevalence of waterborne and water-washed diseases are also primary health problems of the inhabitants, and SSI adoption is common. Figure 2-1 depicts the map of the study areas. The shaded area with light-green represents the Amhara National Regional State (ANRS) map, and the two selected districts (shaded in blue) are shown in the right panel of the figure.

For the reasons discussed earlier, the study was carried out in Fogera and Mecha districts, and these areas are more appropriate in terms of providing the platform to investigate the linkages and interactions between irrigation and domestic water supply and to identify possible channels through which AG−WATSAN nexus works and results in better health and nutritional status. To reduce the burden of conducting complex household and community level surveys, logistic and institutional factors were also taken into account in the selection of these districts.

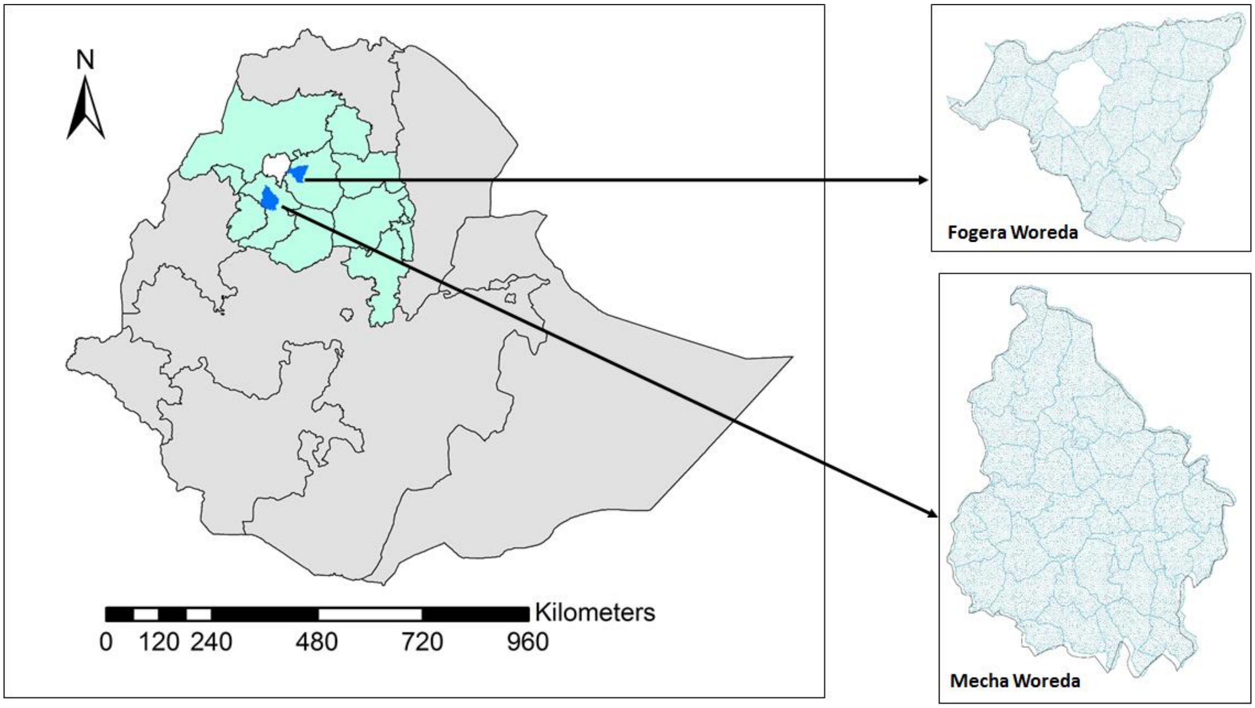

Figure 2-1: Map of the study areas

Source: Author's own illustration.

Fogera woreda

Fogera district is one of the 106 *woredas* of the ANRS and found in South Gondar Zone. It is situated at 110^{o} 58^{o} N latitude and 37^{o} 41^{o} E longitude. Woreta is the administrative town of the district and is situated 625 km north of Addis Ababa and 55 km from Bahir Dar—the capital city of the ANRS. The district is divided into 29 rural and 5 urban Kebeles.[4]

In terms of geography, the district consists of plain or flat lands (which accounts for 76%), hills/mountains (11%) and 13 percent valley bottoms classified locally as highland, midland, and lowland topography levels. Its altitude ranges from 1,774 up to 2,410 meters above sea level, which allows a favorable opportunity for a range of crop production and livestock rearing (ILRI 2005). The mean annual rainfall is 1216.3 mm, with Belg (short rainy season) and Meher (long rainy season) cropping seasons.

The total land area of the district is 117,414 ha, of which about 43 percent is cultivated for the production of various annual crops. Most of the farm land was allocated for annual crops where cereals covered 51,472 ha; pulses cover 9,819.98 ha; oil seeds 6,137 ha; root crops 1,034.29 ha; and vegetables 882.08 ha (CSA 2003). In order of area coverage, the major crops include *teff*,

[4] Kebele is the lowest administrative unit in Ethiopia.

maize, finger millet and rice. As stated by the ILRI (2005) report, average land holding size was about 1.4 ha with minimum and maximum of 0.5 and 3.0 ha, respectively.

In addition to rain-fed subsistence agriculture, most farmers practice irrigation farming using various water sources. Farmers use rivers, such as the Gumara and the Ribb, which drain into Lake Tana, as a primary source of water for irrigation activities. River diversion is the predominant system of irrigation methods, but some farmers also use motor pump technology for irrigation. Most farmers practice traditional irrigation systems mainly to produce onions and tomatoes.

Mecha woreda

Mecha is the other district where the study is conducted, and it belongs to the west Gojjam Zone in ANRS. Merawi is the administrative town of the district and is located about 525 km North of Addis Ababa and 34 km southeast of Bahir Dar. Its climatic condition alternates between a long summer rainfall (June—September) and winter dry season (December—March) with mean annual rainfall of 1200-2000 mm. The mean temperature varies between 24—27^{o}C, and its altitude range from 1800 to 2500 meter above sea level. The study area is located at latitude 10^{o} 30^{o} N and longitude 37^{o}29^{o} E.

Agriculture is the key economic activities in the study area, employing nearly 100 percent of labor forces. Mixed farming is the dominant agricultural practice. Smallholders mainly produce both staples crops—typically wheat, barley and *teff*, and cash crops—such as pepper and potatoes. The Koga irrigation watershed is the principal source for irrigation activities in the area. The Koga irrigation project benefits more than 14,000 households and helps boost agricultural production in the area around Merawi, south of Lake Tana in the ANRS. 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).

WASH and prevalence of WASH-related diseases in the study areas

The provision of improved WATSAN 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 percent (Stel & Abate 2014); while another report estimated even a much lower figure (42%). Furthermore, some community water sources failed to operate regularly due to poor maintenance. On the other hand, only 35 percent of the rural population of Mecha district have access to improved water sources (Beyene 2012). Furthermore, most water sources do not provide sufficient water and become shrink during the summer. Consequently, most rural households depend on unimproved sources, such as unprotected wells/springs, rivers, which are easily polluted by human and animal wastes. The coverage of simple pit latrine in the study areas is low. In some cases, households with a 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 rural communities to improve access to improved WATSAN services.

Increasing access to improved WATSAN services is key development goals for the Ethiopian government. Until these days, however, more than half of the rural households do not have access to improved water sources. Moreover, basic sanitation and disposal facilities that separate waste from human contacts are extremely low, which can seriously affect the health status of the communities. Accurate data on the actual coverage of sanitation and key hygiene indicators are not available at the district level. On the word of the 2013 Mecha health center report, pneumonia, diarrhea (non-bloody), malaria PF, acute febrile illness (AFI), acute upper respiratory infection, malaria PV, and skin infections are reported to be the primary health problems for under-five children. Since the coverage of WATSAN and key hygiene practices are lacking, the incidence of waterborne and water-related diseases are serious public health problems.

2.2 Data Collection and Organization of the Survey

The AG-WATSAN nexus project had been undertaken in collaboration with the Ethiopian Economics Association (EEA) through its research wing called 'Ethiopian Economic Policy Research Institute' (EEPRI), Addis Ababa, Ethiopia. The household survey was carried out under the support of the EEA and was implemented by the Center for Development Research (ZEF), University of Bonn, Germany. The resources and materials for conducting the survey were provided by the regional office of Central Statistical Agency (CSA) of Ethiopia, Bahir Dar branch, Organization for Rehabilitation and Development in Amhara (ORDA), German Agro Action (Welthungerhilfe), and health center of the selected districts.

a) Training, pretest, and fieldwork

Following recruitment of field interviewers and supervisors for the field work in Bahir Dar, interviewers and supervisors trained during the first week of February 2014. Since the quality of data obtained from a survey highly depends on data collectors and supervisors, the necessary training was given to the teams to equip them with skills and techniques required for the survey. The training includes instruction on interviewing techniques and survey procedures, detailed review of the questionnaires contents, instructions and practices in measuring height and weight of children, global positioning system (GPS) reading, and mock interviews among themselves. The Amharic language questionnaires were primarily used during the training, while the English versions were simultaneously checked against the Amharic questionnaires to ensure an accurate translation.

Before the baseline survey, the questionnaires were pretested in Fogera district, Kuahar Michael kebele, to make sure that the questionnaires were clear and can be understood by potential respondents. Anthropometric measurements and water sample quality testing were also conducted during the pretest field work. Finally, the questionnaires were revised based on lessons drawn from the pretest exercises.

Water sample quality-testing and child anthropometric measurements were performed simultaneously during the baseline survey. The microbiological quality of stored household drinking water and primary community water sources were tested for fecal contamination. *Escherichia coli* (*E.coli*) bacteria (CFU/100ml water) is used as an indicator as a proxy for fecal contamination, which is considered to be a major cause of diarrhea. The survey also employed a GPS reading to identify each selected households.

b) Fieldwork and data processing

The survey was carried out by two interviewing teams. Each team consisted of a supervisor (a supervisor is assigned to closely manage and follow-up the work of five enumerators), a water sample collector and health professionals (health extension workers). On top of that, a water sample analyst also participated in the field work. To improve the quality of collected data, most of the questionnaires were checked by both the field supervisors and other external editors. A baseline survey was administered between February and March 2014. After the completion of the baseline survey, all questionnaires were returned to Addis Ababa for data processing, which consisted of office editing, coding of open-ended questions and data entry. The data were processed by a team of four data coders and editors, two data entry operators as well as a data entry supervisor. The data entry and editing processing were started in March and completed in July 2014.

2.3 Survey Design, Sampling Frame and Sample Size

Fogera and Mecha districts were purposely identified from the ANRS based on access to improved drinking water and sanitation coverage, the prevalence of waterborne and water-related diseases and availability of small-scale irrigation practices. The next step in the sampling process was to select sample households from these districts.[5] 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*. To select the sample agricultural households, a total of 20 kebeles were identified based on multiple-use water systems and accessibility: 11 kebeles (8 irrigating and 3 non-irrigating) from Fogera and 9 kebeles (6 irrigating and 3 non-irrigating) from Mecha district.

The sampled households were selected using a stratified two-stage cluster sample design, whereby villages were taken to be the primary sampling units (PSUs), and agricultural households were considered to be the secondary sampling units (SSUs). The first-stage sample selection of villages/clusters was random but proportional to size (PPS). Subsequently, the second-stage sampling units, agricultural households, were selected within each village based on the systematic random sampling (SRS) method. The lowest geographical administrative division of

[5] 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.

the region (i.e., *kebele*) is used to form the first level of stratification. In the first stage of the sample selection process, 61 clusters/villages were randomly selected from 20 administrative kebeles. This was followed by a systematic random sample selection of 454 households from a complete listing of agricultural households. This implies that within each stratum the villages are used as PSUs and agricultural households as SSUs. The household head lists were provided by the Woreda's Agriculture and Extension Bureau. Among the selected households, 302 households engaged in irrigated agriculture and the remaining 152 households do not.

One of the main selection criteria for a household was having at least one child under-five years. As such data were not available beforehand—during the first stage selection process, households without under-five child were replaced by the nearest neighbor households during the fieldwork. The overall sample size was 454 households with 565 children under-five years old. The sample size was determined by taking into account both the required level of precision for the most important indicators and the amount of time and resources available to the survey.

2.3.1 Questionnaires and ethical consideration

Survey questionnaires

The AG-WATSAN household survey collected a range of information using structured module questionnaires:[6] household, WATSAN, primary caregiver, child and community questionnaires. Most of these questionnaires were adapted from various standardized national survey instruments. In addition to the English language, the questionnaires were translated into Amharic—the major language of the study area.

The Household questionnaire was used to list all the members of the selected households and basic characteristics of each listed person, such as age, sex, education, relationship to the household head and other household level information. The household questionnaire also collected information about total agricultural productions and sales, livestock ownership, holdings of various consumer and durable goods and other income sources, food and non-food expenditures, labor and time use, and household members' health status in the last two months preceding the survey. The WATSAN module was used to collect information on characteristics of housing, water supply sources, continuity of water supply and seasonal change, water storage, handling and treatment, community management, toilet facility, waste management, and irrigated agriculture practices. The Primary caregiver questionnaire was used to collect information about hygiene behavior and knowledge, community participation, handwashing demonstration, and food preparation, storage and handling. Furthermore, the Child questionnaire was used to collect information about child feeding practices such as exclusive breastfeeding during the first six months of life, current breastfeeding and complementary foods,

[6] The various questionnaire modules are available at: https://data.zef.de/?uuid=4ac3e43a-557e-4ddc-8f58-d2b51404c581

prevalence of illness in the previous two weeks period (such as diarrhea, malaria, fever, pneumonia, and cough), immunization records and anthropometric measurements. In most cases, the respondents were the primary caretakers concerning household consumption, WATSAN and child health. Moreover, GPS readings were used to identify the relative position of sampled housing units.

Ethical consideration

The study protocol was approved by the Medical Ethic Commission of the Federal Republic of Germany (*Arbeitskreis Medizinischer Ethikkommissionen in der Bundesrepublik Deutschland*). Community leaders and household's head provided informed consents. During the field work, a two-page consent form was read out to a household head with an introduction and purpose of the research, types of research intervention, voluntary participation, participation benefits, confidentiality, and right to refuse or withdraw from the study at any stage. Two copies of the consent forms were prepared, and one copy was given to the participant household (a copy is attached in Appendix B).

2.3.2 Anthropometric measures and water sample testing

a) Height and weight measurements

The AG-WATSAN survey data included height and weight measurements. During the fieldwork, interviewing teams obtained measurements of height and weight of all under-five children listed in the household roster. The primary caretaker's willingness consented to the measurements. The interviewing team was into two teams, and each team carried a balance scale and measuring board. The scales were electronic scales with a digital screen. Height measurements were carried out using measuring boards made of wood. The scales and measuring boards were obtained from the regional office of Ethiopian CSA, Bahir Dar branch office. These resources are mainly designed for use for household survey settings. For instance, they were used by Ethiopian Demographic and Health Survey (EDHS). The measurements were carried out by the local health extension workers (HEWs). Following the DHS standards, children younger than 24 months were measured lying down on the board (recumbent length) and older children were measured while standing. The weight of young children was obtained by subtracting his/her mother's weight from the combined weight of mother and child. Weight is measured to the nearest 100 grams while height is measured to the nearest 0.1 cm.

b) Drinking water sample quality-testing

In addition to collecting information on how households handle and store their drinking water, the quality of the water they drink was tested in each selected household. Drinking water samples were collected for testing the microbiological level of the water to determine the degree of its health risks. We used a Potatest Incubator Kit to test water samples in the field. The Potatest detects the presence of *E.coli* bacteria which indicates the level of fecal contamination of the water. Microbiological water quality tests were also performed for a total of 61 water samples, which were taken directly from community water sources in each selected villages.

The test kit was provided by the German Agro Action (*Welthungerhilfe*)—an NGO working in the WASH sector in rural and peri-urban areas of the country. 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. Then the water samples were kept in coded bottles, which were properly sterilized using autoclaves from the local health centers. The collected water samples immediately placed into the portable test kit on-site and incubated for a maximum of 24 hours at the temperature of 44 degree Celsius. The bacteria colonies grew on the Membrane Lauryl Sulfate Broth (MLSB) medium, which is specifically formulated to facilitate the growth of *E.coli* bacteria and prevent the growth of other micro-organisms. Since bacteria are extremely small, they should be grown on nutrient plates so that they can multiply rapidly and, depending on the test kit, become visible within 24 hours. Upon completion of the incubation period, we enumerated the number of *E.coli* concentration, which is reported as colony-forming units per 100ml (CFU/100ml) water sample (see section 3.3 for further description of the water sample quality-testing procedure).

2.3.3 Follow-up survey

The follow-up surveys were administered between April and July 2014 after completing the baseline survey by the end of March 2014. The aim of the survey was to collect information on under-five children health status—such as diarrhea, fever, vomiting, constant cough, stomach pain/cramps and skin infections in the preceding two weeks. This data collection process requires multiple successive visits to the households, and each household has been visited every fortnightly for a period of three months to record the health status of the children. For this purpose, one-page child health calendar questionnaire was developed to record information about symptoms of a particular illness; how long the symptoms stay; and what treatment they seek for if any. The data collection was done by health and agriculture extension workers who work in the selected kebeles. Training was given to the enumerators during the field organization for the follow-up household survey. In most cases, the data collectors ask the child's primary caretaker—usually the mother or another adult woman household member.

3. Drivers of Microbial Quality of Household Drinking Water in Rural Households

3.1 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 live in the developing countries, are without access to improved and adequate water (WHO/UNICEF 2014). More than 1.5 million under-five children 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 is crucial in the fighting against diarrheal diseases for young children in developing countries.

Figure 3-1 presents the coverage of access to improved water supply in Ethiopia. About 57 percent of households have access to an improved drinking water source, with a higher proportion of urban residents (93%) than among rural residents (49%). The disparity between urban and rural households is big in terms of access and types of services. Moreover, as access to improved sanitation facilities are inadequate in rural areas, the 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 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 overestimation 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 maintenance and repairs (MoWE 2007). This would further reduce the actual number of households reported to have access to improved water sources.

Ethiopia is considered as 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. Often shallow and unprotected community water source points are subject to gross contamination when rainwater washes wastes from surrounding areas into the sources. The situation is much worse where drinking water sources are shared with livestock. 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. Such conditions are believed to contribute to high rates of morbidity and mortality particularly in rural areas of the country (Begashaw 2003).

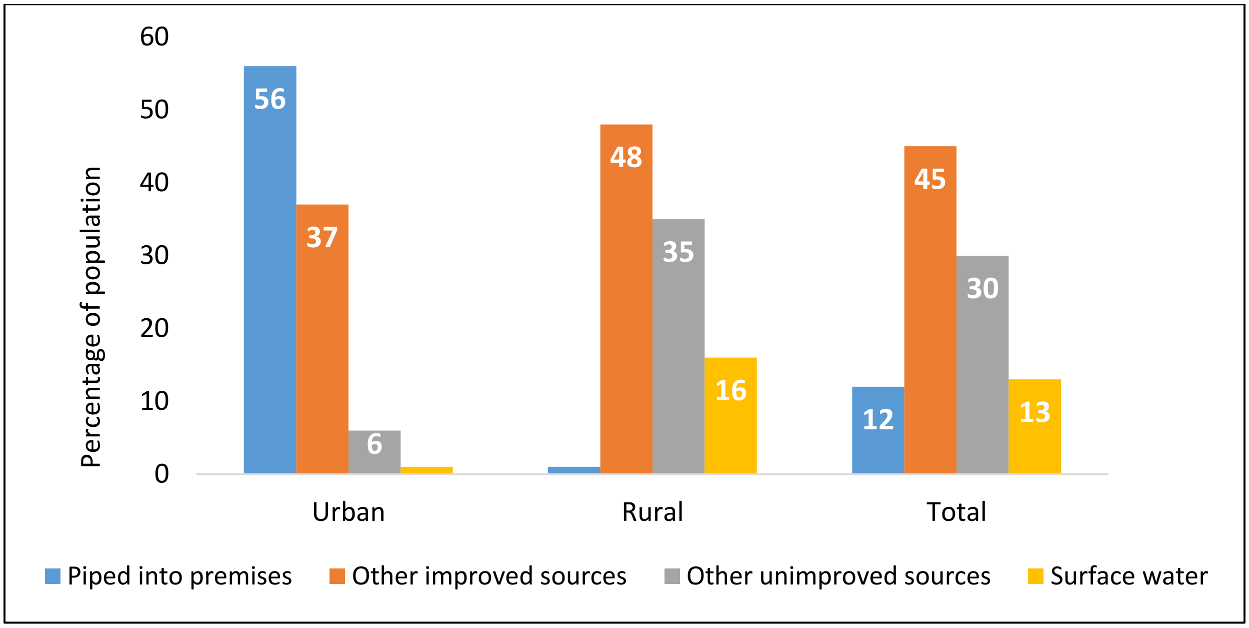

Figure 3-1: Percentage of population by type of drinking water source in Ethiopia, 2015

Source: Author's compilation using the WHO/UNICEF JMP dataset.

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 *E.coli* bacteria—one of the most common indicators 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. As per the WHO drinking water quality guideline, *E.coli* bacteria as a microbial water quality indicator should be zero per 100ml 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 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 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). Given the complexity of water quality problem at the POU, 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 chapter aims to identify the factors that influence the quality of drinking water stored in the households[7] in two rural districts of 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 improved WATSAN infrastructures are limited. This chapter 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 understudied (Scheelbeek 2005; Sutton *et al.* 2011). Irrigated agriculture has a complex interaction with domestic water in rural areas as irrigation water often uses for a range of activities such as drinking, cooking, and bathing among others. This type of work is, therefore, crucial to enhance the understanding of the determinants of the microbial quality of storage water in rural households of Ethiopia and might thus help policy makers to design the right intervention to improve access to safe drinking water in rural areas.

3.2 Context and Related Literature

Ethiopia has made remarkable progress to improve the WATSAN situations 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 an ambitious target to be realized. Ethiopia's UAP defines the minimum standards for rural population as at least 15 liters of water for every one 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 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 been constructed in many rural areas (MoWE 2006). As most of these water supply points fail to function just after their installation, sustainability

[7] Hereafter storage water.

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 percent of hand-pumps and one-third of mechanized boreholes were not functioning mainly because of maintenance and repair 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. Moreover, studies in Ethiopia indicate a strong relationship between rural water supply functionality and governance (Welle & Williams 2014). To make the matter worse, most existing community water sources are often contaminated with fecal materials and pose a high public health risk (Amenu *et al.* 2014; Atnafu 2006; Jano 2007; Tsega *et al.* 2014).

The WHO/UNICEF JMP for WATSAN 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 3-1 shows the current WHO/UNICEF JMP classification of improved or unimproved WATSAN technologies. This definition of access to 'improved' water source, however, does not consider the safety or quality of the water; subsequently, 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 3-1: JMP Classification of drinking water source types and sanitation facilities

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

[a] Normally considered being "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 WHO/UNICEF report presented in Table 3-2 provides some evidence on the status of microbial water quality in Ethiopia at the national level. The result 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/100ml water. However, 7 percent had counts of 1−10 CFU/100ml water, and another 14 percent had counts of 11−100 CFU/100ml water. Overall, 7 percent of all samples had counts >100 CFU/100ml water. The proportion of 11−100 CFU/100ml and >100 CFU/100ml 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. Utility piped supplies are also often chlorinated which protects the water from microbial contamination (WHO/UNICEF 2010a).

Table 3-2: Compliance of drinking water sources in Ethiopia for thermotolerant coliforms [a]

Count category (CFU/100ml)	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: Adapted from WHO/UNICEF (2010a, p.21).

Few studies in Ethiopia 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 region. 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 about 55 percent 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.

The issue of seasonality and water quality was addressed in other studies. For instance, Sandiford *et al.* (1989) examined 150 water samples from rural Nicaragua for the fecal coliforms contamination during the dry and wet season. Seasonality seemed to be less evident as water quality was more likely associated with the type of water sources. The study reports that piped water connections were free of fecal contamination. Interestingly, the fecal coliforms counts in unprotected riverside wells and springs were lower as compared to protected dug wells during the dry season. Despite that protected wells in most countries were less contaminated from fecal coliforms, the authors argued that the possible explanation for this finding might be related to the structures of the unprotected wells. While the unprotected wells were shallower and served several families leading to a rapid turnover which would remove the contaminants (decontaminates itself) frequently, the protected wells were emptied only once or twice a year (Sandiford *et al*. 1989).

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) studied 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 a 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 standard for total and fecal coliforms. Of the total sample, 25 percent of water sources were contaminated with *E.coli* while more than 85 percent 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; McGarvey *et al.* 2008; Rufener *et al.* 2010; Baker *et al.* 2013). Among the earlier studies on water quality, Clasen and Bastable (2003) report that 92.2 percent 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 although most 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. A study that aims to examine the relationship between water handling practice and microbial water quality in Addis Ababa, Ethiopia, finds that 34 percent 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 matters (37%, n=54) than water samples from sources (33%, n=72). The study has also shown that 'dip' methods of water storage, such as bucket and clay vessel, 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 percent of water samples from storage were contaminated with fecal matters although there were no detectable fecal coliforms per 100ml 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. Furthermore, Wright *et al.* (2004) arrived at the same conclusion after systematically reviewing studies on microbial contamination of water between source and POU. In summary, existing empirical studies 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 (POS).

3.3 Methods and Data

3.3.1 Data

a) 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 behavior were recorded. Drinking water samples were collected to analyze the microbial 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.[8] Storage water samples were kept in coded glass bottles which were properly sterilized using autoclaves in the local health centers at a temperature of 121 degree Celsius for 30 minutes.[9] Water sample tests from household's storage were conducted between February and March 2014—which is between the end of winter and the beginning of spring seasons in Ethiopia and considered as a dry period.

b) Community water sources samples

In addition to storage water samples, 61 water source points 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

[8] As stated in 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 100ml 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/100ml water), contamination is indicated and appropriate action is urgently required.

[9] 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.

resource constraints were the major factors that hindered the uptake of water samples from all community sources.

c) Microbial quality of drinking water samples

There are various 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 (CFU/100ml) 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).[10]

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 and 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 other diseases causing organisms 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.[11]

Water samples were collected from household storage for all selected households and the collected water samples immediately were placed into the portable test kit on-site for incubation.[12] The bacteria colonies allowed to culture on MLSB media which are specifically formulated to facilitate the growth of *E.coli* bacteria and prevent the growth of other micro-organisms. As bacteria are extremely 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 100ml (CFU/100ml) of water sample.

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. When all the 100ml 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

[10] 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.

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

[12] It is 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.

and placed the petri-dish into the petri-dish rack. Finally, we placed the filled rack into the incubator and incubate the samples for a maximum of 24 hours at a temperature of 44 degree Celsius. Upon completion of the incubation period, we enumerated the number of *E.coli* CFU/100ml water. In a membrane filtration method, accurate enumeration of bacteria colony is difficult when the fecal coliform bacteria counts are greater than 200 CFU/100ml water.[13]

d) Descriptive analysis

The descriptive statistics about the respondent's background characteristics and socio-demographic variables are presented in Table 3-3. Out of the 454 surveyed households, 277 households belong to Fogera and 177 households belong to Mecha district. The survey finds that average household size is about six persons per household which is higher than the reported mean household size of 5 in rural areas by Central Statistical Agency of Ethiopia (CSA & ICF International 2012). The survey finds that literacy level (for reading and writing in the local language) is 9 percent for primary caretakers and 44 percent for household heads. Only a few have completed primary school indicating that most respondents in this study are illiterate.

Based on the JMP classification; the survey shows that 50 percent of the households get their drinking water from improved water sources, such as protected wells/springs, about 37 percent obtain water from unprotected wells/springs and the remaining 13 percent of the households depend on surface water sources (Table 3-3). 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 percent of rural Ethiopian households have access to improved sanitation facility, but our result shows that access to this service is virtually non-existent in the study areas which is quite surprising. Although 42 percent of the households reported that they have a simple pit latrine, they may not use it frequently. Many of these latrines were constructed in response to a push by the local governments. It is a common practice 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 percent 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 percent of households in the study areas practice open defecation, which is much higher than the rural national average open defecation rate of 43 percent (WHO/UNICEF 2014). The study also finds that only 5 percent of the households have access to protected drinking water source in their own yard/premises, and more than 84 percent of households on average spend about 25 minutes for a round water collection trip. Moreover, about 34 percent 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

[13] For accurate enumeration of bacteria, the number of fecal coliform colonies on the membrane following incubation should be in the range of 20−200, and more than 200 colonies are difficult to count precisely.

30 minutes for a round trip for water collection are lower than what is indicated by the CSA and ICF International (2012) report (34% compared to 62%).

Table 3-3: Descriptive statistics – household and community characteristics (N=454)

Variables	Description	Mean	SD
Demographic characteristics			
Household head age	Age in years	37.72	8.64
Household head literacy	1=read and write; 0= otherwise	0.44	0.49
Primary caretaker age	Age in years	30.33	6.64
Primary caretaker literacy	1=read and write; 0= otherwise	0.09	0.29
Highest education	The highest grade completed in a household	3.50	3.05
Number of adult females	Female household members aged >14 years	1.22	0.49
Household size	Number of household members	5.98	1.77
Household density	Number of people living per room	3.30	1.27
Housing and household possession			
Roofing materials			
Corrugated iron sheet		0.91	0.28
Thatch		0.09	0.28
Assets value	Total asset value excluding livestock in 1000 Birr[b]	5.88	6.05
Water, sanitation and hygiene			
Primary drinking water sources			
Private-protected dug wells		0.05	0.22
Shared-protected dug wells/spring		0.44	0.50
Unprotected dug wells/spring		0.39	0.49
Surface water		0.12	0.32
Minutes to water sources [a]	Time needed for a round trip water collection	24.18	14.19
Stored drinking water quality	1=Contaminated with 1 or more *E.coli*	0.58	0.49
Household water treatment	Treating household drinking water (1=yes)	0.08	0.27
Water collection container	1=Jerrycan; 0=Clay vessel	0.83	0.37
Handwashing with soap	Handwashing with soap by primary caretaker during handwashing demonstration (1=yes)	0.27	0.45
Pit latrine	Households with a pit latrine (1=yes)	0.42	0.49
Garbage disposal			
Burning/Buried		0.11	0.31
Throw-away in the yard		0.54	0.50
Throw-away outside the yard		0.13	0.34
Used as a fertilizer		0.22	0.42
Agriculture			
Irrigation	Practicing irrigation farming (1=yes)	0.66	0.47
Livestock holding	Total livestock holding in Tropical Livestock Units	3.97	1.87
Community characteristics			
Water user association (WUA)	Presence of WUA in a village (1=yes)	0.29	0.46
Distance to health center	Distance to the nearest health center in km	4.97	4.09

[a] The mean is calculated for households whose water sources are not in their own yard/premise.
[b] The exchange rate during the time of the survey was 1 Euro = 26.02 Ethiopian Birr.
Source: Author's compilation using survey data.

3.3.2 Empirical estimations

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. We instead investigate the degree of correlation between the microbial quality of storage water and socio-demographic, water sources, and sanitary factors.

In the multivariate analysis, we examined two different measurement specifications for the dependent variable, that is, water quality. First, the dependent variable indicates the number of *E.coli* (CFU/100ml 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 OLS.[14]This transformation is an alternative to log transformation when the dependent variable takes zero values (MacKinnon & Magee 1990) and we interpret the coefficients of the explanatory variables same as the log transformation. Second, we measured the dependent variable as a binary outcome, which indicates the presence or absence of *E.coli* CFU/100ml water, 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.

3.4 Results and Discussion

3.4.1 Bivariate analysis

This section highlights the relation between socio-demographics, water sources and water handling, or household characteristics and quality of storage drinking water.[15] More than 58 percent of stored drinking water samples were contaminated with *E.coli.*[16] 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 percent of sampled households' storage water were contaminated with *E.coli* (Mengistie *et al.* 2013; Tsega *et al.* 2014). In the bivariate

[14] 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.

[15] The influence of socio-demographic variables, such as primary caretaker's and household head education and household size, turns out to be insignificant. The non-significant bivariate association between water quality and education variable might be partly explained by the low level of actual school attainment among surveyed households (table not presented here).

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

analysis, water quality indicator is measured as a dummy variable (the variable is equal to 1 if 1 or more *E.coli* CFU/100ml water sample is counted, 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 3-4. The results show that types of water sources, types of water collection containers and garbage or waste disposal patterns have statistically significant influence on storage water quality.

We found that types of water sources are highly associated with 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. Kremer *et al.* (2009) shown that simple spring protection significantly improves the microbial quality of both POS as well as POU water. The result in Table 3-4 also shows a significant association between the types of water collection containers and storage water quality ($p=0.000$). More than 83 percent the households use jerrycan for water collection. Most households use the same jerrycan for both hauling and storing drinking water at home. However, household water storage and treatment practice do not have a significant influence on storage water quality. Although half of surveyed households get their drinking water from unimproved source, the proportion of households applying any form of water treatment is low (8%). This clearly indicates a lack of awareness of the need to treat household drinking water among rural households in the country. About 24 percent of households also reported that they do have a separate water storage containers.

Moreover, the proportion of households with contaminated water with *E.coli* was lower among households who had simple pit latrine than those who did not have and the relationship is significant. Similarly, households in which the primary caretaker washes her hands with soap had better storage water quality than households whose primary caretaker did not. Hands may come into contact with feces as a result of multiple factors and pose a potential risk of contaminating household water during water handling (Trevett *et al.* 2005). Safe disposal of household's garbage greatly influenced household water quality ($p<0.000$). Solid garbage disposal methods in the study areas include dug-out/burning (11%), throwing away in the yard (54%), throwing-away outside the yard (13%), and composting or used as a fertilizer (22%). Although a higher percentage of non-irrigator households had better water quality than irrigator households, the relationship is not statistically significant.

Table 3-4: Relationships between water sources, collection and stored drinking 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 containers					
Jerrycan	379	62.01	37.99	14.014	0.000
Clay-vessel	75	38.01	61.33		
Household water treatment					
Yes	35	71.43	28.57	2.748	0.097
No	419	57.04	42.96		
Water storage					
Yes	111	61.26	38.74	0.585	0.445
No	343	57.14	42.86		
Handwashing with soap					
Yes	124	47.58	52.42	7.831	0.005
No	330	62.12	37.88		
Household sanitation facility					
Pit latrine	189	51.85	48.15	5.277	0.022
No facility (open field/bush)	265	62.54	37.36		
Garbage disposal					
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		
Irrigated agriculture practice					
Yes	302	58.94	41.06	0.232	0.630
No	152	56.58	43.42		

Source: Author's compilation using survey data.

Community water sources quality

Of the total 61 community water source samples tested, 73.8 percent of the total samples were contaminated with *E.coli*. Of the water samples collected, 58.6 percent of protected dug wells/springs, 84.6 percent of unprotected wells/springs and 100 percent 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 3-5). Protected wells/spring has lower *E.coli* concentration (CFU/100ml water) than unprotected wells/springs and surface water sources. The finding is evident that most community 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 POS and POU can pose a high risk of public health problems from water-related diseases.

Table 3-5: Community water source sample test results

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

Source: Author's estimates using survey data.

As Figure 3-2 illustrates, about half of the surveyed households reported that they do not have any major problems related to their primary drinking water source. However, one-quarter of the households stated that the water they collect from their primary drinking water source is of poor quality. Traveling long distance and spending considerable time for water collection and irregular water supply also reported as major problems in the study areas. Moreover, due to water unavailability, some water points are only open during certain times of a day and households may be forced to collect water from other unimproved sources.

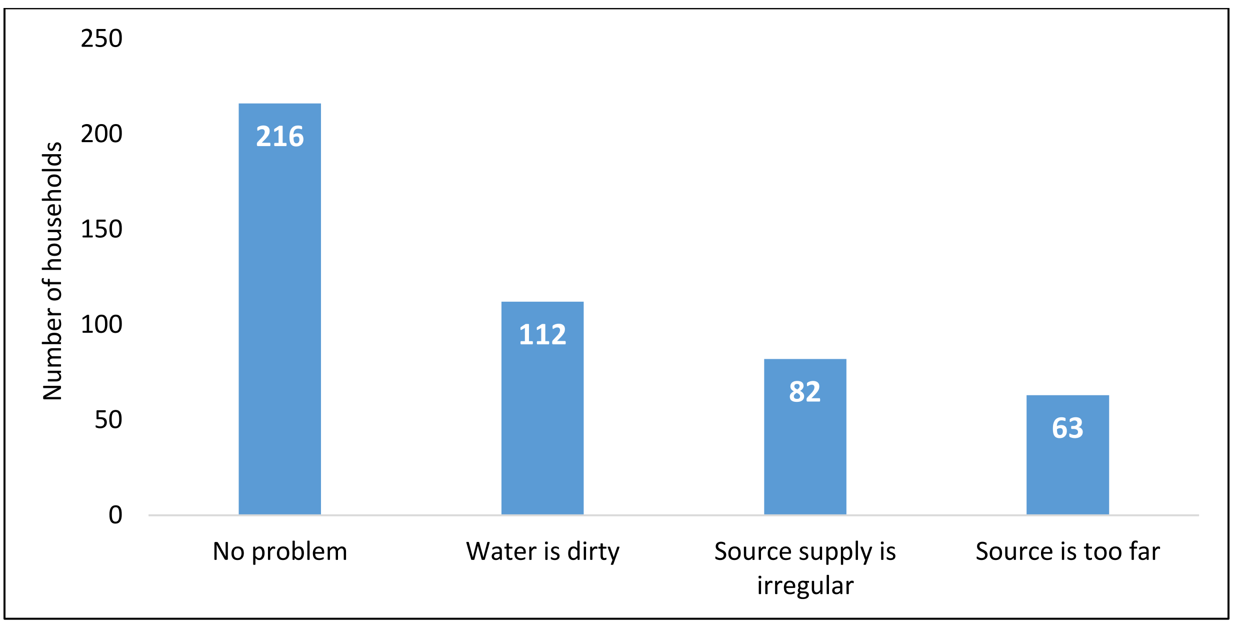

Figure 3-2: Major problems related to drinking water supply in the study areas

Source: Author's computation using survey data.

In many developing countries, particularly in the 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 3-3 shows which household members usually collect water for households whose primary drinking water source is not on premises/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 10 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 & 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. The situation is similar in many other developing countries (Sorenson *et al.* 2011). Therefore, the provision of clean and adequate WATSAN services foremost benefits women and children—because it reduces the burden of traveling long distances to fetch water, which in turn increases their time to participate in community activities and on girls to go to school.

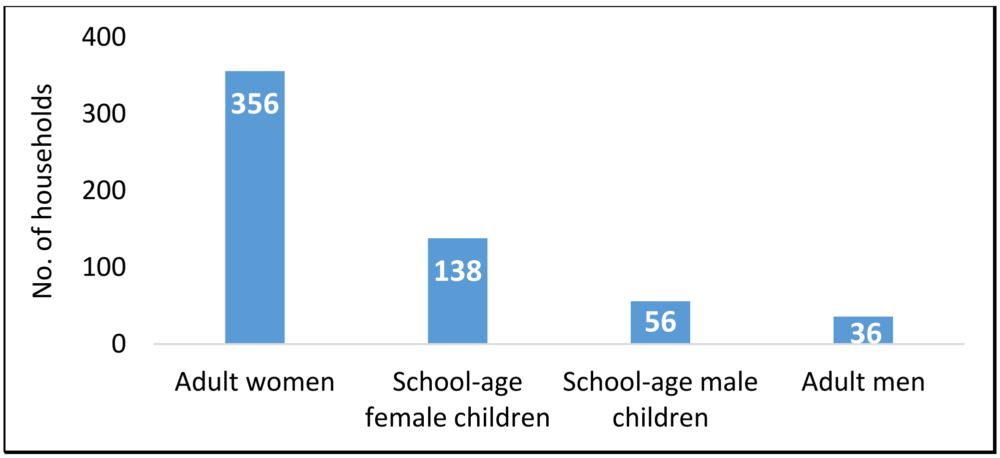

Figure 3-3: Household members who usually collect when water source is not on premises

Source: Author's computation using survey data.

3.4.2 Multivariate analysis

This section discusses the empirical results from the multivariate regression. The OLS regression results are presented in Table 3-6 while the logistic estimated odds ratios are presented in Table 3-7. The OLS model was used to determine the factors associated with the natural logarithm of *E.coli* CFU/100ml water, that is, the intensity of fecal contamination. Given that drinking water is generally of poor quality among the sampled households, this approach allows us to investigate the incremental effects of the covariates on the level of *E.coli* concentration. On the other hand, the logistic regression was used to estimate the odds of contaminated water, that is, the binary outcome of potable or unpotable water (1 if 1 or more *E.coli* CFU/100ml water is counted, otherwise 0). For both types of regression analysis, we estimated different model specifications in stages to control for the potential confounding factors.

The OLS regression results presented in Table 3-6 show that types of primary water sources influence storage water quality. Household storage water from protected wells/spring had lower *E.coli* (CFU/100ml 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 (model 2, Table 3-6). 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 the 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 the difference between water from protected and surface water sources is not statistically significant (model 3, Table 3-6). Similarly, the results from the logistic regression estimates presented in Table 3-7 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 (model 3, Table 3-7). On the other hand, water from unprotected sources is 2—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). The association between household water collection container vessels and the level of *E.coli* is strong 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 clay vessel. In rural Ethiopia, it is found that more than 95 percent of households do not adequately and regularly clean their water jerrycan containers (Kinfegabriel 2014).

Regarding household demographic characteristics, the household level of education, as expected, negatively affects the level of *E.coli* in storage water. Furthermore, household density is strongly positively associated with storage water level of *E.coli* across all model specifications. On the other hand, the number of adult female household members positively 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 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 (Table 3-6). 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.[17] Our results also suggest that handwashing with soap and household assets (a proxy for wealth) are negatively associated with storage water level of *E.coli*, and similar results are shown in the logistic model specification.

Most households practice mixed farming and often livestock lives together with human beings. That is, more livestock unit means more crowded living conditions in rural areas. The negative relationship is expected and the effect size is relatively large. Households engaged in irrigated agriculture have low storage water quality. As irrigated agriculture has complex interactions with drinking water, household water can easily become affected through agricultural practices or through multiple water use. The existence of water user association (WUA) in the community/village is also robustly 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 0.46 when we adjusted for socio-demographic and sanitary characteristics.

In most 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 3-7). Moreover, households who keep livestock is associated with 54 percentage points increase in the odds of contaminating their storage water. However, contrary to the OLS regression results presented in Table 3-6, some of the variables, such as irrigation practice, water source location and its interaction effect with pit latrine, which greatly influence storage water level of *E.coli* at different levels, do not have a statistically significant influence in the logistic regression results (Table 3-7). This indicates that these variables could be proximate causes for poor storage water quality as their effects depend on the distribution of *E.coli* (CFU/100ml).

[17] As the interaction term is not statistically significant in the logistic regression, we did not control for it.

Table 3-6: Estimates from OLS regression predicting the natural log of *E.coli*

VARIABLES	Model 1	SE	Model 2	SE	Model 3	SE
Primary drinking water source [a]						
Unprotected well/spring	1.040***	0.186	1.052***	0.164	0.335**	0.152
Surface water	1.190***	0.261	1.127***	0.238	0.212	0.241
Minutes to water source (1=30min/ less)	-1.061***	0.242	-0.981***	0.225	-0.868***	0.224
Container (1=Jerrycan) [a]	1.197***	0.198	1.146***	0.191	1.048***	0.177
Highest education comp.			-0.081**	0.034	-0.034	0.026
Household size			-0.002	0.068	-0.081	0.057
Household density			0.398***	0.082	0.310***	0.067
Number of adult females			-0.408**	0.178	-0.187	0.135
Garbage disposal methods [a]						
Throw in the yard					1.480***	0.230
Throw away outside the yard					0.559*	0.310
Used as fertilizer					0.860***	0.245
Handwashing with soap (dummy)					-0.547***	0.161
Log of assets value					-0.335***	0.099
Livestock holding					0.275***	0.059
Irrigating households (dummy)					0.532***	0.134
Water user association (dummy)					-1.374***	0.180
Pit latrine (dummy)					-0.025	0.172
Water source location (1=on premises)					-0.496**	0.236
Water source location X latrine					1.070***	0.364
Constant	1.520***	0.281	0.970**	0.389	2.714***	0.816
Observations	454		454		454	
R-squared	0.17		0.25		0.46	
Model F-stat	35.28		34.17		61.32	
Model P-value	0.000		0.000		0.000	

[a] Omitted reference categories are protected well/spring, clay vessel, and dugout/burning.
Robust standard errors adjusted for clustering at the village level are in parenthesis;
Significance *** p<0.01, ** p<0.05, * p<0.1

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 percent of the households having at least 1 *E.coli* CFU per 100ml water. Our results further suggest that storage water quality is strongly associated with water sources, water collection time and types of containers, the existence of WUA in a village, household demographic structures, and households overall sanitary characteristics. Our findings are also consistent with other studies that reveal 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 a substantial risk of waterborne infectious diseases in the country.

Table 3-7: Estimates from Logistic regression predicting *E.coli* contamination (1 if *E.coli* >= 1)

VARIABLES	Model 1	SE	Model 2	SE	Model 3	SE
Primary drinking water source [a]						
Unprotected well/spring	3.246***	0.717	3.582***	0.752	1.958**	0.550
Surface water	3.693***	1.277	3.619***	1.213	1.161	0.433
Minutes to water source (1=30min/less)	0.387***	0.116	0.396***	0.123	0.373**	0.160
Container (1=jerrycan) [a]	2.635***	0.759	2.702***	0.769	3.470***	1.236
Highest education completed			0.901**	0.037	0.909**	0.038
Household size			1.031	0.080	0.904	0.085
Household density			1.428***	0.165	1.466***	0.181
Number of adult female			0.655*	0.160	0.758	0.213
Garbage disposal methods [a]						
Throw in the yard					14.755***	7.629
Throw away outside the yard					2.869*	1.765
Used as fertilizer					5.770***	3.245
Handwashing with soap (dummy)					0.394***	0.120
Log of assets value					0.734**	0.101
Livestock holding					1.571***	0.176
Irrigating households (dummy)					1.640*	0.435
Water user association (dummy)					0.157***	0.055
Pit latrine (dummy)					0.981	0.250
Constant	0.795	0.277	0.471	0.243	0.672	0.910
Observations	454		454		454	
Pseudo R-squared	0.10		0.15		0.35	
Model Chi2	55.79		105.46		170.34	
Model p-value	0.000		0.000		0.000	

[a] Omitted reference categories are protected well/spring, clay vessel, and dugout/burning.
Robust standard errors adjusted for clustering at the village level are in parenthesis;
Significance *** p<0.01, ** p<0.05, * p<0.1; and 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 is estimated that, at any given time, one-third of rural water supply schemes are non-functional (MoWE 2007). A recent survey of 57 diverse water source schemes also showed that 38.6 percent 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 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 requires 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 3-4). 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 80 percent of these households applying chlorine-based methods, of which 72 percent 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. This is because of a lack of awareness about domestic water quality and its health consequences, people often perceive that clean water is 'clean' as long as it is not turbid. For instance, about 87 percent of urban households and 91 percent of rural households do not practice any form of household water treatment in the country (CSA & ICF International 2012).

The types of household storage container can also influence household water quality (Levy *et al.* 2008; Günther & Schipper 2013). In this study, types of water collection containers are significantly associated with the quality of water consumed by the household. More than 83 percent of the households identified jerrycan as a favorite container for hauling and storing their drinking water and 24 percent 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. Cleaning its inside part with a simple washing is challenging. A study in rural Ethiopia reported that more than 95 percent 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 assumed that water pouring is safer than dipping but this research questioned if a narrow-necked container, such as jerrycan, is the safest methods of water storage. Households opt to store water for future use when the 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). For instance, hands may become into contact with feces through various mechanisms and become contaminated with water. This implies that proper hygiene practices can reduce storage water contamination.

Household demographic variables, particularly household density are strong predictors 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. It is also a common understanding that the level of *E.coli* in storage water is expected to positively correlate to household size due to possible contacts from the many hands to water containers, but the effect of this variable turns out to be statistically insignificant. Moreover, higher household education is expected to correlate with a better understanding of water quality and sanitary behavior, which in turn could influence household water quality through improved water handling and hygiene practices. However, our results show that the effect of education is small, or even statistically insignificant (model 3, Table 3-6). This could be explained by low levels of school attainment, or suggest that the primary caretaker's level of education might be more important in determining stored water quality than any other household members.

On the other hand, pit latrine availability increases the level of *E.coli* on storage water for households who use well water sources in their own premises. Megha *et al.* (2015) showed that the microbiological quality of ground water deteriorates where pit latrines are placed close to the source. In support of this, our result shows 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 problem with groundwater supplies is directly related to 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 channel for high contamination of storage water. Moreover, as private-wells are often shallow and inadequately protected compared to community 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.

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 lives together with human beings, increasing the risk of household water contamination. The negative relationship is expected and the effect size is also relatively large. Households engaged in irrigated agriculture have 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 are lacking.

We also expect households with more accumulated assets (wealth) to live in a more sanitary environment, which can reduce drinking water contamination. Livestock ownership may offset the net positive gains of household assets on stored water quality, as livestock can be a source of pathogens which directly affect the water quality. Moreover, household assets are moderately correlated with livestock ownership, irrigation practices, and household education outcomes. This suggests that most socioeconomic variables can influence water quality indirectly through various pathways.

Another interesting finding is that the existence of WUA in the village influences the quality of storage water quality. Households that 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 for monitoring, supervising and handling conflicts among household users of community water sources. The influence of WUA on storage water quality might 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).

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 that may not even guarantee them to get improved water sources. Moreover, widespread household water contamination undermines 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 70 percent of the diarrheal diseases burden in the country (FMoH 2005). Unsafe water is not just dirty; it can be deadly if people drink it without any prior treatment. Therefore, any intervention that aims at increasing access to safe and clean rural water supply should be accompanied by large-scale household interventions such as safe water storage, POU water treatment.

3.5 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 findings that 74 percent of water sources and 58 percent of stored household drinking water samples were positive for *E.coli* bacteria indicated that majority of the rural population is at high risk of waterborne diseases. About 50 percent the surveyed households get their water from protected or ‘improved’ water sources; however, more than 42 percent 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). Moreover, Wright *et al.* (2004) showed that microbiological quality of drinking water significantly declines after collection from the acceptable quality of water sources. It is widely understood 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 a need to promote water safety along the POS to POU to advance the Sustainable Development Goal (SDG-6) of ensuring access to clean water for everyone. Therefore, some interventions 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 WATSAN 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 community water sources considered being ‘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. Second, promoting household water treatment methods and products to make water safer. A simple water treatment practices of drinking water avoids the risk of contaminated water. Household water treatment and safe storage, 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 the 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 and school-age children are disproportionately responsible for household water collection, targeting these age groups in any hygiene education intervention on handwashing, water collection and storage may generate substantial improvement in 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 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. Fifth, Private-well water sources should not be developed close to household’s latrine to prevent 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. Six, building the capacity of WUA and providing training in water source protection, environmental sanitation, and systems operation and maintenance. The provision of drinking water in rural areas through community water scheme is the conventional way and this is the only existing alternative to increasing access to clean water. Supporting WUA to enable them to repair and manage available water sources is, therefore, critical in the provision of sustainable rural water supply.

On top of that, variations in the community and household behavioral and sanitary factors are key determinants of household storage water quality. Unsafe sanitation habits, inadequate garbage disposal, and widespread open defecation could be the primary causes of drinking water contamination. Furthermore, 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 principal sources of disease-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 SDG-6 indicator as well.

4. The Impact of Drinking Water Quality and Sanitation on Child Health

4.1 Introduction

Globally, more than 700 million people live without an improved water source, and eight out of 10 of these people live in rural areas (WHO/UNICEF 2014). An estimated 2.5 billion people also lack access to improved sanitation facilities, of which a billion people practice open defecation (WHO/UNICEF 2014). Sub-Saharan Africa and Southeastern Asia are the regions with the lowest coverage of improved sanitation in the world. In parallel, millions of people are suffering worldwide from WASH related diseases such as diarrhea, skin diseases and trachoma. Inadequate WASH services are linked to 88 percent of diarrhea cases worldwide and result in more than 1.5 million children deaths each year—mostly under-five children (WHO 2002; WHO/UNICEF 2009).

Ethiopia is the second-most populous country in Africa and about 85 percent of the country's 96 million people live in rural areas.[18] Mortality and malnutrition are serious health problems among under-five children in the country. Although the country has reduced under-five mortality rate by more than half since 1990 (UNICEF 2012), Ethiopia was ranked 27th in the global under-five child mortality rate estimates in 2007 (UNICEF 2009). As per the World Bank (2005) Country Status Report on Health and Poverty, child mortality in Ethiopia is among the highest in the world; almost one out of 10 babies born in the country (97 per 1000) do not survive to celebrate their first birthday, and one in every six children die before their fifth birthday. More than 90 percent of these deaths were due to preventable diseases such as pneumonia, diarrhea, malaria, measles, malnutrition and HIV/AIDS (FMoH 2010). As a result of inadequate access to improved WASH services in both rural as well as urban areas, the spread of diseases caused by them is a major health problem in the country. It is estimated that 60 percent of the country's disease burden and 70 percent of the diarrheal diseases were mainly attributed to poor WASH services (FMoH 2005). It is commonly understood that most of these deadly diseases caused by poor WASH are largely preventable.

In the last decade, the GoE has made significant progress in increasing access to WATSAN services, and in modifying long-held hygiene habits. Nonetheless, as shown in Figure 4-1, access to proper sanitation facility is inadequate—particularly in rural areas. The difference between urban and rural households is also striking: based on the WHO definition, only 28 percent of rural households have access to improved sanitation while the remaining households rely on unsafe sanitation services and open defecation. This issue is compounded by water source contamination by animal and human feces, which is caused by inadequate protection to most water sources in rural areas. WHO/UNICEF (2015) estimated that 57 percent of Ethiopian households have access to improved drinking water sources—93 percent in urban areas and 49

[18] http://worldpopulationreview.com/countries/ethiopia-population/

percent in rural areas. As a result, most of the rural population rely on unimproved water sources, such as rivers, lakes, ponds, streams, rainwater, unprotected springs and wells, irrigation water from canals and dams, as a source of water for drinking and other domestic uses. Moreover, less than 20 percent of the population is regularly washing their hands with soap and water at critical times (FMoH 2011). The same report indicated that 8 percent of the population follow the safe drinking water chain from source to mouth (FMoH 2011). Due to unsafe handling and storage of drinking water, 40 percent of the domestic water consumption is contaminated with fecal matters.

The impacts of unsafe drinking water and sanitation behavior on child health outcomes have not been investigated sufficiently, and little is known about the impacts in the context of rural Ethiopia. Existing empirical works on the health impacts of WATSAN in Ethiopia did not give due attention to water quality at the household level and child stool disposal habits (Cameron 2009; Kirchberger 2008).

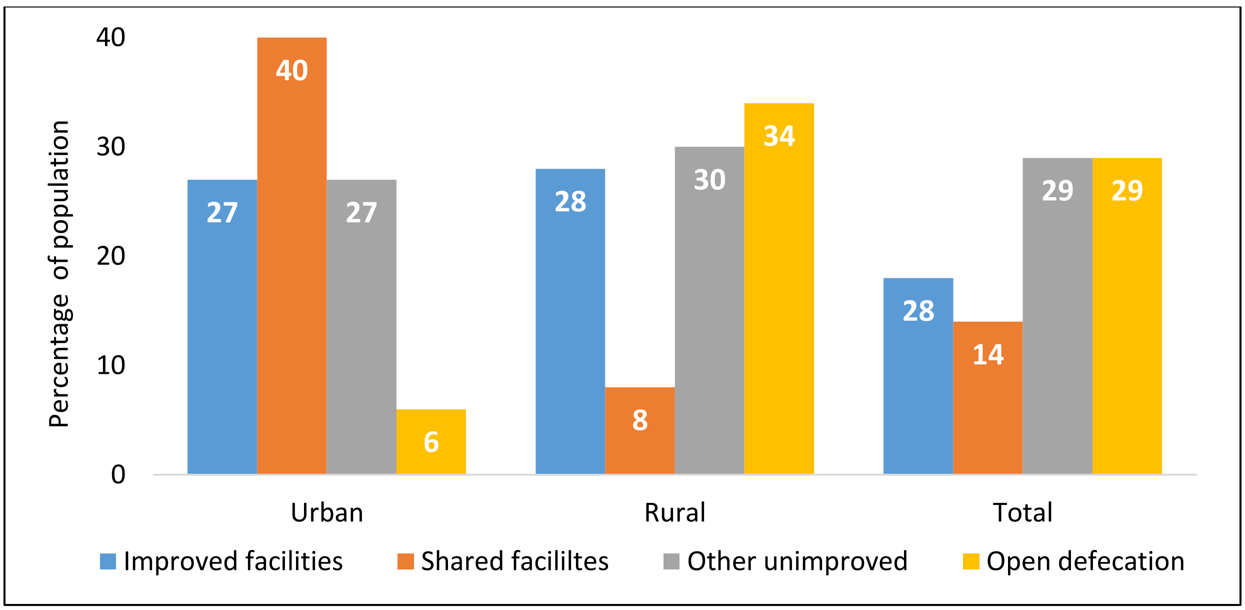

Figure 4-1: Percentage of population by type of sanitation facility in Ethiopia, 2015

Source: Author's compilation using the WHO/UNICEF JMP dataset.

Using a variety of impact evaluation methods, this chapter aims to shed more light on the health impacts of household drinking water quality and sanitation behavior on under-five children in two rural areas in Ethiopia—Fogera and Mecha districts. The innovative aspects of this chapter lie in two key contributions: first, household's drinking water quality was determined by actually testing the microbiological quality of water samples taken from drinking water stored in the household[19] using a membrane filtration method rather than looking at the types of household drinking water sources. The second novelty of this chapter is that we take into account household's behavior on child stool disposal, which is critical in child health outcomes. The key findings are that improved storage water quality and safe child stool disposal highly influence childhood diarrhea. However, contrary to widely held perceptions, the results suggest that we should think differently about the health impacts of simple pit latrines in rural areas.

4.2 Water Supply, Sanitation, Hygiene and Health

Improving WASH services has been recognized as a fundamental factor to improve health and as one of the driving forces of social and economic progress in developing countries. Improving water quality and sanitation, together with better hygiene practices, can have significant effects on the health of a population. It reduces the incidence of a variety of waterborne diseases, such as diarrhea, intestinal helminths, guinea worm, skin diseases, and trachoma (Esrey *et al.* 1991), by interrupting or decreasing the transmission of pathogenic disease agents. These health improvements can, in turn, lead to improved nutritional status and reduced morbidity and mortality, particularly among under-five children. Table 4-1: presents potential transmission routes of pathogens and a broader classification of the disease burden associated with unsafe and inadequate water supply.

Table 4-1: Transmission Routes of Water-Related Diseases

Classification	Transmission route	Examples of diseases transmitted
Waterborne	through ingestion of pathogens in drinking water	Diarrheal diseases Enteric fevers, such as typhoid Hepatitis A
Water-washed	through incidental ingestion of pathogens in the course of other activities; results from having insufficient water for bathing and hygiene	Diarrheal diseases Trachoma Scabies
Water-based	through an aquatic invertebrate host; results from repeated physical contact with contaminated water	Guinea worm Schistosomiasis
Water-related insect vector	through an insect vector that breeds in or near water	Malaria (parasite) and Yellow fever (virus)

Source: Bradley (1977).

Diarrhea is both a waterborne as well as a water-washed disease, and it can be caused by ingesting water contaminated with human and animal feces which contain pathogenic agents or ingesting these pathogens directly through various fecal-oral pathways. The latter is likely to occur when water availability is limited, which hinders proper hygiene practices (e.g., washing

[19] Hereafter referred to as storage water

hands after defecation). Although diarrhea and malaria are the most prevalent diseases in the study areas, this chapter focuses on diarrhea in under-five children.

Figure 4-2 shows the fecal-oral routes of disease transmission and how intervention can break the chain of contamination at various stages of the transmission pathways. Human and animal excreta are the primary sources of most disease-causing pathogens. As the figure illustrates, these pathogens are passed from an infected host to a new one via various transmission routes. They are transmitted via the fecal-oral routes through fluids, hand contact, flies, and food. The figure also shows the importance of sanitation and safe removal of human feces as a primary barrier to prevent these pathogens from reaching the domestic environment. Good hygiene practices and household water treatment also serve as a secondary barrier to prevent the transmission of disease-causing pathogens. For example, washing hands with soap after defecation and contact with child stools, and before eating and preparing food stop the transmission of disease agents because the source of the diarrhea pathogen is removed. Therefore, washing hands with soap can significantly reduce the burden of diseases associated with feces and polluted water. The secondary barriers are extremely important when sanitation services are inadequate and feces are disposed of into the domestic environment.

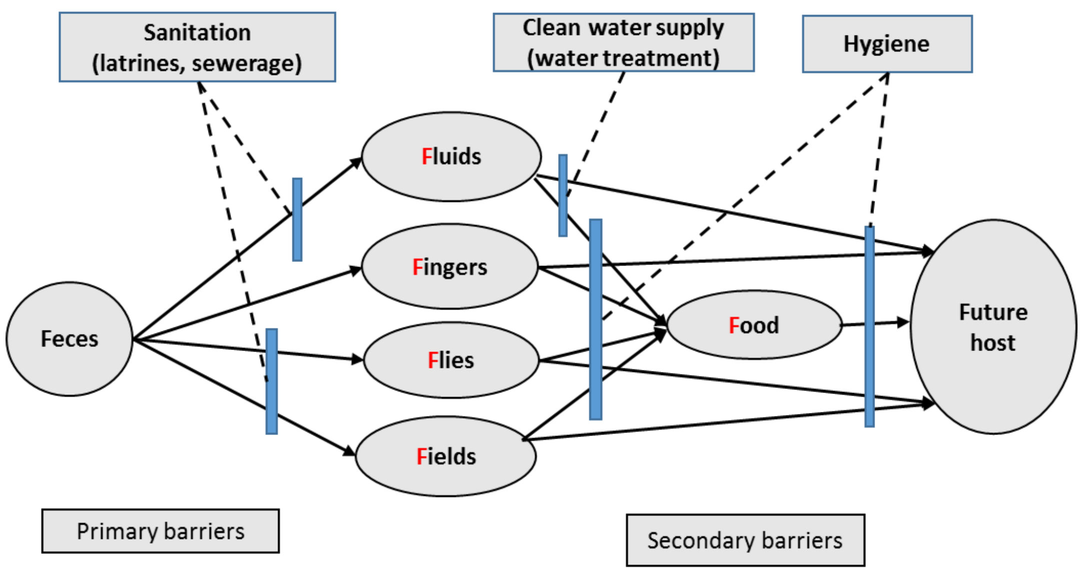

Figure 4-2: The "F-diagram" shows the pathways of fecal disease transmission and the barriers that can prevent infection

Source: Adapted from Wagner and Lanoix (1959).

4.2.1 Water supply and health

Water is an essential resource needed to sustain life on earth. Numerous empirical studies have investigated the impact of WATSAN infrastructure on human health. There is compelling empirical evidence that access to improved drinking water supply substantially improves child health in terms of reducing the risk of diarrheal diseases (Esrey *et al.* 1990; Fewtrell *et al.* 2005; Overbey 2008). Safe, reliable, and easily accessed water is crucial for the preservation of good health. However, in many developing countries—particularly in rural areas – the available water is often either unsafe or insufficient to meet basic health needs. The United Nations General Assembly declared "safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights" and openly called for actions leading to the provision of "safe, clean, accessible and affordable drinking water and sanitation for all" (UN 2010).

The quantity of water available to a given household is largely affected by traveling and waiting time taken to collect water (Cairncross 1987). After reviewing several studies, Cairncross (1987) found the following general relationship between water use and collection time: a) the quantity of water collected decreases considerably once the time taken to collect water is greater than 5 minutes (water source is located 100m away from home); b) the quantity of water remains the same between 5 and 30 minutes of collection time (distance travelled lies between 100m and 1000m); and c) the quantity of water decreases further when the nearest water source is 1000m away from home (total collection time longer than 30 minutes). The findings of an empirical study in Uganda provided evidence to support this observed relationship (WELL 1998). Reducing water collection time directly increases water availability, and this may translate into more bathing and washing (Cairncross & Cuff 1987). In particular, the frequency of handwashing is highly correlated with the quantity of water available to households (Cairncross 1997; Curtis *et al.* 2000; Gilman *et al.* 1993). To reduce the health risk associated with poor hygiene, 50 liters of water per capita per day (l/p/c/d) is recommended to ensure adequate personal and food hygiene, domestic cleaning, and laundry needs (WHO 2011); 7.5 liters of water is the recommended absolute minimum for consumption and cooking in emergencies and disasters (Howard & Bartram 2003). In rural Ethiopia, the average domestic water consumption is probably much lower than the recommended amounts, with the estimated amount of drinking water for urban and rural population varying between 3 and 20 l/p/c/d (Kumie & Ali 2005). This is mainly due to the long distances between households and their nearest water source, which requires much time and energy to collect water.

Water access and collection time

In sub-Saharan Africa, Blackden & Wodon (2006) estimated that 40 billion working hours are lost each year as a result of collecting water. It is also well-documented that it is mostly women and girls who have to travel long distances and spend their productive time on fetching water (WHO/UNICEF 2010b). For instance, in Malawi, 87 percent of water fetching duties are taken up by women and 20 percent of the households spend more than an hour for each water collection trip (Sorenson *et al.* 2011). In rural Ethiopia, adult women are 10 times more likely to collect water for household consumption than adult men and 63 percent of the households need to travel 30 minutes or more for each water collection trip (CSA & ICF International 2012; Usman *et al.* 2016). Consequently, it is argued that the time spent collecting water by women and girls could be used for other income-generating activities, such as seeking access to health care, schooling, leisure, participating in community activities, and taking care of young children (Ray 2007; Sorenson *et al*. 2011), with direct and indirect health consequences.

Water quality is also an essential aspect of access to improved water supply. Unsafe drinking water is not only dirty, but it can also be pathogenic and deadly if people consume it untreated. More than 1.5 million children die each year due to diarrhea and other gastrointestinal diseases, mostly in developing countries, and contaminated drinking water is considered to be one of the major causes (Kremer & Zwane 2007; WHO/UNICEF 2009). Unsafe drinking water may also result in other waterborne diseases such as typhoid, cholera, and dysentery. The empirical support for the role of safe water supply in improving and preserving good human health is extensive, in both rural and urban areas. Most of the existing literature focuses on the impacts of households having access to piped water connection, and children have been shown to benefit substantially from improved water sources (Bukenya & Nwokolo 1991; Mangyo 2008). Moreover, the health benefit of in-house water connection is substantially greater than that of improved public sources such as standpipe and other protected water sources (Bartram & Cairncross 2010; Curtis *et al.* 1995).

4.2.2 Sanitation and health

Improved sanitation facility, together with safe water and proper personal hygiene, is fundamental to good health. In consonance with the World Health Organization (WHO), "no single type of intervention has a greater overall impact upon national development and public health than the provision of safe drinking water and the proper disposal of human excreta" (WHO 1996). Lack of adequate sanitation facility can cause diarrheal and other diseases which can be transmitted via the fecal-oral route. Access to safe and adequate drinking water alone is not enough to decrease the disease burden because improved sanitation is also a crucial component of the WASH sector. Improved sanitation technology (e.g., flush toilet and sewerage systems) creates the primary barriers to prevent fecal pathogens from reaching the environment and can reduce some health risk factors.

Kumar and Vollmer (2013) analyzed nationally representative data (District Level Household Survey, DLHS-3) for India and found a 2.2 percentage point reduction in diarrhea incidence in under-five children living in households with improved sanitation facilities. A similar study in Nepal by Bose (2009) showed an even larger reduction (11%) among younger children (below 24 months old).

The child stool disposal behavior of households is also an important factor in the prevention of diarrheal diseases. If children's feces are not contained or safely disposed of away from the living area, young children might be exposed to the stools through direct contact, which can cause diarrhea via the hand-to-mouth pathway. Haggerty *et al.* (1994) found that promoting handwashing and safe disposal of human and animal excreta from domestic environment results in an 11 percent reduction in diarrhea morbidity in rural Zaire.

4.2.3 Hygiene behavior and health

Promoting good hygiene behavior is crucial for realizing the full benefit of improved WATSAN facilities. While WATSAN infrastructure interventions are often considered as the 'hardware' of WASH, the promotion of behavior change is usually considered as the 'software' of such interventions. Hygiene is a set of practice or change of behavior that people adopt to preserve their health. Changing hygiene behavior is, however, a complex process as it requires people to change their long-held habits, which have been influenced by cultural and socioeconomic factors. Although educating people to change their behavior is a complex and uncertain task, Curtis *et al.* (2000) suggested that hygiene interventions can be successful if a few behaviors that have most potential health impacts are targeted and promoted. For instance, promoting handwashing intervention, and safe water storage and handling practices can produce significant health gains.

Hands are a key vector in the transfer of pathogens from feces as hands can become contaminated through various mechanisms: during defecation, while disposing of child stool, or by touching other contaminated objects (Hill *et al.* 2004). There is, however, a growing body of evidence that simply washing hands with water and soap at critical times—such as after stool disposal or defecation, and before preparing food or eating—can help a person avoid life-threatening water-related diseases. Existing literature also suggested that promoting handwashing has shown the most success in achieving greater health impact. Curtis and Cairncross (2003) suggested that handwashing with soap could reduce diarrhea incidence by 47 percent and save one million lives per year. This is consistent with other studies which found that handwashing interventions achieved a median reduction in diarrhea incidence by 35 percent (Hill *et al.* 2004). In a randomized controlled trial in urban Pakistan, Luby *et al.* (2006) found that intensive handwashing promotion could reduce diarrhea incidence by 51 percent. Luby *et al.* (2005) also analyzed the effect of handwashing with soap on the incidence of pneumonia and diarrheal diseases and found strong supporting evidence: in households that received the intervention, diarrhea incidence reduced by 53 percent, and pneumonia incidence by 50 percent in under-five children. A recent review of hygiene practices by Cairncross *et al.* (2010) also indicated that handwashing with soap can result in a 48 percent diarrhea risk reduction in low- and middle-income countries where there is access to water.

There is also a wealth of evidence indicating that POU water treatment, and safe water storage and handling lower the risk of exposure to waterborne pathogens, in turn reducing child diarrhea incidence. A systematic review suggested that treating water with chlorine tablet at the POU reduces not only the risk of *Escherichia coli* (*E.coli*) contaminating storage water but also the risk of child diarrhea significantly in developing countries (Arnold & Colford 2007). Few empirical studies have investigated the impact of improved water transport and storage containers on health outcomes. However, a recent study examining the impact of improved water transport and storage on water quality and health outcomes in Benin by using a randomized control trial approach found that improved water storage and containers are associated with both a reduction in *E.coli* colony count in water and a lower incidence of self-reported diarrheal diseases (Günther & Schipper 2013).

Improving the quality of drinking water at the household level can bring additional health improvements. Drinking water collected from improved sources may be contaminated because of poor water storage and unhygienic water handling before reaching the drinking cup. For instance, a systematic meta-analysis of 33 studies conducted by Clasen *et al.* (2007) showed that water treatment at the POU using flocculation or disinfection is more effective in minimizing the risk of diarrhea than water source improvements.

Generally, existing empirical studies suggest that some WASH interventions are effective in reducing water- and fecal-related disease burden. However, the empirical evidence regarding whether multiple interventions are more effective than single intervention is mixed. Some studies have shown that using various combinations of interventions are more effective than using one alone (ALAM *et al.* 1989; Esrey *et al.* 1991; van Der Hoek *et al.* 2001). On the other hand, a comprehensive meta-analysis by Fewtrell *et al.* (2005) found that combining interventions did not have any synergistic effect, which is contrary to the above discussion and the wider beliefs. Table 4-2 presents the summary of a meta-analysis of the percentage reduction in diarrheal diseases by intervention type. Waddington *et al.* (2009) found that water supply interventions did not bring a statistically significant reduction in diarrheal morbidity but water quality interventions generated greater diarrheal morbidity reduction. On the other hand, Fewtrell *et al.* (2005) and Esrey *et al.* (1991) respectively found hygiene and sanitation interventions had greater impacts.

Table 4-2: A meta-analysis of percentage change in diarrheal diseases by intervention type

	Esrey *et.al.* (1991)	Fewtrell *et.al.* (2005)	Waddington *et.al.* (2009)
Water quality	-15%	-31%	-42%
Water supply	-20%	-25%	-2%*
Sanitation	-36%	-32%	-37%
Hygiene	-33%	-45%	-31%

Source: Author's compilation.
*Not significant

4.3 Data and Methods

We used the same household survey data collected in two districts of rural Ethiopia between February and June 2014. It covers 454 households across 20 kebeles with 565 children aged five or younger. The data comprises household- and community-level data with microbiological water sample test results.

Microbiological water quality tests

There are several physiological, chemical and microbiological standards for a water supply to be acceptable for human consumption. One of the most commonly used indicators for microbial water quality is the level of *E.coli* bacteria,[20] which only comes from human and animal feces. It is almost impossible to reliably predict the microbial quality of water at the household's storage unit based on the type of the water source as water collected from improved sources is often re-contaminated by fecal matters during collection and transportation due to poor water handling and storage (Wright *et al.* 2004). In this analysis, therefore, the level of *E.coli* bacteria (CFU/100ml) of storage water sample was used as the indicator of the microbial drinking water quality (see section 3.3 for a detailed description of the procedure).[21]

4.3.1 Variables and measurement

a) Dependent variable

In this chapter, we use diarrheal diseases as a health indicator and focused on child health outcomes.[22] In agreement with the WHO, diarrhea is generally defined as the passage of three or more "loose watery stools" or a loose stool containing blood or mucus in a twenty-four hours period. Data on the incidence of diarrheal diseases in the two weeks preceding the survey were collected. In most cases, the respondents are the child's primary caretaker—usually his/her mother.

b) Control variables

Based on existing empirical literature, a set of household and child characteristics, water collection time, latrine characteristics, child stool disposal, and handwashing practices are included in the analysis to control for observed differences among households. The study, therefore, makes the hypothesis discussed below concerning the independent effects of

[20] We could not test all known pathogens that can pose a health risk because it is both complicated and expensive. For instance, streptococci and thermotolerant are used as an indicator of drinking water quality as they have a close relationship to bacteria indicators of known fecal origin.

[21] The general WHO Drinking Water Quality Guideline suggests that the number of *E.coli* bacteria CFU/100ml water should be ideally zero when it is used as an indicator of microbiological drinking water quality.

[22] Although poor water quality can cause other communicable diseases and can also affect adults, we focused on child diarrheal diseases as the health indicator in this analysis. Young children and infants are more prone to diarrheal diseases than adults due to their weak immune system. Moreover, diarrhea is one of the primary causes of under-five child mortality and morbidity, and contaminated drinking water is considered to be the main cause of diarrheal diseases.

explanatory variables on childhood diarrhea. The description of variables and units of measurement are summarized in Table 4-3.

c) Socioeconomic variables

We start here by considering the "traditional" variables. The ages of both parents and children are expected to have a negative impact on childhood diarrhea incidence. Younger mothers may lack the necessary experience to provide better care for their children. Due to their weak immune systems, infants and young children are susceptible to diarrheal diseases; however, they become more resistant to the diseases as they grow older. The level of household awareness of the health benefits of water quality, safe sanitation, and good hygiene practices highly depends on the level of education among household members and is expected to affect child health positively (i.e., decrease diarrhea incidence). As the level of education for both household head and primary caretaker were extremely low, the highest grade completed among the household members was used as a proxy for education.

Moreover, in developing countries, socioeconomic factors, such as wealth, also influence the type of drinking water source used by households (Braind *et al.* 2010; Larson *et al.* 2006) and are expected to be negatively correlated with the incidence of childhood diarrhea. To control for wealth and other unobserved health practices, household assets value and livestock holding were used as a proxy for wealth.

A household's demographic structure may play a role in determining health outcomes. Household density, dependency ratio, and the number of young children are expected to be positively associated with childhood diarrhea incidence. In rural areas, housing structures are poor, with few rooms and crowded living conditions. Consequently, infectious diseases tend to spread quickly within larger households. However, having a higher proportion of adult women in a household may reduce childhood diarrhea incidence as children might get better care and more time, therefore resulting in improved health outcomes.

d) The link between agriculture and WASH

The linkages between WASH, health outcomes and agriculture are crucial. In the context of the rural households in our study, we looked at two specific areas of such interactions. First, animal excreta can be a source of pathogens; therefore, keeping livestock may increase the risk of childhood diarrhea. The sampled households practiced mixed farming, and more than 97 percent of the households own livestock, which often shares the same space with the people. All these factors are expected to result in a positive correlation between the presence of livestock and child diarrhea incidence, although it might be partly offset by the nutritional impacts of a more diverse (animal protein) diet. Importantly, we recorded not only livestock ownership, which could be used as a proxy for the wealth effect but also the presence of livestock in/around the human living area. Second, we tested for the impact of irrigation on childhood diarrhea. The theoretical relationship between these two factors is unclear. The availability of irrigation water may allow households to use more water than households without irrigation, thus having a positive impact on sanitation activities and resulting in a lower diarrhea incidence among young children. The quality of irrigation water may, however, create new sanitation and hygiene issues and therefore reduce the positive impact of water availability.

Finally, we controlled for basic child health parameters by using exclusive breastfeeding for the first 6 months of life as an indicator of parental care towards a child's health, which is strongly correlated with health outcomes.

e) Water, sanitation, and hygiene

Improved household water quality is expected to reduce the risk of childhood diarrhea by acting as a barrier to disease-causing pathogens. The traveling and waiting time used for collecting water determines the amount of water collected by a given household and reduces the time available for child care and other activities. A recent empirical study has shown that the time spent on fetching water from distant sources for domestic use significantly affects child health (Pickering & Davis 2012). Insufficient water may also limit good hygiene practices such as washing hands regularly at critical times. Overall, water collection time is assumed to be positively correlated with childhood diarrhea incidence. We also controlled for the practice of handwashing with soap, which is a defensive mechanism to improve household health and therefore expected to be negatively correlated with diarrhea incidence.

4.3.2 Descriptive statistics

Table 4-3 shows the descriptive statistics of variables of the sample households used in our empirical analysis. Some of the variables, which are not shown here, have been already presented in Table 3-3. As we have discussed earlier in the preceding chapter, the level of education is exceptionally low in the study areas. Although household heads are much better than the primary caretakers in terms of self-reported literacy (44% as opposed to 9%). Yet, few household heads in our sample have completed primary school (less than 4%).

Table 4-3: List of variables: Definitions and summary statistics

Variables	Description	N	Mean	SD
Household characteristics				
Household head literacy	1= read & write; 0=otherwise	454	0.44	0.50
Primary caretaker literacy	1= read & write; 0=otherwise	453	0.09	0.29
Highest education	The highest grade completed in a household	454	3.50	3.05
Proportion of adult female	Share of female household members aged > 14	454	1.22	0.49
Under 8 years children	Number of children under 8 years	454	1.99	0.72
Dependency ratio	Share of household members aged below 15 and above 64 to those aged 15-64	454	0.55	0.12
Consumption expenditure	Total household consumption expenditure per adult equivalent in 100 Birr	454	1.46	6.67
Under 5 child characteristics				
Age	Child age in months	562	29.02	16.30
Gender	1=male; 0=female	565	0.46	0.50
Breastfeeding	Exclusive breastfeeding for the first 6 months (1=yes)	562	0.69	0.46
Medical visit	Number of medical visits in the past one year	565	0.80	1.28
Child diarrhea	Having diarrhea in the last 2 weeks (1=yes)	562	0.16	0.36
Water and sanitation				
Drinking water source	1=improved; 0=otherwise	454	0.50	0.50
Water quality	1=uncontaminated; 0=otherwise	454	0.42	0.49
Minutes to water source	Time needed for a round trip for water collection	454	20.40	15.72
Time spent fetching water	Total time spent in hours over the last 7 days before the survey	454	16.53	13.64
Pit latrine	1=yes; 0=otherwise	454	0.42	0.49
Safe child stool disposal	1=yes; 0=otherwise	454	0.36	0.23

Source: Author's computation based on own survey data.

Other crucial descriptive statistics in Table 4-3 include WATSAN infrastructure. While 50 percent of the households in our sample have access to improved water supply (based on the JMP definitions), about 58 percent of the households had contaminated drinking water at storage. The results suggest that the JMP definition of 'improved' drinking water sources overestimates access to improved drinking water when taking in consideration POU water safety or quality. The study also reveals that only 5 percent of the households had access to improved water source in their own yard or living area, and 34 percent of the households took 30 minutes or more for a round trip to obtain drinking water (see, Table 3-3). As a result, households spent much time fetching water, on average about 2 hours and 22 minutes per day.

Improved sanitation facilities are virtually non-existent in rural communities of Ethiopia. About 42 percent of the households reported that they have simple pit latrines while 58 percent of the households defecate in the open. The reported open defecation rate is much higher than the rural national average open defecation rate of 43 percent (WHO/UNICEF 2014). Moreover, most adult women prefer defecating in a bush. The survey also revealed that more than 74 percent of the primary caretakers practiced open defecation for the last stool before the survey. As many of the latrines were constructed in response to a push by the local government, open defecation is still a norm and practiced by most people in the study areas. Furthermore, due to the limited awareness of the harmful nature of child stools, only 33 percent of last child stools preceding the survey were adequately disposed of.[23] As Figure 4-3 shows, about 20 percent of children's stool dropped into the toilet or latrine, 2 percent of children's stool were rinsed or washed away and water is discharged into the latrine, 11 percent of children's stool were buried. In contrast, 25 percent of the children's stools were not removed safely, that is, the stools of a child in every four are left in the open. Studies have shown that sanitary disposal of fecal matters is an effective mechanism for reducing child morbidity (Curtis *et al.* 2000). Leaving child stools in the immediate vicinity or yard increases the risk of young children coming into direct contact with stools, which causes diarrheal diseases.

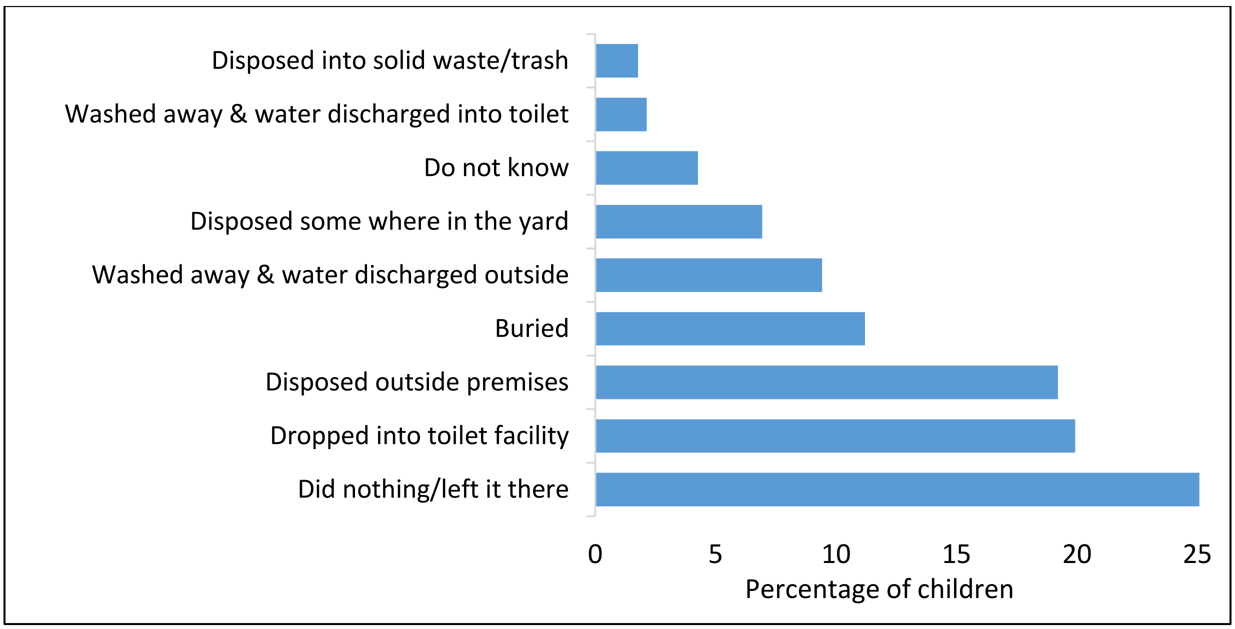

Figure 4-3: Method of disposal for the last child stool preceding the survey

Source: Author's computation using survey data.

a) Diarrhea as a child health problem

Our illustration shows that 16 percent of under-five children were reported by their primary caretakers to have experienced diarrheal illness during the two weeks preceding the survey (Table 4-3). The incidence of child diarrhea in relation to child and parental education

[23] A report also shows that there is clear difference between urban and rural areas in the way children's stools are disposed of. Nationally, a higher proportion of urban children's stools (63%) are disposed of safely than of rural children's stools (31%) (CSA & ICF International 2012).

characteristics is presented in Table 4-4. Diarrhea incidence was higher among children younger than 24 months, particularly among those between 6 and 23 months old. Children aged between 36 and 47 months old were the least affected by diarrhea. However, there was no significant difference in diarrhea incidence by the sex of the child; boys were slightly more likely to have experienced diarrhea (16.34%) than girls (15.08%).

Surprisingly, the reported diarrhea incidence was low among the children with illiterate primary caretakers and household heads. We had expected that diarrhea incidence to decrease with increasing education levels and literacy of primary caretakers and household heads. This could have been the result of a lower level of school attainment. For instance, only 4.3 percent of the household heads and 1.2 percent of the primary caretakers have completed primary school education. There is not much variation in the outcome of education. Also, this observation could also be due to primary caretakers who are illiterate having lower knowledge of the symptoms of childhood diarrhea.

Finally, children living in households with corrugated iron sheet roofing had lower diarrhea incidence than those living in households with thatch roofing (15.40% and 18.37% respectively). Although the physical characteristics of a household's environment often serve as indicators of the household's socioeconomic status, they are also considered to be an important determinant of the health of children and other household members (Cattaneo *et al.* 2009).

Table 4-4: Diarrhea incidence by demographic characteristics (last two weeks)

Age of child (months)	Incidence of diarrhea (%)	Number of children
< 6	11.54	52
6 -11	30.36	56
12 -23	33.02	106
24- 35	12.03	133
36 – 47	4.10	122
48 - 59	9.96	93
Sex of child		
Male	16.34	257
Female	15.08	305
Primary caretaker's literacy		
Yes	17.39	46
No	15.50	516
Household head's literacy		
Yes	16.36	238
No	14.71	324
Housing roofing material		
Corrugated iron sheet	15.40	513
Thatch	18.37	49

Source: Author's computation using survey data.

b) The effect of improved water supply and sanitation on child diarrhea

Diarrhea incidence among under-five children by the household WATSAN characteristics is presented in Table 4-5. Based on the WHO definition of improved water sources, children living in households with unimproved water sources were more likely to have had diarrhea in the past two weeks (18.34%) than those living in households with improved water sources (12.82%). This result is consistent when broken down by detailed water sources. Children living in households with private protected water had lower diarrhea incidence compared to those living in households with shared protected water sources. This might be because water is more available to households with private protected water, therefore resulting in less interruption to because of long traveling distance. Moreover, since water is available near to their living area, household members, especially adult women, can use the time and energy saved to provide better care for their children. However, diarrhea incidence was much higher in households with contaminated POU water (24.46%) than a household with uncontaminated POU water.

The hygiene habits of a child's caretaker were also an important factor. As shown in Table 4-5, the diarrhea incidence among children was lower if their caretaker practiced handwashing (18.02% as opposed to 9.55%). Diarrhea incidence was also higher among children whose households treated their drinking water, although the number of such households is small. Households that treated their water likely have water sources with poorer quality than households that do not treat water. However, children in households treated their water had lower diarrhea incidence than those in households that did not treat their water. Households in the study areas seldom practiced water treatment. Slightly below 8 percent of households reported that they use some form of water treatment with 81 percent of these households applying chlorine-based methods to treat their water during the month preceding the survey. On the other hand, no significant difference in diarrhea incidence was observed between irrigating and non-irrigating households in the two weeks preceding the survey. There was also no significant difference in diarrhea incidence between households with and without a pit latrine.

Table 4-5: Diarrhea incidence by WASH characteristics (last two weeks)

	Incidence of diarrhea (%)	Number of children
Water source based on WHO		
Improved source	12.82	273
Unimproved source	18.34	289
Water sources		
Private protected dug well	6.67	30
Shared protected dug well/spring	13.58	243
Unprotected well/spring	18.83	223
Surface water	16.67	66
Storage water quality		
Contaminated	24.46	327
Uncontaminated	3.4	235
Handwashing with soap		
Yes	9.55	157
No	18.02	405
Water purification/treatment		
Yes	5.00	40
No	16.48	522
Latrine		
Yes	15.41	231
No	16.02	331
Irrigation farming		
Yes	15.38	377
No	16.22	185

Source: Author's computation using survey data

c) Health knowledge and hygiene awareness

While 77 percent of the primary caretakers thought that diarrhea can be prevented, most did not see that poor water quality and lack of proper hygiene and sanitation as potential causes of childhood diarrhea. In most cases, the primary caretakers considered contaminated food as the major cause of diarrhea in young children, followed by bad or poor water quality. While 15.42 percent of the primary caretakers did not know what causes diarrhea, other factors, such as poor hygiene, dirty hands, flies and germs, and poor sanitation practices, were cited as causes of high diarrhea incidence by the study participants (Figure 4-4).[24]

[24] A report from the Mecha woreda health center, one of the study district, showed that pneumonia, diarrhea (non-bloody), malaria PF, acute febrile illness (AFI), acute upper respiratory infection, malaria PV and infection of skin were the top seven diseases morbidity for under-five years in 2013.

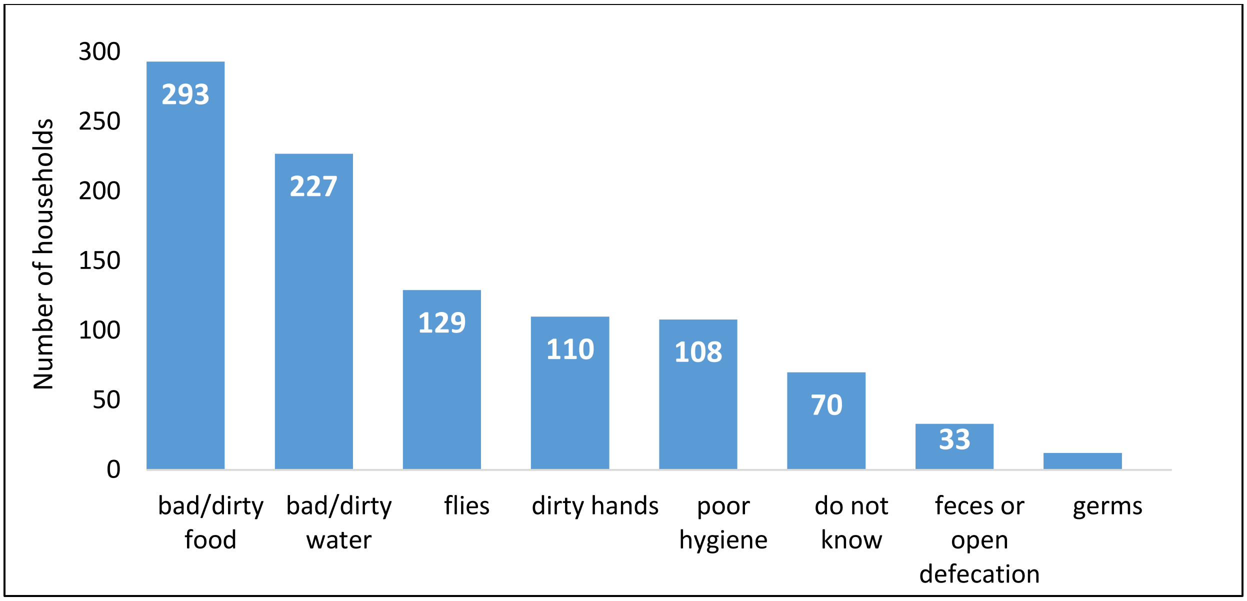

Figure 4-4: Causes of childhood diarrhea reported by the primary caretakers

Source: Author's computation using survey data.

4.4 Empirical Strategy

This section outlines the empirical strategy employed to explain the impact of household drinking water quality and sanitation behavior on child health outcomes. The dependent variable indicates the self-reported diarrhea incidence in the two weeks preceding the survey. To identify a robust relationship between POU water quality and sanitation and health outcomes, the robustness of the results was examined using a range of estimation strategies.

Establishing the causal impact of drinking water quality on child health outcomes based on cross-sectional data is difficult as it requires a careful investigation of the treatment variable to address the possible endogeneity problem. For instance, endogeneity can arise where there is an unobserved covariate that determines both water quality and health outcomes.[25] In this analysis, POU drinking water quality was used as the treatment variable. Water quality was determined based on the results of the microbiological water sample tests during the data collection period. In line with the WHO guidelines for drinking water quality, water is considered unsafe or contaminated if the *E.coli* colony count per 100ml of water is greater or equal to one. In this case, however, endogeneity of sanitation variables was not an issue as we used village-level (neighborhood mean) indicators for both pit latrine and the disposal of child stools.

[25] Moreover, the water quality variable may be an endogenous regressor due to unobservable heterogeneity among household members or omitted variables which cannot be captured in our data affecting both household drinking water quality and health or measurement errors.

4.4.1 Instrumental variable approach

Given the likely endogeneity of POU drinking water quality, inferring the causal impact of water quality on health outcomes from cross-sectional data is difficult. In this chapter, the impact of drinking water quality on child health outcomes was analyzed using a two-stage instrumental variables approach. For the first stage consider the following linear probability model:

$$W_{ij} = X_{ij}\beta_1 + Z_{ij}\eta_1 + N_j\mu_1 + \upsilon_{ij} \tag{4.1}$$

where treatment W_{ij} of each household i in community *j* is predicted using a vector of household characteristics X_{ij} ; Z_{ij} is a vector of instrumental variables; N_j is a vector of socio-demographic factors, which is constant within a community *j*; and a non-systematic error term υ_{ij}, which varies over households such that $E\left[\upsilon_{ij} \middle| X_{ij}, Z_{ij}, N_{ij}\right] = 0.$ While β_1, η_1 and μ_1 are unknown parameters to be estimated in the first stage. The second stage employs the predicted treatment status $\widehat{W_{ij}}$ from Equation (4.1) to estimate the treatment effect on outcome H_{ij}, such that

$$H_{ijk} = X_{ij}\beta_2 + \widehat{W_{ij}}\theta + N_j\mu_2 + \varepsilon_{ij} \tag{4.2}$$

where H_{ijk} denotes the outcome (e.g., diarrhea) for child k in household i and in community j, X_{ij} is a vector of household- and child-specific characteristics, and N_j are the same covariates as used in stage 1.

4.4.2 Bivariate probit estimator

As an alternative to the standard linear instrumental variable (IV) methods, Greene (2012) has shown that average treatment effects (ATE) can be obtained by a bivariate probit model (BP). The BP model is a two-equation binary outcome model with correlated error disturbances. The disturbance terms of the two equations are assumed to be jointly distributed as standard bivariate normal. In this approach, the models are estimated simultaneously using maximum-likelihood (ML) estimation.

To account for any potential selection effects, the endogeneity of treatment (W) and outcome (H) may be modelled jointly based on the assumption that the treatment has a direct causal impact on the outcome and both are influenced by common observable factors. Suppose H represents the observed health status of a child and takes a value of 1 if a child had diarrhea in the last two weeks preceding the survey, and zero if otherwise, then the observed response variable H is related to an unobserved latent variable H^* as follows:

$$H_{ijk}^{*} = \alpha_{1i}X_{ij} + \alpha_{2i}W_{ij} + \varepsilon_{1i}$$

$$H_{ijk} = \begin{cases} 1 & if \quad H_{ijk}^{*} > 0 \\ 0 & otherwise \end{cases} \tag{4.3}$$

where X is a vector of control variables; W is a dummy variable with a value of 1 if the water is uncontaminated, and zero if otherwise; α_1 is a vector of parameters to be estimated; α_2 is the parameter of interest associated with the dummy variable; ε_{1i} is a residual term, with $E[\varepsilon_{1i}] = 0$ and $var[\varepsilon_{1i}] = 1$; and i indexes households.

Equation (4.3 gives an unbiased parameter estimate of α based on the assumption that W is an exogenous variable. But the validity of this assumption can be questioned because the observed variation in W may reflect the unobserved factors that also influence the outcome variable H. Within a given neighborhood, some households may have unobserved preferences that causes them to have better household water quality than other similar households (Koolwal & Van de Walle 2010). Therefore, a simplistic comparison of child health status between households with contaminated water and households with uncontaminated water would lead to biased results. To account for the endogeneity of the water quality variable W, the bivariate probit model was constructed as:

$$H_{ijk}^{*} = \alpha_{1i}X_{ij} + \alpha_{2i}W_{ij} + \varepsilon_{1i}$$

$$W_{ij}^{*} = \beta_{1i}X_{ij} + \beta_{2i}Z_{ij} + \varepsilon_{2i} \tag{4.4}$$

$$W_{ij} = \begin{cases} 1 & if \quad W_{ij}^{*} > 0 \\ 0 & otherwise \end{cases}$$

where W_{ij}^{*} represents a latent continuous variable, Z is a vector of instrumental variables, and by assumption we have $E[\varepsilon_{1i}] = E[\varepsilon_{2i}] = 0$ and $var[\varepsilon_{1i}] = var[\varepsilon_{2i}] = 1$ with $cov[\varepsilon_{1i}\varepsilon_{2i}] = \rho$. *Rho* measures the correlation between omitted or unobserved factors in the health and water quality equations (Wooldridge 2010). β_1 and β_2 are vectors of parameters to be estimated, and a Wald test can be applied to ρ to test for the exogeneity of W. If ρ is significantly different from zero, then we can estimate the two equations jointly with a bivariate probit approach using maximum likelihood (ML), and it will produce consistent estimates. Here, we estimated a recursive bivariate probit model whereby water quality appeared as a regressor in the health outcome equation.[26]

[26] Generally, Nichols (2011) showed that in case of a binary regression with a binary endogenous variable linear IV generates robust consistent estimates of the ATT (average treatment on the treated) while bivariate probit produces efficient estimates of the ATE.

4.5 Estimation Results and Discussion

To address the possible endogeneity of POU water quality, we proposed two variables as instruments for the treatment variable. The first instrument is the type of primary sources from which households fetch their drinking water. In the study areas, most households take water from community water sources, and most rural households do not have alternative drinking water sources. In our sample, only 5 percent of the households have access to an improved private water source in their living area. The second instrument is the existence of water user association/committee in the village. We asked households whether there is a WUA responsible for taking care of community water sources in the village. Water user associations are primarily responsible for monitoring, supervising and handling conflicts among household users of community water sources. Such groups are instituted in many villages for governing rural communal water sources when a new water source is developed. For instance, 62 percent of the villages in Mecha district had water user groups (Tilahun *et al.* 2013). Water source and water user group can both be treated as exogenous variables in the context of this study as they do not affect child health outcomes directly.

The impact of safe water and sanitation behavior on childhood diarrhea estimation is presented in Table 4-7. Columns 1 to 3 report the linear probability model (OLS) and the binary probability model (Probit), which do not take into account any endogeneity problem. Estimating the "naïve" model helps to examine the extent to which our results are sensitive to the assumption that stored household water quality is an exogenous variable. Columns 4 to 7 show the standard instrumental variable (IV) models and the recursive bivariate probit (BP) models. As the regression results show, drinking water quality, safe child stool disposal and latrine density significantly affected child diarrhea incidence in all model specifications. The estimates of other relevant variables coefficients are also statistically significant with the expected signs across all specifications.

Both the linear IV and BP two-stage models require a strong treatment prediction in the first stage. The first-stage regressions showed a statistically significant relationship between the treatment and instrument variables in Table 4-6. This relationship is robust with and without second-stage controls. The r-squared is modest, and a large F-statistics in the first-stage regression suggests bias from weak instruments is unlikely to be a problem. For the linear IV model, the over-identification restriction test regarding the instruments is not violated ($p=0.764$), which implies that we can reject the null hypothesis that at least one of the instruments is invalid. On the other hand, considering the exogeneity test for household water quality, Wooldridge's score (robust regression) test does not reject the null hypothesis that water quality is exogenous at any of the conventional significance levels ($p=0.867$), as presented in Table 4-6. Even if stored household water quality were exogenous, the linear IV estimates are still consistent but are less efficient than the least-square estimates.

Table 4-6: Household water quality: First-stage regression

VARIABLES	(1) LEAST SQUARES	(2)	(3) PROBIT	(4)
Water source (1=protected)	0.134**	0.124**	0.127***	0.115***
	(0.055)	(0.048)	(0.049)	(0.042)
Water user association	0.383***	0.328***	0.337***	0.273***
	(0.060)	(0.058)	(0.048)	(0.046)
Observations	565	562	565	562
Stage 2 controls	NO	YES	NO	YES
R-squared	0.19	0.32		
Model F-Test	53.37	21.44		
Model Chi2			78.03	186.09
Instruments jointly p-value	0.000	0.000	0.000	0.000
Basmann over-identification p-value	0.764	0.915		
Robust regression test for endogeneity p value	0.867	0.958		

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1
Probit in average marginal effects.

Moreover, the exogeneity test from the BP framework, as shown in columns 6 and 7 (Table 4-7), indicated that $\widehat{\rho}$ is not statistically different from zero (p=0.648). The result indicated that the error terms are independent, that is, the variable stored water quality can be treated as exogenous. The BP model is, therefore, equivalent to two independent probit models.

In the preferred probit model (column 2 of Table 4-7),[27] uncontaminated stored water and safe child stool disposal decreased the incidence of child diarrhea, whereas a higher pit latrine density increased the risk of diarrhea for under-five children in all model specifications. The impact of safe drinking water on child diarrhea incidence was modest and statistically significant at 1 percent level, with a marginal effect of 0.15; that is, the probability of child diarrhea was 15 percentage points lower in households with safe household drinking water. Safe child stool disposal decreased child diarrhea incidence by 23 percent, and pit latrine density increased it by 13 percent. The finding that neighborhood pit latrine concentration increased the risk of diarrhea in young children casts serious doubt on the assumed health and social benefits of moving from open to fixed-location defecation.[28]

[27] The probit regression model is preferred because it is more efficient than the 2SLS or BP when endogeneity is not a problem.

[28] This indicates that household level variation alone does not seem to be sufficient to capture children's potential exposure to poor WATSAN. Rather, the type of sanitation technologies and the practice of child stools disposal at your neighbour are also important determinants of a child's health status.

Table 4-7: Health effects of water quality and sanitation: Diarrhea in under-five children

VARIABLES	(1) OLS	(2) Probit	(3) Probit	(4) 2SLS	(5) 2SLS	(6) BP	(7) BP
Water quality (1= no *E.coli*)	-0.140***	-0.149***	-0.148***	-0.119**	-0.137**	-0.119*	-0.125*
	(0.027)	(0.031)	(0.030)	(0.059)	(0.058)	(0.070)	(0.073)
Child age in months	-0.004***	-0.004***	-0.004***	-0.004***	-0.004***	-0.004***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Child is male	0.005	0.003	0.002	0.005	0.007	0.003	0.002
	(0.026)	(0.021)	(0.021)	(0.025)	(0.025)	(0.021)	(0.021)
Mother age	-0.062***	-0.052***	-0.049***	-0.062***	-0.058***	-0.052***	-0.048***
	(0.023)	(0.017)	(0.018)	(0.022)	(0.022)	(0.017)	(0.017)
Mother age square	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Highest education completed	0.003	-0.000	0.002	0.002	0.006	-0.001	0.001
	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.006)
Number of adult female	-0.073**	-0.073*	-0.068*	-0.076**	-0.072**	-0.075**	-0.070**
	(0.030)	(0.037)	(0.036)	(0.031)	(0.031)	(0.036)	(0.035)
Household density	0.046**	0.036***	0.037***	0.047***	0.048***	0.037***	0.038***
	(0.019)	(0.012)	(0.012)	(0.018)	(0.018)	(0.012)	(0.012)
Exclusive breastfeeding (dummy)	-0.083***	-0.071***	-0.070***	-0.083***	-0.084***	-0.070***	-0.070***
	(0.026)	(0.021)	(0.021)	(0.026)	(0.027)	(0.021)	(0.021)
Dependency ratio	0.024	0.040	0.068	0.016	0.073	0.031	0.061
	(0.150)	(0.131)	(0.135)	(0.139)	(0.146)	(0.126)	(0.131)
Number of medical visits	0.043***	0.032***	0.032***	0.043***	0.043***	0.032***	0.032***
	(0.014)	(0.009)	(0.009)	(0.013)	(0.013)	(0.009)	(0.009)
Minutes to water source	0.002*	0.002**	0.002**	0.002*	0.002*	0.002**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Handwashing with soap (dummy)	-0.055*	-0.059*	-0.059*	-0.058*	-0.059*	-0.062*	-0.061*
	(0.032)	(0.033)	(0.032)	(0.033)	(0.032)	(0.035)	(0.034)
Livestock holding	0.021**	0.020**	0.022**	0.023**	0.025**	0.023**	0.024**
	(0.010)	(0.010)	(0.010)	(0.011)	(0.010)	(0.011)	(0.011)
Irrigating households (dummy)	-0.005	-0.009	0.003	-0.004	0.014	-0.007	0.003
	(0.036)	(0.037)	(0.042)	(0.035)	(0.039)	(0.037)	(0.041)
Log of assets value	-0.046**	-0.037**	-0.030*	-0.047**	-0.034*	-0.039**	-0.031*
	(0.020)	(0.017)	(0.018)	(0.019)	(0.020)	(0.017)	(0.017)
Safe child stool disposal	-0.216***	-0.229***	-0.226***	-0.218***	-0.219***	-0.229***	-0.225***
	(0.078)	(0.084)	(0.086)	(0.076)	(0.077)	(0.083)	(0.085)
Latrine density	0.141**	0.135**	0.128**	0.137**	0.129**	0.129**	0.124**
	(0.066)	(0.062)	(0.058)	(0.064)	(0.062)	(0.063)	(0.060)
Log of total expenditure			-0.051		-0.086**		-0.051
			(0.041)		(0.037)		(0.041)
Distance to health center			0.000		0.000		0.000
			(0.004)		(0.004)		(0.004)
Constant	1.467***			1.468***	1.857***		
	(0.304)			(0.296)	(0.344)		
Observations	562	562	562	562	562	562	562
Model F-Test	14.58						
Model Chi2		232.22	252.73	273.79	295.08	652.61	809.36
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Probit rho Chi2						0.208	0.108
Probit rho p-value						0.648	0.742

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1; and Probit and BP in average marginal effects.

Regarding the control variables, most of the estimated coefficients had the expected signs. Child age is significant and negative, implying a reduction of diarrhea incidence as a child grows older.[29] In terms of gender, male and female children are equally affected by diarrhea. The relationship between a mother's age and diarrhea incidence in her children is nonlinear, and this indicated that children with a younger mother tend to fall ill more often. However, the age of a household head had no significant impact on childhood diarrhea incidence. Also, the level of household education showed no clear effect. This is because usually the primary caretaker's level of education is most important in improving child health.

Time to a water source was marginally significant at 5 percent level, but the estimated effect on diarrhea incidence was much smaller than some of the estimates reported in the existing literature in sub-Saharan Africa (Pickering & Davis 2012). The estimated coefficient is extremely small, and this might be because households with water sources on their premises are not better off due to contamination from own latrine and unhygienic water withdraw from sources. Distance to the water source also affected the quality and quantity of water a household could collect. The farther a water source from home, the less water a household could collect and use. In addition to affecting health, inadequate water quantity may cause households to limit their handwashing and key hygiene practices and to wash dishes and clothes using water from unimproved sources. This evidence further suggested that the health benefits of having access to improved water may not be substantial if water sources are further away from the house and therefore requiring much time and energy to fetch the water. Moreover, closer proximity to a water source could have an indirect health benefit. By reducing the time spent on collecting water, more time is available for looking after children or engaging in other productive and income-generating activities. In terms of hygiene behaviors, we also found that handwashing with soap marginally improves child health outcomes. Handwashing with soap is considered to be an effective defensive mechanism to remove germs and pathogens from hands.

Children belonging to a household with a greater number of adult women seemed to be better off Table 4-7. It can be argued that children with an additional adult woman get better care. The household density variable had a positive sign and was statistically significant at 1 percent level. It was expected that the relative disease burden would increase in households living in congested or overcrowded conditions. It seemed plausible that children living under such conditions are more exposed to health risks. Moreover, children in larger families are more exposed to health risks because of the larger number of hand-to-water pathogen transmission pathways. On the other hand, household dependency ratio did not have any significant effect on child health.

Exclusive breastfeeding also had a significant effect (7%) on diarrhea incidence in young children. It is one of the most robust findings in determining childhood diarrhea with large protective

[29] Child age-squared term was excluded in the regression as it is not statistically significant, but children between 6 and 24 months old were the most affected age group in this study.

effect. We expected a much stronger effect for children under-three years than under-five years but the impact is the same. However, this variable is more likely to suffer from recall bias or measurement error. The number of medical visits in the previous year significantly increased with diarrhea incidence. This variable is used as a proxy for the general health status of a child in the previous year. We expected that children who often fall sick have a weak immune system and are therefore more susceptible to diarrheal diseases.

We could not find any significant difference in childhood diarrhea incidence between irrigating and non-irrigating households. However, livestock ownership increased diarrhea incidence, and its coefficient was statistically significant at 5 percent level. On the other hand, we expected children from wealthier households to be better off than those from poorer households because higher income allows a household to access better health-care services and invest in measures that improve their health. Though the estimated effect is marginally statistically significant, its economic relevance is quite small as the value is logged. Distance to the nearest health center did not have any significant impact on health either. It is evident from this study that stored drinking water quality, sanitation, handwashing and breastfeeding habits are important factors in determining the risk of childhood diarrhea.

Our findings regarding the health effects of latrine contradict the claim that moving from open defecation to the first ladder of sanitation services generates the greatest amount of benefits from sanitation services. There could be a few reasons for this apparent paradox: first, pit latrine attracts flies, which are vectors of pathogens that can transmit diseases through direct contact with young children or food; second, we found that availability of latrine deteriorates POU water quality, particularly for households whose water sources are located within the living area. The sub-sample analysis presented in the appendix Table A1 showed that the concentration of *E.coli* is significantly higher in households whose water source was located near their living area, even after controlling for other household characteristics (p=0.001). Well water may be polluted by leachates from latrines if the latrines are not located sufficiently far away from water sources. Other studies have shown that in rural areas, latrines can be a source of ground water pollution (for a detail discussion see Banks *et al.* 2002; Graham & Polizzotto 2013). Poorly maintained latrines can generate negative externalities, which affect not only its owner but also the neighboring communities. There must be a shift in government policy away from building simple pit latrines to create open defecation free villages in rural areas because it may not generate the desired health benefits from sanitation services. Existing latrines should be upgraded to make them safer and hygienic as simply adopting pit latrines may worsen a community's health status at large.

Generally, the study highlights the evidence that stored drinking water quality and sanitation issues are a great public health concern in rural Ethiopia. Infants and young children are more likely to suffer from water- and fecal-related diseases than any other age groups. Promoting the following among the rural communities could substantially reduce the transmission of germs and pathogens that can cause diarrheal and other infectious diseases: 1) washing the hands of caretakers and children with soap at critical times, 2) adequate household water treatment and safe handling of water, 3) safe disposal of child stools, and 4) good hygiene practices when feeding and handling food. On the one hand, women are primarily responsible for collecting water for household use and other household chores, and they are usually the ones reinforcing hygiene practice at home. On the other hand, the level of education in the study areas is extremely low, especially for mothers (primary caretakers). Primary caretakers and women are therefore an important target group of any WASH-related interventions for them to be effective in reducing overall diseases burden.

Robustness check

The impacts of drinking water quality, safe stool disposal, and latrines on child diarrhea incidence are robust to model specifications and age. The result of the subsample analysis for under-three children (presented in Table 4-8) showed that good water quality and proper child stool disposal have a larger positive impact on younger children, while the impact of latrine density remained the same. Moreover, almost all the results are statistically not different from one another. With the regression estimates shown in (column 1, Table 4-9), we measured the effects of latrines at the household level, and the results showed that latrines had still a strong positive impact (8%) on child diarrhea incidence. However, the effect of water quality on child diarrhea is not big when *E.coli* coliform counts are considered as a continuous variable (presented in column 2, Table 4-9). Moreover, the way we defined 'safe child stool disposal' created some correlation between the variables 'safe child stool disposal' and 'latrine'. However, it did not cause much problem because less than 22 percent of the households used a toilet to dispose of the child stool.

Table 4-8: Health effects of water quality and sanitation: Diarrhea in under-three children

VARIABLES	(1) PROBIT	SE	(2) PROBIT	SE
Water quality (1= *no E.coli*)	-0.199***	0.044	-0.199***	0.043
Child age in months	-0.005***	0.002	-0.005***	0.002
Child is male	0.010	0.031	0.009	0.031
Mother age	-0.060**	0.024	-0.057**	0.024
Mother age squared	0.001***	0.000	0.001**	0.000
Highest education completed	0.002	0.007	0.003	0.007
Number of adult female	-0.082*	0.049	-0.081*	0.048
Household density	0.039**	0.016	0.039**	0.016
Exclusive breastfeeding (dummy)	-0.074**	0.037	-0.074**	0.037
Dependency ratio	0.025	0.178	0.034	0.183
Number of medical visits	0.041***	0.012	0.041***	0.012
Minutes to water source	0.002**	0.001	0.002**	0.001
Handwashing with soap	-0.056	0.043	-0.055	0.043
Livestock holding	0.014	0.015	0.015	0.015
Irrigating households (dummy)	-0.020	0.048	-0.017	0.054
Log of assets value	-0.046*	0.026	-0.043	0.027
Safe child stool disposal (village mean)	-0.324***	0.103	-0.307***	0.111
Latrine density (village mean)	0.137**	0.065	0.138**	0.068
Log of total household expenditure per adult equiv.			-0.021	0.056
Distance to health center			0.002	0.006
Observations	361		361	
Pseudo R-squared	0.30		0.30	
Model Chi2	154.98		206.70	
Model p-value	0.000		0.000	

Robust standard errors adjusted for clustering at village level;
Significance *** p<0.01, ** p<0.05, * p<0.1
Probit in average marginal effects.

Table 4-9: Health effects of water quality and sanitation: Diarrhea in under-five children

VARIABLES	(1) PROBIT	SE	(2) OLS	SE
Contaminated water quality (log(1+*E.coli*)			0.082***	0.008
Water quality (1=no *E.coli*)	-0.150***	0.033		
Pit latrine (dummy)	0.078**	0.035		
Latrine density (village mean)			0.157**	0.060
Safe child stool disposal	-0.186**	0.078	-0.201**	0.083
Child age in months	-0.004***	0.001	-0.004***	0.001
Child is male	0.005	0.020	0.009	0.025
Mother age	-0.055***	0.018	-0.049**	0.021
Mother age squared	0.001***	0.000	0.001**	0.000
Highest education completed	0.000	0.005	0.003	0.005
Number of adult female	-0.079**	0.038	-0.050	0.031
Household density	0.038***	0.012	0.028*	0.016
Exclusive breastfeeding (dummy)	-0.071***	0.022	-0.078***	0.025
Dependency ratio	0.077	0.134	0.002	0.142
Number of medical visits	0.032***	0.009	0.036***	0.013
Minutes to water source	0.002**	0.001	0.001	0.001
Handwashing with soap	-0.063*	0.034	-0.030	0.029
Livestock holding	0.018*	0.010	0.004	0.009
Irrigating households (dummy)	-0.013	0.040	-0.023	0.037
Log of assets value	-0.040**	0.018	-0.024	0.018
Distance to health center	-0.001	0.005	-0.001	0.004
Constant			0.966***	0.287
Observations	562		562	
Model Chi2	218.48			
Model F-stat			18.40	
Model p-value	0.000		0.000	
Pseudo / R-squared	0.33		0.35	

Robust standard errors adjusted for clustering at village level;
Significance *** p<0.01, ** p<0.05, * p<0.1
Probit in average marginal effects.

Longitudinal diarrhea prevalence

It is understood that 'period prevalence' is more preferred to 'point prevalence' in many health outcome studies—particularly infectious diseases.[30] Morris *et al.* (1996) argue that longitudinal prevalence (LP) of diarrhea is more closely associated with child growth faltering and mortality than the incidence of diarrhea. Therefore, in this section, we measure diarrhea using longitudinal prevalence rather than incidence. LP can be calculated as the total number of days a child has diarrhea divided by a total number of days of observation (Morris *et al.* 1996). We examined what determines LP for under-five children; is there any significance difference in the LP of diarrhea between children from irrigator and non-irrigator households. Further, we also discussed the number of episodes of diarrhea and duration.

The data comes from the same households. Field workers visited each household biweekly, for 12 weeks (April 2014—June 2014), that is, each household was visited a maximum of six times, and asked the child's primarily caretaker—usually the mother, if the children had diarrhea defined as 'three or more loose stools or a loose stool containing blood or mucus in a twenty-four hours period' in the preceding two weeks. If so, the primary caretaker's also asked for how many days the symptoms stayed.

Descriptive analysis

The proportion of under-five children with diarrhea in the last two-weeks preceding the survey in each visit round is presented in Figure 4-5. The minimum prevalence rate was observed during the 1st visit-round while the maximum was observed during the 5th round (15.96% versus 20.11%, respectively). The overall average prevalence rate during the whole period was 17.85 percent, which is slightly higher compared to the baseline prevalence rate of 16 percent. As can be seen from the figure, diarrhea prevalence rate is, however, drastically increased from 15.96 percent to 18.94 percent (visit 1 to visit 2) and from 16.7 percent to 20.11 percent (visit 4 to visit 5). Moreover, based on irrigation status, we find that children from irrigator households are more likely to experience diarrhea than children from non-irrigator households.

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[30] Point prevalence is a single assessment of a fixed time whereas period prevalence is defined as "the percentage of a population that are cases at any time within a stated period." In period prevalence subjects being followed or observed repeatedly over a period of time (for instance, multiple episodes of diarrhea or other infectious diseases).

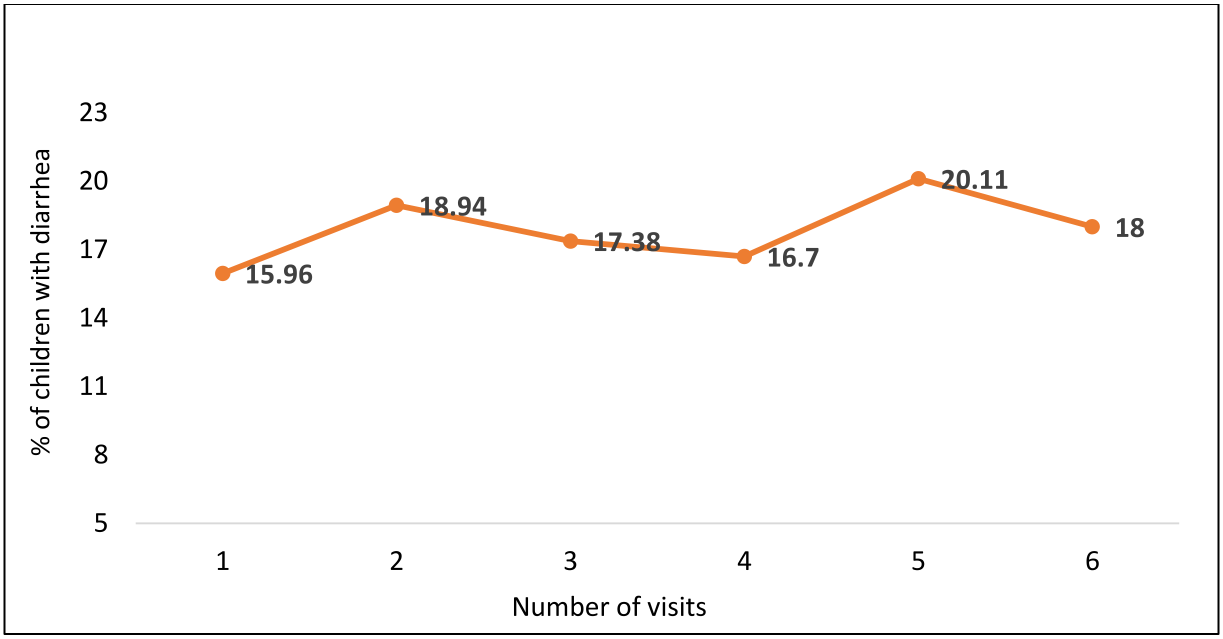


Figure 4-5: Prevalence of diarrhea for under-five children in the follow-up survey

Source: Author's computation using own survey data.

The proportion of children with diarrhea by the number of episode is presented in Figure 4-6. It shows that about 35 percent of the children did not have diarrhea, and one-third of the children had diarrhea once over the observation period. Moreover, few children had experienced diarrhea more than three times over the period. On the other hand, the proportion of children with diarrhea by the number of episodes and irrigation status is presented in Figure A1 (see Appendix 4). The figure suggests that on average children living in irrigator households are slightly more likely to experience more diarrhea episodes than children living in non-irrigator households (5.22 episodes per child-year compared with 4.35 episodes per child-year). Confirming to the recent estimates of Walker *et al.* (2012), the incidence of diarrhea per child year in Africa is 3.4 (2.2, 5.1) episodes.

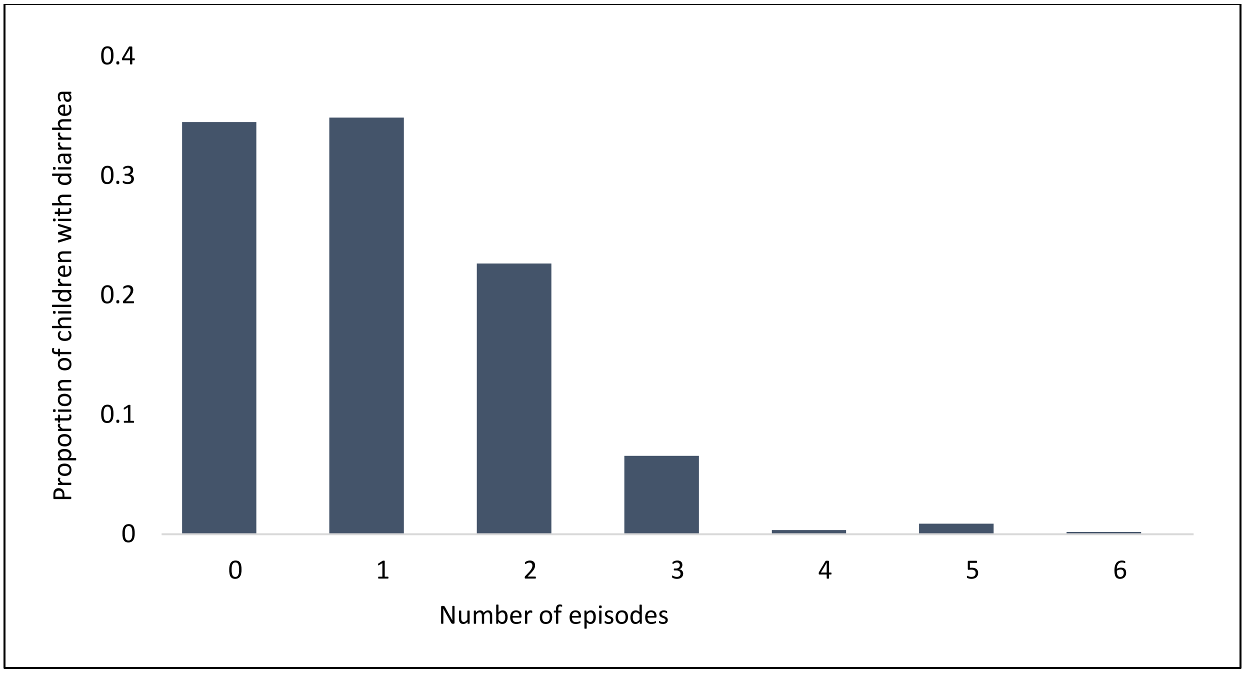


Figure 4-6: Proportion of children with diarrhea by number of episodes

Source: Author's computation using own survey data.

The proportion of children with diarrhea by the number of episode duration day is presented in Figure 4-7. It suggests that diarrheal illness lasts for three days for more than one-third of the children who had already diarrhea over the period. The mean episodes duration of diarrhea is about 3.4 days; however, as the figure shows few children had persistent diarrhea during the period (lasting for 10 or more days). Similarly, the proportion of children with diarrhea by episode duration days and irrigation status is presented in Figure A2 (see Appendix 4). In general, the results may be suffered from long recall periods (last 14 days).

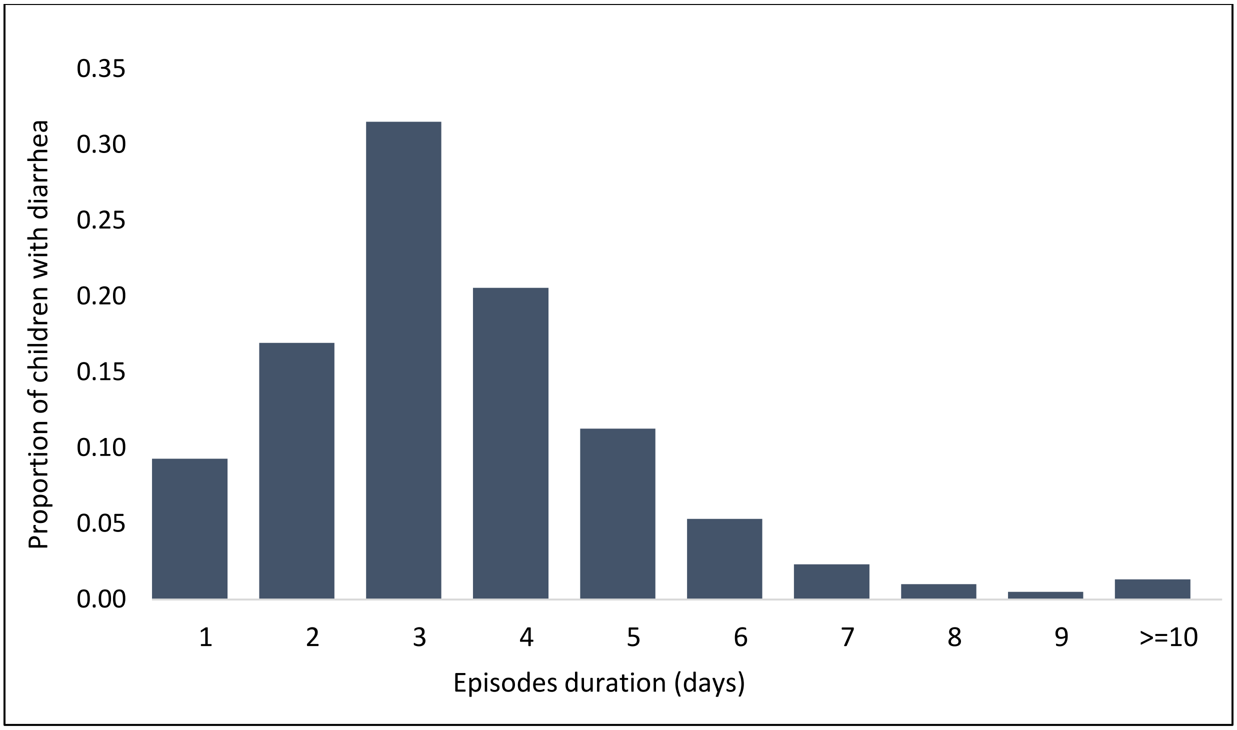


Figure 4-7: Proportion of children with diarrhea by episode duration

Source: Author's computation using own survey data.

4.6 Conclusions and Recommendations

Using a combination of estimation methods, this study examined the impact of household drinking water quality and sanitation behavior on child health in rural Ethiopia. Diarrhea was used as a health outcome. In this chapter, we focused on children under the age of five because children in this age group are the most vulnerable to water- and fecal-related diseases. The study relied on primary survey data from rural areas in Fogera and Mecha districts of Ethiopia. As access to clean water and improved sanitation is lacking, water-related diseases are the most prevalent health problem in the study areas.

Some studies have been conducted to quantify the impact of safe drinking water on child health. However, still little is known about it in the context of rural areas, where access to improved water is inadequate and the majority of the population rely on unimproved water sources. One of the innovations of this study is that household drinking water quality was determined by testing the microbiological quality of household storage water using membrane filtration method rather than looking at the types of household drinking water sources.

Inadequate access to improved WATSAN facilities remains a major cause of health problems in Ethiopia, particularly in the rural areas, where a lack of clean drinking water and unsafe sanitation practices are the main causes of diarrheal diseases among under-five children (CSA & ORC Macro

2006). The negative health impact of contaminated water is worsening because most rural households only have access to drinking water from unprotected sources and they often consume the water without any in-house treatment. Moreover, most rural population have a poor understanding of the importance of proper hygiene practices, which further increases their already high risk of contracting infectious diseases.

The findings suggest that access to an improved drinking water source is low in the study areas —only 50 percent of the households have access to improved water sources. The household water sample test also indicated that poor POU water quality is a significant problem in rural Ethiopia. Besides, most of the so-called 'improved' water sources in rural areas do not guarantee the water is safe for consumption, the problem of unsafe drinking water is exacerbated by POU water contamination through unsafe water storage and handling practices. Even though access to clean water and simple pit latrines has increased significantly during the last decade, many of the surveyed rural residents did not regard the progress as satisfactory in terms of access to clean water supply. Rural households complained about a lack of access to safe water sources, poor water quality, and having to travel long distances to access drinking water.

In terms of sanitation, we found that 42 percent the households were equipped with a simple pit latrine while the rest of our sample households defecated in the open. Access to improved sanitation facility is virtually non-existent in the study areas, and the existing sanitation technology used there is considered unimproved based on the commonly used WHO definition. In some cases, these latrines do not have proper structure and become dysfunctional for many reasons, including the fact that they are not connected to any sewerage system.

Surprisingly, neighborhood latrine concentration increased the risk of childhood diarrhea. We found that children living in neighborhoods with high latrine density are at higher risk of contracting diarrheal disease. This indicates that existing pit latrines are not safe to use and do not protect against diarrheal diseases. Others have argued that the greatest benefit of sanitation, for both health and social reasons, can be achieved when people move from open to fixed-location defecation (Mara *et al.* 2010). However, contrary to the belief of many, our study suggests that in a rural setting, where settlements are scattered, defecating in the open might not be more harmful than using a simple pit latrine. Nevertheless, we are not encouraging open defecation per se, but rather arguing that simple pit latrines are not good enough to achieve the desired health benefits of sanitation. A study conducted in Ethiopia also found using pit latrines offered no improvement over defecating in the open in terms of health outcomes (Cameron 2009).

Some policy recommendations can be derived from these findings. First, more efforts should be put into increasing the existing coverage of improved rural water supply. This can be achieved by developing new water points and upgrading existing unimproved sources. Improving access to clean water supply not only increases the quantity of clean water available for household consumption but also allows households to save much time by reducing the distance between each household and the nearest water access point. Second, pit latrines should only be adopted if adequate hygiene can be maintained, otherwise, they can pose a serious health risk, especially if they are not fly-proof or insufficiently away from water wells. Third, a water quality monitoring system which monitors a set of common water quality indicators should be in place to ensure rural water supply schemes comply with quality standards. Fourth, household water treatment and safe water storage should be promoted to address POU water quality concerns. Increasing the provision of rural water supply alone may not be enough if households do not treat their water or practice safe water storage and handling. We, therefore, recommend all rural households to develop the habits of household water treatment to ensure safe water quality—particularly for drinking. Fifth, households should be made aware of the importance of safe WASH through educational campaigns so as to help them change their long-held habits and hygiene behaviors. As the study revealed, when primary caretakers consistently practice handwashing with soap at critical times and safe child stool disposal, the risk of young children contracting diarrhea was reduced. Therefore, educating rural communities on the potential sources of water contamination, proper water treatment methods, safe disposal of feces away from the domestic environment, and good hygiene practices, such as handwashing with soap at critical times, could result in significant health gains to the rural population. At the same time, containers used for collecting or storing water need to be cleaned regularly to ensure safe water quality.

On a policy level, our findings indicate that WASH interventions are also needed to improve household water treatment, safe sanitation and hygiene practices in rural areas. Primary caretakers often undermine the critical role that good hygiene plays in improving overall health outcomes (Roushdy *et al*. 2012). In addition to affecting health, inadequate water supply may cause households to limit their handwashing practices and to wash dishes and clothes using water from unimproved sources. The study also highlights that proper child stool disposal behavior is lacking. Most of the households perceived child feces to be less harmful than adult ones and child feces were therefore often left around or disposed close to a household's living area. This further highlights the lack of awareness among the study households about the causes of diarrhea and the necessary remedial measures. Moreover, many primary caretakers do not consider diarrhea to be a serious health problem as it is common among young children. Education and public awareness campaigns could be an effective channel to disseminate information that can reduce child morbidity associated with insufficient WASH. This is particularly important in many rural areas of the country, where mothers usually have little education. Such campaigns can be implemented on the ground by health extension workers. Proper hygiene and childcare practices can be promoted through the Ethiopian government's Health Extension Program (HEP) in many rural villages of Ethiopia. A report on rural water supply in Ethiopia found that most rural water sources were poorly maintained and often contain water unsafe for drinking; in some instance, water sources were not functioning due to repair and maintenance problems (UNDP 2006). Poor people are the ones suffering the most from the burden of diseases associated with a lack of improved WATSAN services. The poor also lack awareness about the detrimental health impacts of poor water quality, unsafe sanitation habits, and inadequate hygiene practices. Our descriptive statistics provided clear evidence that most rural households practice unsafe child stool disposal, inadequate household water treatment, and improper hygiene.

Finally, to address the problem of WATSAN, the GoE has committed by adopting the Universal Access Plan to achieve 100 percent drinking water coverage at the national level. However, the overall progress has been slow and there is a disparity in development between urban and rural areas. The WHO/UNICEF (2015) report on the progress on WATSAN showed that in 2015, 57 percent of the population have access to improved water sources (compared to 13% in 1990) and 28 percent of the population have access to improved sanitation services (compared to 3% in 1990). It is clear that sanitation coverage is lagging far behind water supply coverage. There should be more concerted and coordinated actions to meet the SDG-6 which aims to ensure access to WATSAN for all. Unless efforts to increase access to improved WATSAN services are intensified and implemented in conjunction with the promotion of proper hygiene practices, communicable diseases will continue to remain a major cause of child morbidity and mortality in rural Ethiopia.

4.7 A Cost-Benefit Analysis (CBA) for Rural Water Supply in Ethiopia

This section analyzes the cost-effectiveness of investing in rural water supply. We considered a project to construct a drinking water well fitted with a hand pump in the study areas. Following Rogers *et al.* (1998) framework, we assessed the various components of costs and benefits of water supply as socioeconomic goods.

Welthungerhilfe provided data on capital investments, operation and maintenance (O&M) costs, the number of beneficiaries, and the lifespan of the well. The followings are assumptions for the cost-benefit ratio of investment on drinking water well with a hand pump in rural Ethiopia

- Average exchange rate $1 = 22.3 ETB (December 2016)
- Service life of the well is 10 years
- Capital charges (up-front initial investment) = $2,909
- Number of beneficiary households per well = 80 (400 people)
- Estimated shadow wage for adult woman and man is equal to $0.9, $1.9, respectively. That is, average shadow wage rate is equal to $1.4
- Discount rates 3, 5 and 10 percent

Shadow wage is derived from the marginal productivity of labor based on the estimated agricultural production function (see column 2 Table A10 in Appendix A), and computed as:

$MPL_i = \hat{\beta}_i \frac{\hat{y}}{L_i}$, where $\hat{\beta}_i$ the coefficient on log ($Labor_i$) and Y is the predicted values of output.

a) Costs Analysis

As a rule of thumb, 10 percent of capital charges are considered to be O&M expenses (Cameron *et al*. 2011). In this case, however, only the cost of the pump and salary for a security guard should be used for this calculation, which is much lower than the 10 percent of capital charges. Considering this, the O&M cost is estimated to be $141 per year. As the O&M cost is a recurring expense, it needs to be projected over the next 10 years, and the resulting O&M cost is $1,241 using 3 percent discount rate.

The next component of this analysis is the opportunity cost, which is the next best use of an input. The opportunity cost of an input is the competitive market price of that input. Beneficiaries of a well project are likely to participate in training for several hours (e.g. health and hygiene education, technical training). We assume that one working day per household is required at the time of well construction, and this should be accounted for as an opportunity cost for the beneficiaries. In this analysis, we used the average shadow wage rate to monetize all time-based measurements due to lack of competitive market price, and the total present discounted value (PDV) for the opportunity cost is estimated at $112.

As drinking water contamination both at the POS and POU is high, increasing access to safe water supply alone is not sufficient to improve health outcomes. We take into account the expenses required for treatment. Assuming the per capita per day water consumption is treated (8 liters per day), each person will need 2, 920 liters treated per year. Water treatment cost is estimated to be $0.70 per cubic meter (Rogers *et al*. 1998). The benefits for societal objectives can be significantly low unless water treatment is provided.

The last section of the cost analysis is to determine negative externalities (economic and environmental costs) associated with the project. As the negative economic externalities for constructing a well is unclear (Whinnery 2012) and data is not available, a value of $0 is used for this analysis. On the other hand, although the values are relatively small, there are possibly significant environmental externalities associated with the construction of a well. These costs are related to the raw materials and estimated to be $48 per well in east Africa (for a detail discussion, see Whinnery 2012).

b) Benefits Analysis

Improving access to safe drinking water can generate a broad range of economic and social benefits. One of the primary benefits of the project is the value to water users. In addition, other potential net benefits including benefits from indirect uses, benefits from return flows, adjustment for societal objectives, and intrinsic value can result from improved water supply. Benefits from return flows, intrinsic value, and indirect use from drinking water supply are set to values of zero because they are often assumed to be insignificant (Whinnery 2012). These benefits, however, could be much higher in irrigation and hydropower developments projects. In most cases, it is possible that livestock and/or small-scale agriculture could benefit from an improved water supply in rural areas. Excluding this and other possible indirect benefits make the analysis more conservative. This analysis focuses on the direct health impacts of clean water in terms of associated reduction in diarrhea and related diseases. Although there are other health issues related to lack of access to clean water, diarrhea is the most significant. This study does not take into account all secondary benefits or positive externalities to avoid possible double counting. Other direct benefits, such as money saved on medical expenses, are not included in this section either. Generally, such an approach only makes this analysis more conservative.

For estimating the value to water users, this analysis uses monetary value of time saved due to improved access to clean water supply for assessing the value of the project to its beneficiaries. In this case, data is available that estimates the average number of water collection trips per week and the time needed for a round water collection trip in rural households. An average household spends 2.36 hours per day for water collection activities. Multiplying this figure by 365 and then by the number of total beneficiary households gives the total hours spend for water collection. Furthermore, to monetize the value of time-saved, we use the average shadow wage rate ((1/8*2.36*80*365)*$1.4 = $12, 060. This benefit needs to be discounted for annual benefits in the future, and the resulting PDV of time saved is $114,934. The benefits of time saved due to a new community water source highly depend on the population density surrounding the location of the well. As populations are sparsely settled in rural areas, assuming zero water collection time for all the beneficiary households would over-estimate the value of users to water. However, this could be partly compensated by their willingness to pay the available water services, which we did not take into account.

Another important benefit from this project is to improve the health of community currently lacking access to safe drinking water; this might be the central reason for many organizations working in this sector. These key societal objectives can be measured using the concept of value-of-statistical-life (VSL), which VSL places an economic value to life lost/saved and/or productivity gain/reduction for a given individual. Viscusi and Aldy (2002) estimated the VSL in the United States at $8.9 million. To value the health impacts of the project (the monetary values estimates) the VSL must be set. The VSL in Ethiopia can be estimated by making appropriate adjustments (using GDP or GNI per capita), between the US and Ethiopia, and this results in a VSL of $257,018.

The next step is to estimate the value of a disability-adjusted life year (DALY). The DALY approach is designed to quantify the impact of various diseases on the productivity and well-being of people by estimating the monetary values (Li 2014). It is, however, highly controversial and criticized by many in the evaluation field (for a detail discussion, see, Li 2014). It has been criticized for discriminating the disabled people, that is, the lives of disabled people are less valuable than the lives of people without disability. This unequal valuing of life is unethical and discriminatory (Bickenbach 2008). Despite demonstrated flaws in its intrinsic assumptions and justification, the DALY is still widely used in the field of public health to estimate the cost-effectiveness of different programs. Disability-adjusted life year (DALY) combines all associated health costs, including Years Lost due to Disability (YLD) for people living with the diseases and Years of Life Lost (YLL) due to premature mortality. The World Health Organization (2012) commonly uses an average equivalency of 36 DALYs per premature death. Again replicating the same approach, the value per DALY can be determined by dividing the VSL by the number of DALYs assigned for a premature death, and this results in the value of $7,139 per DALY in Ethiopia; see Table 4-10.

Table 4-10: Metrics summary of value per DALY calculation

	GNI per capita, PPP adjusted	Value of a Statistical Life (VSL)	DALY equivalent for a premature death, on average	Value per DALY
US	$56,189	$8,914,553	36	$247,626
Ethiopia	1,620	$257,018	36	$7,139

Source: Column 1 (World Bank 2015); column 2 (Viscusi & Aldy 2002); column 3 (WHO 2012).

To quantify the number of DALYs averted due to this project, we have to determine the number of YLD and YLL averted. In our sample, the average number of diarrhea cases per child per year is 4.8, and a case of diarrhea lasts 3.4 days. The disability weight for diarrhea is 10 percent (Cameron *et al*., 2011; Pruss *et al*. 2002). The number of beneficiary households is assumed to be 80 for a well. The average number of under-five children is 1.24, that is, about 100 children can benefit from the project. The number of morbidity-based DALYs averted by this program is estimated to be 0.067 per year.

YLD = (100 beneficiaries) (4.8 diarrhea cases per year) (3.4 days per case) (1/365) (10% disability weight) (15% reduction)

As reported by the WHO, an average of 64 lives per 1000 under-five children are lost each year in Ethiopia, of which nine of them is due to diarrheal diseases alone. This is the national average, however, the number of children lost due to diarrhea could be much higher in rural areas compared to urban. Assuming improving access to drinking water reduces deaths caused by diarrhea at the same rate as the incidence reduction (15 percent), 0.135 mortality-based DALYs are averted each year.

YLL = (100 beneficiaries) (9/1000 lives lost) (15% reduction)

In addition to these averted deaths, there could be additional averted deaths due to access to safe drinking water through indirect/secondary pathways. Adding up the two components, 0.202 DALYs are averted annually that can be attributed to improved access to drinking water.

Discounting for future benefits over the anticipated life of the project, the PDV of the adjustment for societal objectives is $13,749. For the computation see Table 4-11.

Moreover, health benefits for non-preschool household members and all indirect health impacts including health externalities of communicable diseases were not fully accounted for. Hence if all the possible benefits could be monetized, the benefit-cost ratios would be considerably higher than the one presented. Finally, despite our conservative assumptions, this study has confirmed that drinking water supply in rural areas generates high economic returns, with returns far exceeding costs even at 10 percent discount rate. For instance, the results suggest that for every US$1 invested in rural water supply, there is an economic return of US$19 by saving water collection time and keeping people healthy and productive. The estimated cost-benefit ratio is relatively higher than what is being reported by Hutton and Haller (2004). They estimated cost-benefit ratio between US$10 and US$15 for improved water supply and sanitation in developing countries. While the aforementioned study is at a global level based on the WHO sub-regions, this is a case study in rural areas where access to drinking water supply and sanitation is low and diarrhea prevalence is high. In such circumstances, the time benefits from the proximity of water supply and the health benefits from reduced morbidity and premature child mortality due to diarrheal diseases is expected to account for a large share of expected total benefits (Hutton & Haller 2004).

Table 4-11: Metrics and summary of value per DALY calculation

YLD (Morbidity)		**YLL (Mortality)**	
Average annual diarrhea cases per child	4.8	Proportion of lives lost to diarrhea each year per 1000 child	0.009
Days lost per case of diarrhea	3.4	Reduction in diarrhea due to intervention (Table 4.7)	15%
Disability weight for diarrhea	10%		
DALYs averted each year	0.067	DALYs averted each year	0.135
Value of YLD averted each year	$478	Value of YLL averted each year	$964

Source: Author's own computation.

Table 4-12: Summary of cost-benefit analysis

Costs	Descriptions	Estimated values	Reference(s)
Capital Charges	well construction & development	$2,909	Welthungerhilfe
O&M Cost	PDV assumes 5% capital cost as proxy for annual O&M cost, including security guard	$1,241	Welthungerhilfe
Opportunity Cost	time spent for training (1 day per beneficiary)	$112	estimated based on the market assumption
Economic Externalities	negative economic impacts	$0	n/a
Environmental Externalities	negative environmental impacts	$48	see Whinnery 2012
Water treatment	assume 8 liters per user per day need to be treated, and the cost is $0.70 per cubic meter (1000 liters)	$1,944	Reed 2005; Roger et al. 1998
Total PDV Costs		**$6,254**	
Benefits	**Descriptions**	**Estimated values**	**Reference(s)**
Value to Users of Water	PDV of Value to Users of Water	$114,934	estimated
Net Benefits from Return Flows	n/a	$0	n/a
Net Benefits from Indirect Uses	n/a	$0	n/a
Adjustment for Societal Objectives	PDV of DALYs Averted	$13,743	estimated
Intrinsic Value	n/a	$0	n/a
Total PDV Benefits		**$128,677**	
NPV (total PDV Benefits - total PDV Costs)		$122,423	
Benefit/Cost Ratio (discount rate 3%)		**20.58**	
Benefit/Cost Ratio (discount rate 5%)		**19.72**	
Benefit/Cost Ratio (discount rate 10%)		**17.80**	

Source: Author's own computation.

Table 4-13: Present discounted value (PDV) computation details

Year	PDV O&M	PDV Water Treatment	PDV Value to Users of Water	PDV DALYs Averted
0	n/a	$204.00	$12,067.00	$1,442.64
1	$141.21	$198.06	$11,715.53	$1,400.63
2	$137.10	$192.29	$11,374.30	$1,359.83
3	$133.11	$186.69	$11,043.01	$1,320.22
4	$129.23	$181.25	$10,721.37	$1,281.77
5	$125.47	$175.97	$10,409.10	$1,244.44
6	$121.81	$170.85	$10,105.92	$1,208.19
7	$118.26	$165.87	$9,811.58	$1,173.00
8	$114.82	$161.04	$9,525.80	$1,138.84
9	$111.48	$156.35	$9,248.35	$1,105.67
10	$108.23	$151.80	$8,978.98	$1,073.46

Note: Discount rate = 3% and $PDV = \sum_{t=0}^{n} \frac{D_t}{(1+r)^t}$

Appendix 4

Figure A1: Proportion of children with diarrhea by number of episodes and irrigation

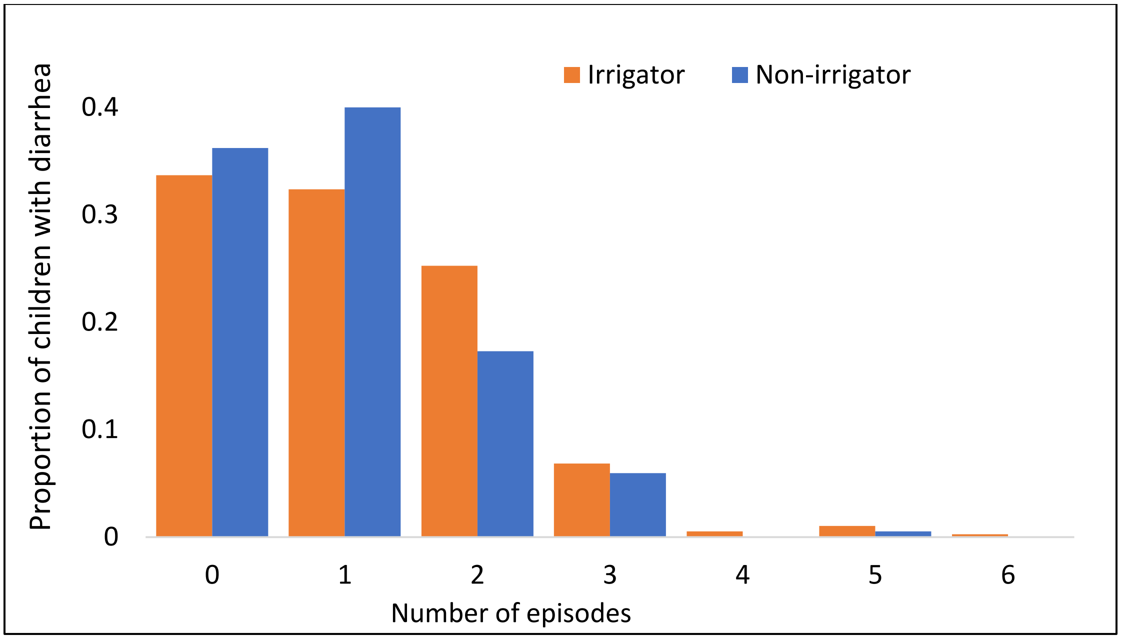
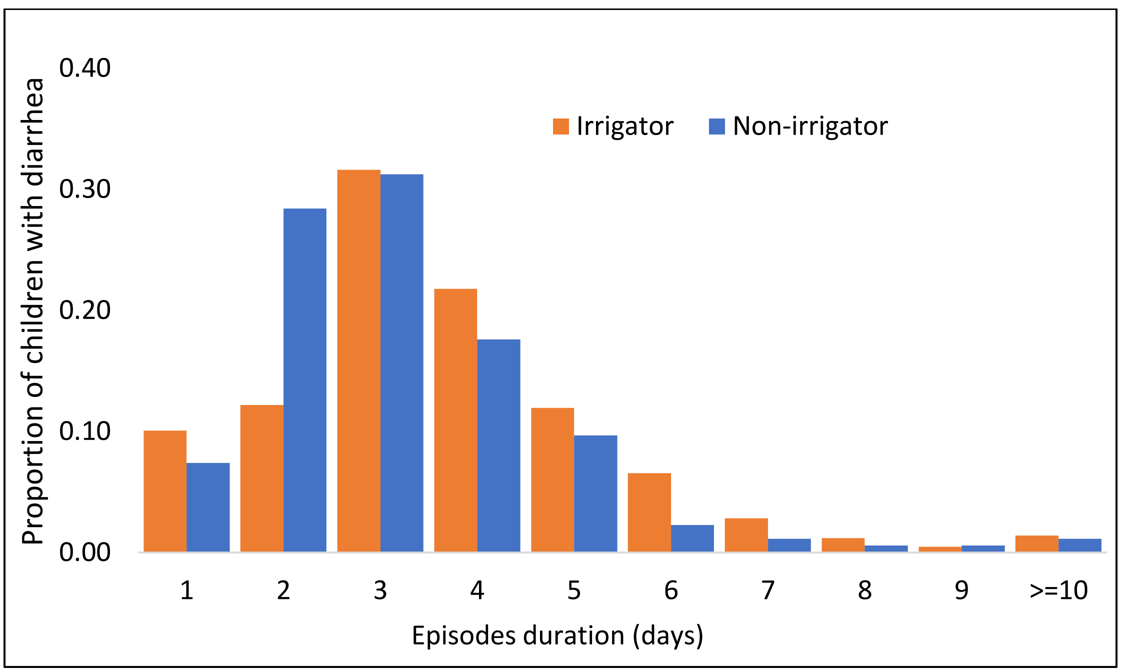


Figure A2: Proportion of children with diarrhea by episode duration and irrigation



Source: Author's computation using own survey data

5. Water, sanitation, and agriculture: Linkages and impacts on health outcomes

5.1 Introduction

The interactions between irrigated agriculture and water and sanitation (AG-WATSAN) are complex where water is an important determinant factor for livelihoods. As water is a key aspect for subsistence farmers, the implications of lack of water access are extremely broad. In a country where agriculture is the backbone of the economy, water shortages mainly affect not only its economy but also the lives of many smallholder farmers whose livelihoods entirely depend on crop production. Consequently, supporting small-scale irrigation (SSI) has been identified by the GoE as a key poverty reduction strategy to overcome existing challenges and to build household resilience and sustainable solutions.

The country's Agricultural Growth Program (AGP) is focused on improving water availability for small-scale agriculture in rural areas where people's livelihoods highly depend on water. Water resource management is, therefore, vital for transforming rain-fed farming to irrigated agriculture thereby improving productivity in a sustainable manner. Irrigated agriculture is expected to increase agricultural production and productivity through the use of water resources such as surface, ground and rainwater and use of appropriate input mix (Asayehegn *et al.* 2012; Burney *et al.* 2010; FAO 2000). In the last few years, more and more small-scale farmers have been adopting irrigation technology to increase production on top of subsistence farming.

Improved rural water supply coverage is also inadequate in the country: if any, it is basic and inadequate (van Koppen, Smits, Moriarty*, et al.* 2009; Usman *et al.* 2016). Consequently, separate sources of water for household and water for agricultural uses do not exist in several rural areas. On the one hand, domestic water supply is often used for watering livestock, SSI and gardening, and other income generating activities (Butterworth *et al.* 2013; Scheelbeek 2005; van Koppen, Smits, & Mikhail 2009). On the other hand, as access to safe drinking water supply is inadequate, households may be often forced to use irrigation water for a wide range of domestic purposes.

There is, however, a trade-off in the domestic use of irrigation water. On the one hand, irrigation water might serve as an option to increase the availability of water for domestic uses and saves water collection time and energy. On the other hand, use of poor quality irrigation water for domestic purposes is harmful to health due to the presence of disease-causing pathogens. Nevertheless, the empirical evidence on the health impacts of multiple-use of irrigation water is scant (Boelee *et al.* 2007; Tsegai *et al.* 2013). Furthermore, Boelee *et al.* (2007, p.49) recommend that "the interactions between irrigation and domestic water supply, water quantities involved, hygienic behavior, and mechanisms of disease transmission are poorly understood." They suggest that more field studies are needed particularly in sub-Saharan Africa to identify the right technical and institutional arrangements under which irrigation and domestic water supply could improve human health and rural livelihoods. This study, therefore, attempts to fill this research gap by examining the linkages and interactions between water supply for domestic use and for agricultural production, and their health and nutrition impacts on households under a multiple-use water system setting.

5.2 Linkage between WASH, Health, and Agriculture

In rural communities, irrigated agriculture has a complex interaction with drinking water supply and sanitation services. Use of irrigation water for the domestic purpose can have some negative effects but it also has positive impacts in terms of improving human health and nutritional status. Increasing water availability—a critical linkage to hygiene—very close to the house primarily allows a given household to collect enough water for better hygiene practices in addition to overcoming a lack of basic needs. This prevents diseases that are related to the amount of water available for personal hygiene. In addition to the health benefits of a large amount of water availability for domestic uses, there may be other indirect effects by reducing water fetching time and energy, which in turn increases time availability for, for example, childcare, food preparation and engaging in other productive activities (Dufour *et al.* 2012; Hagos *et al.* 2008; Koolwal & Walle 2013; Pickering & Davis 2012; Wang & Hunter 2010).

Irrigation impacts human health in several pathways. Irrigated agriculture often increases productivity (production) and creates opportunities for diversification of livelihoods that allows households to have better nutrition and earn a higher income (von Braun *et al.* 1989). The use of water resources for productive activities has high value in terms of household income, nutrition, and health. In addition to providing more nutrient-rich foods and vegetables for household consumption, irrigation activities generate higher income that allows access to improved health-care services. Therefore, irrigation has an indirect effect on health via income. However, irrigation systems might have other downside effects and can be sources of health hazards-especially in areas prone to waterborne diseases as standing water provides a conducive environment for diseases (for example, malaria). In Ethiopia, several empirical studies revealed that the prevalence of malaria and water-related disease are higher in villages closer to micro dams or irrigation systems (Amacher *et al.* 2004; Asayehegn 2012; Ersado 2005), which is among the top five deadly diseases in the country. However, a study in Tanzania shows that malaria prevalence in irrigated areas was lower because the improved income from rice-growing enables the farm-households to afford to use insecticide-treated nets (Mutero *et al.* 2006). Malaria and other waterborne diseases affect the person's ability to work and reduce the time available for productive activities. Other members of the household will have less time for productive activities as they have to spend time away from work to take care of ill relatives. This affects the income of the household directly due to an increase in medical expenses and indirectly by reducing their ability to work on their farm yards.

It is estimated that more than 52 percent of rural population in sub-Saharan Africa alone could benefit from the multiple-use water system if rural water supply is designed to accommodate additional services beyond the domestic water supply (Faurès *et al.* 2008). In summary, most existing empirical studies suggest that water resources and irrigation systems management should be given high importance to avoid the unpremeditated negative health repercussion for the most vulnerable people and communities while exploiting the opportunities opened up to change and improve the livelihood of the poor at large.

5.3 Theoretical Framework

This analysis draws upon the household production model (Becker 1965) in which households are assumed to maximize their utility function subject to a budget and a time constraint. In line with the theory, households purchase different goods and combine them into a household production system to produce various goods and services under a given time constraint. These purchased goods and produced commodities directly enter into the household's utility function. Since most human capital outcomes are not available in the market, households have to produce them on their own based on the integration of biological, demographic, and economic considerations.

Consider a one-period household production model with constrained maximization of a joint utility function,[31] that is, non-separable determination of household production—consumption decision. Extending the exposition set out in Behrman and Deolalikar (1988), assume that the household preferences constituting of *T* individuals are represented by the following preference function:

$$\mathrm{U} = \mathrm{U}(X^i, C^i, T_l^i, H^i) \qquad i = 1, \dots, T \tag{5.1}$$

where X^i is the consumption of purchased goods of household member *i,* C^i is the consumption of own production of household member *i,* T_l^i is the leisure time of household member *i*, H^i is the health of household member *i.* The utility is assumed to depend on the consumption of goods (both markets purchased goods and own produced agricultural goods), the leisure time and the health status of each of the household members.

The preference function in equation (5.1) is maximized subject to the following constraints. The first constraint is a health production function. The health of the i^{th} individual is produced by the consumption of goods and leisure. Health also depends on the consumption of non-food health inputs which do not provide utility directly (such as medical treatment from local clinics); a vector of household resources (such as drinking water and sanitation facilities); a vector of irrigation

[31] The assumption of "unitary" household preference approach may be questioned, but it is still unclear how a cooperative bargaining process affects our outcome variable and changes the theoretical pathways through which improved WATSAN affects health (for further discussion see Alderman *et al.* 1995; Mwabu 2007).

water characteristics (such as types of irrigation water, distance from the household); the *i*'s innate health endowment and specific individual characteristics, and a vector of community characteristics that include variables that affect an individual's health (such as access to health facilities, infrastructure and prices, cleanness of the environment).

Irrigation technology can improve health and nutrition by providing nutrient rich and fresh vegetables. It can also improve health by providing greater water availability for domestic use and enables households to maintain key hygiene and sanitation practices (van der Hoek *et al.* 2002). However, irrigation intervention can affect health negatively in areas prone to vector-borne diseases (Amacher *et al.* 2004; Ersado 2005).

The health production function then is given by:

$$H^i = \mathrm{H}(X^i, C^i, Z^i, T_l^i, T_h^i, G, D, \eta^i, \Omega) \quad (5.2)$$

where Z^i is the consumption of non-food health inputs of household member *i* (e.g. health care services), T_h^i the time spent on production of health (e.g. taking care of ill family members), G a vector of household resources which affect health (e.g. water & sanitation facilities), D a vector of irrigation water characteristics (e.g. its type and distance from the dwelling unit where the individual lives), η^i the observed and unobserved individual characteristics, and Ω the endowment of the households and community characteristics (e.g. the general environment), and the other variables are defined above.

The production/consumption of water for domestic use depends upon the quality of the water source, the time spent by the *i*th household member collecting water and is assumed to be a function of distance to the water source; the knowledge of good health practices in the household as they relate to water collection and storage, the capital goods used in the transport and storage of water.[32] Water quality at the source and quality of water at the POU may substantially vary. The average water quality at the POU can be lower relative to the quality of water at the source as it is affected by factors such as transportation, knowledge of safe water handling, the quality of storage containers and duration time (for a discussion see Wright *et al.* 2004; Zwane & Kremer 2007).

The second constraint is a water production function that can be defined as follows:

$$W^h = \mathrm{W}(\varpi, T_w^i(D_w), A_w, H^i, D, \Omega) \quad (5.3)$$

where ϖ is the quality of water available to the household member *i*, T_w^i the time spend by household member *i* on water collection, D_w the distance to water source, A_w the capital goods

[32] It is possible that ϖ and D_w become a choice variable if households can choose among different sources of water for domestic consumption.

used in the transport and storage of water (e.g. buckets and pots), and the other variables are defined above.

The household farm production depends not only on the characteristics of all individuals in the household who work on these activities but also on the amount of land, the levels of input use and the practice of irrigation technology. A study by von Braun *et al.* (1989) shows that utilization of irrigation technology in the production of rice in Gambia increases not only the household's real income but also it increases their calorie consumption and food expenditure. Agricultural production can also be affected by the household members' health status either through its effect on the quality of own labor or through reducing labor availability.

The third constraint is a farm production function:

$$Y^h = \mathrm{Y}(C^i, T_f^i, L_h, A, K, H^i, D, \Omega) \tag{5.4}$$

where Y^h is the household farm output aggregated overall crops and vegetables, T_f^i the time of the i^{th} household member spent on household farm production, L_h the amount of hired labor used in farm production, A the amount of land used in the farm production process, part of which may be owned by the households (A^h) and the rest of which may be rented (A^*), K other variable inputs used in farm production and all other variables have been defined above.

Finally, there are time and full-income constraints. Household's total labor time (*T*) available is allocated to leisure, health-care activities, water collection, and agricultural production and off-farm income generation:

$$\mathrm{T} = T_l^i + T_h^i + T_w^i + T_f^i + T_{off}^i) \qquad \forall\, i \tag{5.5}$$

Continuing with the description of the model, it is also assumed that households face a monetary budget constraint where income equals expenditure for consumption goods, leisure, health-care services, expenditure for water container, hired labor is represented by a full-time income constraint as:

$$\begin{aligned} P_y Y^h + \mathrm{R} = \mathrm{rA} + P_k K + \omega L_h + P_x X + P_c C + P_z Z + P_w W \\ + \sum \omega(T^i - T_l^i - T_h^i - T_w^i - T_f^i - T_{off}^i) \end{aligned} \tag{5.6}$$

where r is the rental rate of land, R other exogenous income, ω the market wage rate, T^i total time of the i^{th} individual, T_{off}^i the labor market work time of the i^{th} individual, P_j refers to the different prices, where j = y, k, x, c, z and *w.*

Maximizing equation (5.1) subject to the (5.2), (5.3), (5.4) and (5.6) constraints yields the following reduced-form demand function for all choice variables in which all exogenous variables appear on the right-hand side of each equation, and the left-hand-side variables are the endogenous variables in the system for the household. Therefore, the reduced-form demand functions for our choice variables are given as:

$$V = f(E) \tag{5.7}$$

where $V = (H^i, W^h, Z^i, Y^h, X^i, C^i, T_j^i) \quad where \;\; j = l, h, w, f, off;$ and

$$E = \left(r, P_s, \omega, G, D_w, R, D, \eta^i, \Omega\right) \quad where \;\; s = a, c, w, x, y, z$$

This theoretical framework tries to show the nexus among WATSAN, irrigation and health functions. This framework helps us to identify some policy variables that affect the demand for health, water, sanitation and agricultural irrigation system. Therefore, estimation of the reduced-form demand functions provides a consistent framework.

5.4 Data and Empirical Strategy

5.4.1 Data

The data come from the same household survey used in the previous empirical chapters. The descriptive statistics for the combined sample has been presented in the previous chapters (see, Table 4-3 and Table 4-3). Table 5-1, however, presents the summary statistics of the variables of interest by irrigation status.

The descriptive statistics presented in Table 5-1 shows that the prevalence of diseases appears significantly higher among irrigator households than non-irrigator households in all health outcomes measures except for diarrhea. Moreover, health expenditure is higher among irrigator than non-irrigator households, and this difference is statistically significant at the 1 percent significance level. Regarding access to improved WATSAN, the result shows that irrigator households had better access to improved water source than non-irrigator households; however, storage water quality is slightly better for non-irrigator than irrigator households. Furthermore, the l/p/c/d water consumption is relatively higher among irrigator households which may be because irrigator households spent lower time per water collection trip than non-irrigators. We also observed difference between irrigator and non-irrigator households in terms of access to pit latrine, and this significant difference in terms of access to pit latrine can be interpreted as higher proportions of irrigator households practicing open defecation than non-irrigator households. On the other hand, as expected, household income from agriculture (excluding livestock) is much higher among irrigator than non-irrigator households. The table also shows that 66 percent of the total sampled households engaged in irrigated agriculture.

Table 5-1: Descriptive statistics

Variables	Total sample mean	N	Irrigator household		Non-irrigator household	
			Mean	SD	Mean	SD
Health outcomes						
Diarrhea prevalence	0.09	2149	0.10	0.30	0.09	0.28
Malaria incidence	0.04**	2149	0.05	0.21	0.03	0.17
Water-related diseases [a]	0.11**	2149	0.13	0.33	0.08	0.28
Overall morbidity [b]	0.31***	2149	0.34	0.47	0.26	0.44
Total medical expenditures in the previous two months (ETH BIRR)	84.36***	454	102.83	201.93	47.64	107.87
Healthcare expenditures in the last one year (ETH BIRR)	268.89***	454	313.51	421.59	180.24	214.05
Water supply and sanitation						
Access to improved water source	49.56	454	0.51	0.50	0.46	0.50
Storage water quality (1=no *E.coli*)	0.42	454	0.41	0.49	0.43	0.49
Level of *E.coli* (CFU/100ml) water	23.31	454	24.72	40.75	20.52	34.16
Minutes to water sources	20.38***	454	17.18	13.56	27.10	17.48
Per capita per day water consumption in litters (l/p/c/d)	8.77***	454	8.96	2.36	8.39	2.36
Soap availability (1= yes)	0.76	454	0.76	0.43	0.77	0.42
Access to pit latrine (1= yes)	0.44***	454	0.40	0.49	0.52***	0.50
Socioeconomic and demographic characteristics						
Household head age	37.72	454	37.98	0.51	37.19	0.67
Household head's education	1.02	454	0.10	0.11	1.07	0.16
Highest education completed	3.5*	454	3.37	0.18	3.76	0.24
Household size	5.98*	454	6.08	0.10	5.79	0.14
Number of children under 5 years	1.24	565	1.26	0.47	1.22	0.41
Agri. land size in hectare (operated)	1.31	454	1.29	0.04	1.34	0.06
Agricultural income in 1000 Birr	7.58***	454	10.17	8.53	2.14	2.22
Non-farm income in 100 Birr	7.57	454	8.25	21.34	6.21	15.08
Community characteristics						
Distance to the nearest asphalt road in km	5.96**	454	6.45	0.33	4.98	0.67
Distance to the nearest periodic market km	4.40***	454	5.05	0.26	3.10	0.38
Altitude above sea level (meters)	1902.56***	454	1857.00	4.25	1993.07	8.64

[a] Water-related disease includes malaria, pneumonia, skin itching, typhoid fever, trachoma & giardiasis.
[b] Morbidity includes any diseases symptoms except injuries.
Significant difference at *** p<0.01, ** p<0.05, * p<0.1
Source: Author's estimates using own survey data.

Outcome variables

We have proposed an array of outcome variables to measure the health status of a household. In this section, we use diarrhea prevalence as the main outcome variable because it is strongly associated with drinking water quality. For robustness test, we also use water-related diseases (such as malaria, pneumonia, skin-itching, typhoid fever, giardiasis, and trachoma) and morbidity (general illness of household member excluding injuries) as health indicators for non-preschool household members. Data on the health status of all household members in the preceding two-months before the survey were collected.

5.4.2 Empirical strategy

This section outlines the empirical strategy we use to estimate the impact of irrigation water use for domestic purposes on household health status. Following equation (5.7), the reduced forms of *h*(health)* and W^h*(household water)* are influenced by *D (a vector of irrigation charachterstics)*, and a set of other explanatory variables. Hence, we are interested in estimating the effects of domestic use of irrigation water on household health, the reduced form equation can be expressed as:

$$h = \beta\chi + \delta Q + \varepsilon \qquad (5.8)$$

where *h* denotes health outcomes and *X* is a vector of exogenous explanatory variables that influence the outcome variables, and it includes household and individual characteristics, such as age, gender, household size, among others, and their impact is captured in the vector of parameters β. *Q* is a dummy for households directly withdrawing water from irrigation sources for domestic purpose and the coefficient *δ,* measures the impact of irrigation water use on households' health status, ε is the error term. The variable, *Q,* is potentially endogenous since irrigation water for domestic use is not randomly assigned, and households may decide whether or not to use irrigation water for domestic purposes (i.e. self-selection bias), that is, households using irrigation water for domestic consumption may be systematically different from the comparison group households for several reasons. If there is a self-section problem and/or if any unobserved household characteristics influence both the outcome and the variable of interest—domestic use of irrigation water, *δ* will not capture the true impacts of domestic use of irrigation water on households' health outcomes. As a result, estimating equation 5.8 without controlling for such potential endogeneity may yield biased results, and the estimated coefficient hardly be interpreted as an impact. To account for this, an instrumental variable approach is often suggested. As we are constrained with a valid instrument to use a two-stage least squares estimation strategy, we estimated several models with different specifications to test the robustness of estimated results.

In this chapter, we mainly focused on the sub-sample households, who have already adopted irrigation technology, to investigate the effects of domestic use of irrigation water on health status and drinking water quality/quantity. However, we also briefly investigated the role of irrigation on household income, health and domestic water quantity using the whole sampled households.

5.5 Results and Discussion

5.5.1 The influence of demographic and WATSAN characteristics on diarrhea and other water-related diseases

The incidence of diarrhea in the last two months prior to the survey among non-preschool household members by demographic and WASH characteristics is presented in Table 5-2. The table shows that individual's age highly influences the prevalence of diarrhea. Diarrheal incidence was much higher among young household members—particularly among those young children between 5 and 6 years old followed by children between 7 and 9 years old. Moreover, female household members are more likely to be affected by diarrhea than male household members. In addition, a lower incidence of diarrhea was reported among individuals living in households where household's head or primary caretaker is literate. The result also shows that individuals living in households with improved drinking water source are less likely to have had diarrhea in the past two months (6.20%) than those living in households with unimproved water sources (12.55%). The result is same when disaggregated by actual water sources, that is, household members with unprotected well/spring or surface water sources are more likely to experience diarrhea than household members with protected private/shared wells. Similarly, higher diarrhea incidence was reported among households whose POU (storage) water is contaminated with *E.coli* than households with uncontaminated POU water (5.36% compared to 12.29%). The result also shows that soap availability is associated with lower diarrhea incidence. On the other hand, the difference in the prevalence of diarrhea in the last two months before the survey between households with and without a pit latrine is negligible. Moreover, diarrhea incidence was slightly higher among irrigator households than non-irrigator households (9.76% compared with 8.65%).

Table 5-2: Diarrhea incidence by demographic and WASH characteristics (last two months)

Variables	Incidence of diarrhea* (%)	Number of individuals
Demographic characteristics		
Age in years		
5 - 6	36.41	217
7-9	15.85	347
10 -15	6.18	453
16 years/older	3.53	1132
Sex		
Male	8.82	1134
Female	10.05	1015
Primary caretaker's literacy		
Yes	5.75	174
No	9.73	1974
Household head's literacy		
Yes	7.84	1008
No	10.43	1141
WASH characteristics		
Water source based on WHO		
Improved source	6.20	1065
Unimproved source	12.55	1084
Water sources		
Private protected dug well	6.03	116
Shared protected dug well/spring	6.22	949
Unprotected well/spring	12.62	848
Surface water	12.29	236
Variables	**Incidence of diarrhea* (%)**	**Number of individuals**
Storage water quality		
Uncontaminated	5.36	896
Contaminated (at least one *E.coli*)	12.29	1253
Soap availability		
Yes	8.69	1645
No	11.71	504
Pit latrine		
Yes	9.64	944
No	9.21	1205
Irrigation farming		
Yes	9.76	1455
No	8.65	694

Note: * Only non-preschool household members.

Source: Author's estimates using own survey data.

Table 5-3: The influence of demographic and WASH characteristics on water-related diseases and overall morbidity (last two months)

Variables	Incidence of other water-related diseases (%)	Overall Morbidity (%)	Number of individuals
Demographic characteristics			
Age			
5-6	7.37	50.23	217
7-9	7.49	29.68	347
10-15	10.60	23.40	453
16 years or older	13.69	31.45	1132
Sex			
Male	11.33	29.63	1134
Female	11.46	33.30	1015
WASH characteristics			
Water source based on WHO			
Improved source	11.55	29.11	1065
Unimproved source	11.25	33.58	1084
Water sources			
Private protected dug well	16.38	31.90	116
Shared protected dug well/spring	10.96	28.77	949
Unprotected well/spring	10.14	32.78	848
Surface water	15.25	36.44	236
Storage water quality			
Uncontaminated	10.04	27.12	1253
Contaminated	12.37	34.40	896
Irrigation farming			
Yes	7.15	34.02	1455
No	4.61	25.79	694

Note: Water-related diseases include malaria, pneumonia, skin itching, typhoid, trachoma, and giardiasis for non-preschool household members.
Source: Author's estimates using own survey data.

The incidence of other water-related diseases (such as malaria, pneumonia, skin-itching, typhoid, trachoma, and giardiasis) and overall morbidity (excluding injuries) in the last two months prior to the survey by demographic and WASH characteristics is presented in Table 5-3. As we can see, younger household members are the least affected groups in terms of incidence of water-related diseases; however, looking at the overall health status in the last two months, they are the most affected segments of the population in the study areas. Male and female household members were equally affected by water-related illness; nevertheless, male household members are relatively healthier than female household members in the previous two months. Moreover, household members with improved water sources are slightly healthier than households without improved water. Surprisingly, however, the result presented in in Table 5-3 indicates that individuals living in households using a protected private-well or surface water sources are more likely to have had health problems in the past two months than those living in households using either a shared-protected or unprotected-well. On the other hand, as expected, the incidence of water-related diseases and morbidity status are significantly higher among households having contaminated storage water and engaging in irrigation farming.

The following Figure 5-1 presents the incidence of diseases among non-preschool household members in the preceding two months before the survey by income quintile (we used adult equivalent total household expenditure to construct the income quintile). Although observed household income variability is high, the result shows that income does not play a significant role in the determination of household members' health status. That is, both poorer and richer households are fairly equally prone to diarrhea and other health problems. In other words, higher income does not make household members immune from contracting diarrheal and other infectious diseases in the study areas. The role of income on household health status may also be moderated by poor access and utilization of health facility in the study areas. It is argued that increased household income permits a given household to access improved health services and improve their health status. However, this might not hold where access and quality of health facilities are under developed. In addition, there might be measurement issues related to household income.

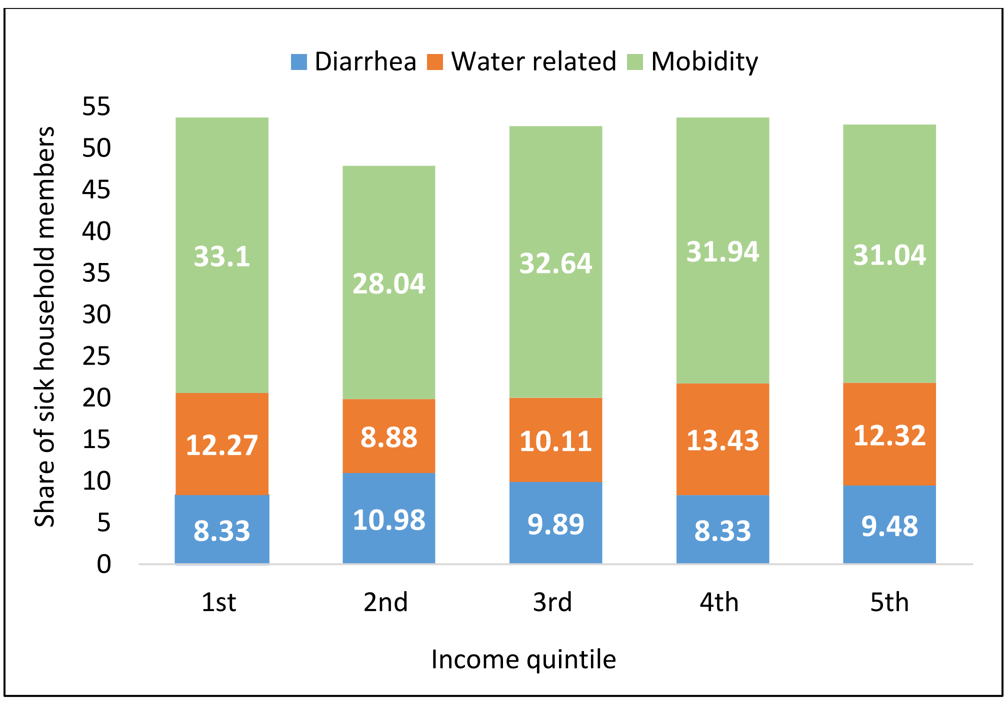


Figure 5-1: Prevalence of illness in the last two months by income quintile

Source: Author's estimates using own survey data.

5.5.1.1 The interaction between irrigation and domestic water supply

Small-scale irrigation practices

In the study areas, farmers practice similar irrigation methods. Furrow and surface irrigation methods are the dominant irrigation methods practiced by most farmers. Furrow irrigation method is a "partial surface flooding method of irrigation normally used with clean-tilled crops where water is applied in furrows or rows of sufficient capacity to contain the designed irrigation system" whereas surface irrigation method is "where the soil surface is used as a conduit, as in-furrow and border irrigation as opposed to sprinkler irrigation or sub-irrigation." [33] In our sample, 59 percent of households use furrow methods, 23 percent of households practice surface (run-of-river) irrigation type, and the remaining 18 percent of households use manual-bucket irrigation (Table 5-4). Surface and Furrow irrigation methods are almost similar, while manual-bucket is a drip irrigation method and mostly used to irrigate small plot of lands.

Table 5-4: Types of irrigation mostly practiced by farmers

Irrigation type	Frequency	Percent	Cumulative
Surface –run of river	77	23.48	23.48
Furrow system	193	58.84	82.32
Manual-buckets /drip	58	17.68	100.00
Total	328	100.00	

Source: Author's estimates using own survey data.

Households use various water sources to irrigate their farm. Rivers/streams, canal water, ground water, natural pond and harvested water used as a source for irrigation farming (Figure 5-2). For instance, rivers are the main irrigation water sources in Fogera district, whereas canal water is the principal water sources for most farmers in Mecha district—Koga irrigation dam. However, concurrent use of several water resources for different purposes and/or during a different time of the years is common in these areas. Moreover, WATSAN and irrigation are interlinked as water from rivers, springs and groundwater are used as a source for irrigation as well as for domestic consumption and on-site sanitation, which is common among rural households.

[33] http://water.usgs.gov/edu/irquicklook.html (accessed on February 2016).

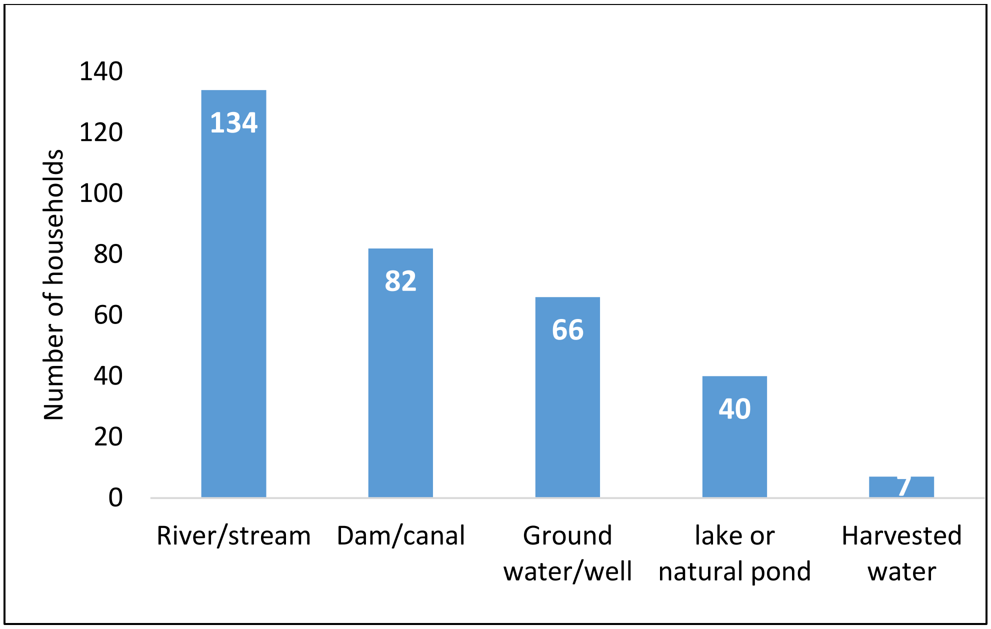


Figure 5-2: Primary water sources for irrigation purpose

Source: Author's computation using own survey data.

Smallholder farmers use a single or a combination of water-lifting technologies to irrigate their farm plots (Table 5-5). River and stream diversions using gravity are the most widely used practices to deliver water from sources to the farm fields. They are technically simple and reliable. However, some farmers also use motor pumps where diversion by gravity is impossible. Motor pumps can be an appropriate water-lifting technology for groundwater utilization but it may not be economically affordable for most smallholder farmers. Moreover, buckets are also used to withdraw water from groundwater and to irrigate homestead plots. Inappropriate water withdrawal technologies for multiple-use water services can also increase water source contamination.

Table 5-5: Main types of water delivery system from irrigation water source

Water delivery system	Frequency	Percent	Cumulative
Motor pumps using diesel	109	32.54	32.54
Diversion using gravity	168	50.15	82.69
Manual-buckets	58	17.31	100.00
Total	335	100.00	

Source: Author's estimates using own survey data.

As Figure 5-3 shows, more than 50 percent of households reported that their primary source of drinking water on the field is carried from home. However, above 24 percent of households reported that they do not have a separate source of drinking water other than their irrigation water. The remaining households obtained their drinking water from a nearby protected or unprotected wells/springs.

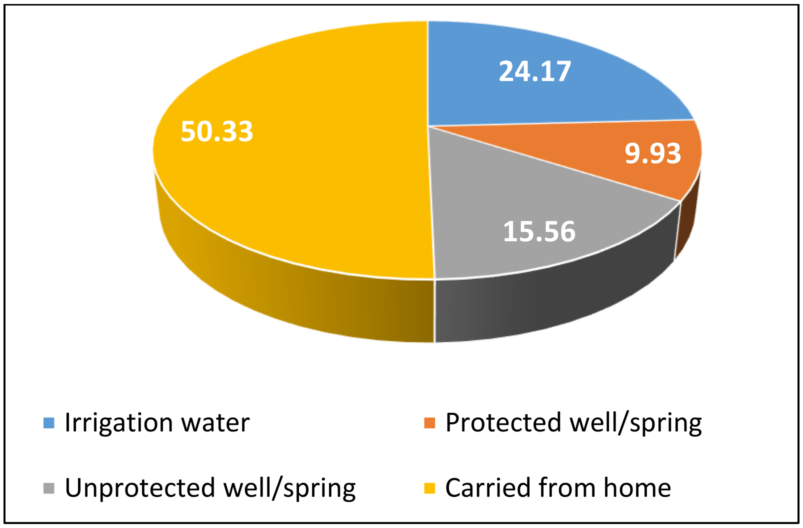


Figure 5-3: Primary source of drinking water on irrigation site

Source: Author's computation using own survey data.

Figure 5-4 shows the major problems related to irrigation water sources in the study areas. Most households reported that they experience water shortage (lack of access to year-round water sources). Some households acknowledged that their irrigation water is of poor quality, while others reported that irrigation water sources create infectious diseases or intensifying the breeding of mosquitoes. It is understood that there is a high personal judgment about the perception of water quality among farm households. Domestic use of irrigation water is highly correlated with individual's perception of the quality of their irrigation water and lack of alternative sources.

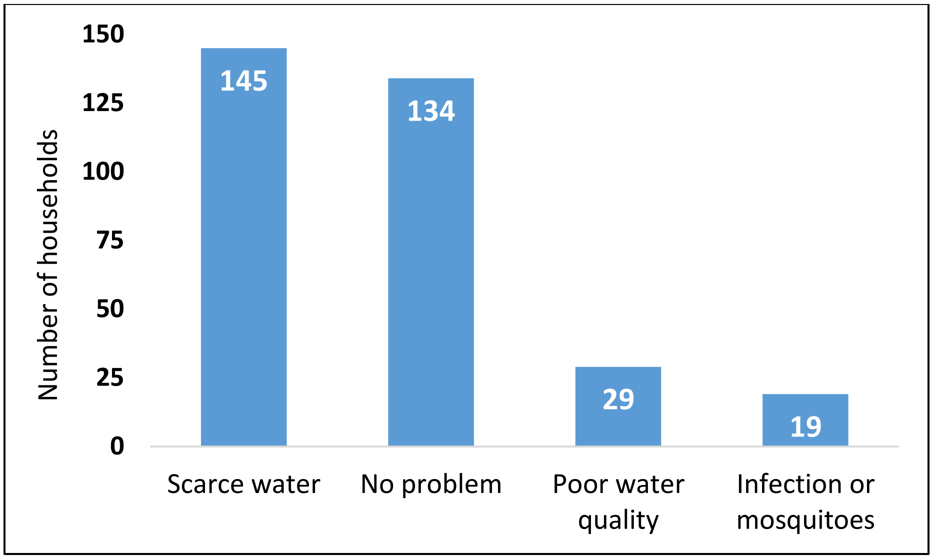


Figure 5-4: Major problems related to irrigation water sources

Source: Author's computation using own survey data.

As shown in Table 5-6, the incidence of diseases by drinking water sources on irrigation field, the highest proportion of incidence of diarrhea, other water-related illness and overall morbidity is reported among households using irrigation water sources for drinking on the field. On the other hand, households carrying water from home had better health status in the preceding two months before the survey in terms of diarrhea incidence and overall morbidity status. This might indicate that households who carry water from home have better health knowledge than others. Moreover, households using protected wells had also better health status compared with households using unprotected wells and/irrigation water except for diarrhea incidence.

Table 5-6: Incidence of diseases by drinking water source on irrigation site

Sources	Diarrhea	Water-related diseases	Morbidity	Obs.
Irrigation water	14.12	17.06	43.24	340
Protected well	10.71	11.43	33.57	140
Unprotected well	10.24	13.78	36.61	254
Carried from home	7.35	10.82	28.85	721

Source: Author's estimates using own survey data.

Using irrigation water for domestic purpose is not uncommon in many rural areas of Ethiopia where improved drinking water is limited—particularly on-site access to clean water supply is lacking. Figure 5-5 shows the number of households who use irrigation water for various types of household purposes. Only 22 percent of households do not use irrigation water other than for production purposes while more than 22 percent of households reported that they get their drinking water from irrigation water sources. Most respondents indicated that irrigation water is used mainly for livestock watering, gardening and washing/bathing purposes.

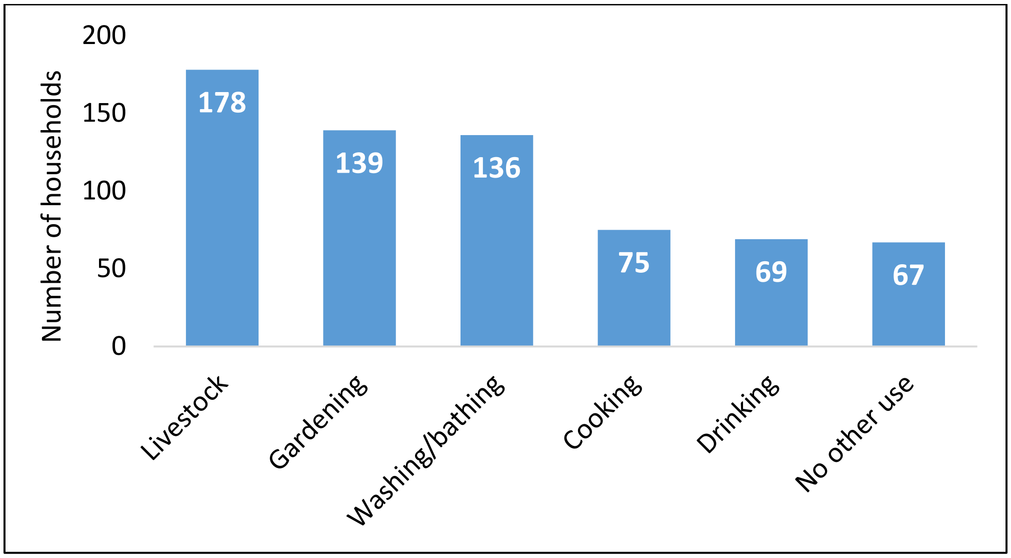


Figure 5-5: Irrigation water use for domestic purposes

Source: Author's computation using own survey data.

As discussed earlier, most farmers have access to more than one water sources for irrigation and they also use various irrigation methods which constrained us to further investigate if any systematic pattern exists between households' health status and irrigation water sources/irrigation methods.

5.5.1.2 Estimation results: Impact of irrigation on water quantity and diarrhea

In this section, we try to examine the impacts of irrigated agriculture on health outcomes, household income, demand for health inputs and household water quantity/quality using the full sample. The impacts of irrigation on household water quantity, measured by l/p/c/d is presented in the Appendix A (column 1—3, Table A2). The results show that irrigated households consume relatively more water than non-irrigator households after controlling distance to drinking water source, container size and other demographic variables (column 3, Table A2). The result further suggests that being an irrigator household does not automatically translate into high per capita water consumption. The influence is mediated via other channels (column 2, Table A2). In addition, the marginal health gains associated with the increase in household water consumption (lower than half a liter per day per person) would be imperceptible.

The health impacts of irrigation are analyzed both at the individual and household level. Table 5-7 presents the health effects of irrigation on non-preschool household members in the last two months before the survey. Columns 1—4 present individual level estimated regression while the last two columns report the household level analysis. In column 5, the outcome variable is 1 if there is any reported diarrhea cases in the household in the last two months preceding the survey and 0 otherwise. In column 6, we counted the number of diarrhea cases per households.

As the result shows irrigation does not appear significantly impact diarrhea prevalence in the first two columns of Table 5-7. The effect of irrigation on diarrhea, however, becomes large and statistically significant in the subsequent regression results. This dramatic change happens when we control the model for the proportion of irrigated land. This variable probably predicts the extent to which the households are engaged in irrigated agriculture. On the other hand, the dummy variable for irrigation could not capture the 'pure' influence of being irrigator household on diarrhea incidence. The estimated coefficient of the irrigation dummy variable is contaminated with kebele fixed effects, that is, the estimated coefficient partially captures *kebele* fixed effects as irrigator and non-irrigator households are mutually exclusive at the *kebele* level.

Generally, the association between irrigation and diarrhea incidence appears robust in both model specifications when we control for the proportion of irrigated land. For instance, a person living in irrigator household is four percentage points higher in the probability of contracting diarrhea in the last two month prior to the survey than a person living in non-irrigator households (columns 3—4, Table 5-7). Moreover, in column 6, the estimated incidence-rate ratio for irrigation is 1.74, implying a 74 percent increase in the number of diarrhea prevalence (1.74 times) among irrigator households per time unit (last two months preceding the survey) for given covariate values. The impact of water quality is also robust and associated with 6 percentage points decrease in the likelihood of contracting diarrhea (column 4), or 44 percent reduction in the number of diarrheal illness in the last two months preceding the survey (column 6).

Regarding other control variables, household pit latrine marginally increases the number of diarrhea cases in both model specifications. As expected, household size is significantly associated with poor health status, but the magnitude of the estimated coefficient is low in the individual level analysis (column 4, Table 5-7). Age is also a significant determinant of individual health outcomes, that is, on average older household members are healthier than younger ones. Moreover, distance to the nearest health center is associated with household health status. While household assets and the proportion of irrigated land have a protective effect against diarrhea, livestock holding slightly increase the incidence of diarrhea incidence, particularly at the household level. The proportion of irrigation land may partly reflect the income effects, that is, household income is positively related to the proportion of irrigated lands.

Table 5-7: Health effects of irrigation—Diarrhea

VARIABLES	(1) Model	(2) Model	(3) Model	(4) Model	(5) Model	(6) Model
Irrigating households (dummy)	0.014	0.009	0.039**	0.044***	0.095*	1.744***
	(0.011)	(0.011)	(0.017)	(0.016)	(0.056)	(0.297)
Water quality (1= *no E.coli*)	-0.063***	-0.057***	-0.057***	-0.051***	-0.176***	0.557***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.046)	(0.087)
Water collection time (1=30min/less)	0.018	0.017	0.011	0.014	0.075	1.149
	(0.013)	(0.013)	(0.014)	(0.014)	(0.049)	(0.188)
Pit latrine (dummy)	0.012	0.023*	0.031**	0.032**	0.115***	1.457***
	(0.016)	(0.012)	(0.013)	(0.013)	(0.041)	(0.181)
Age in years: reference (5—6)						
7—9 years	-0.193***	-0.188***	-0.190***	-0.188***		
	(0.043)	(0.041)	(0.041)	(0.041)		
10—15 years	-0.286***	-0.282***	-0.282***	-0.281***		
	(0.037)	(0.036)	(0.036)	(0.035)		
16 years/older	-0.310***	-0.306***	-0.307***	-0.305***		
	(0.035)	(0.033)	(0.033)	(0.033)		
Gender (male=1)	-0.007	-0.008	-0.008	-0.008		
	(0.012)	(0.012)	(0.012)	(0.012)		
Average household member age					-0.023***	0.905***
					(0.006)	(0.021)
Household size	0.010**	0.010***	0.010**	0.011***	0.078***	1.360***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.014)	(0.055)
Household density	0.008**	0.005	0.005	0.003	0.023	1.006
	(0.004)	(0.004)	(0.004)	(0.004)	(0.016)	(0.038)
Highest education completed	-0.009***	-0.008***	-0.008***	-0.008***	-0.028***	0.908***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.008)	(0.022)
Distance to health center		0.005**	0.004**	0.004**	0.013**	1.042**
		(0.002)	(0.002)	(0.002)	(0.005)	(0.021)
Livestock holding		0.006		0.007*	0.028*	1.118**
		(0.004)		(0.004)	(0.016)	(0.050)
Log of assets value		-0.016*		-0.016*	-0.059*	0.826**
		(0.008)		(0.008)	(0.035)	(0.078)
Proportion of irrigated land			-0.075***	-0.077***	-0.258***	0.324***
			(0.027)	(0.027)	(0.088)	(0.093)
Constant						1.532
						(1.299)
Observation	2149	2149	2149	2149	454	454
Model Chi2	228.84	280.39	244.64	336.54	124.88	255.92
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1;
Regression coefficients in average marginal effects for column 1—5 and in IRR (Incidence-rate ratios) for column 6.
Dependent variable: Diarrhea prevalence among household members older than 5.

5.5.1.3 Estimation results: Domestic use of irrigation water and household water quality, quantity, and health outcomes

This section is the central objective of this chapter and presents the estimated results of the impacts of irrigation water use for domestic purpose on storage water quality and household members' health status. As all irrigator households do not use irrigation water for domestic consumption, we need to focus on the sub-sample households to examine the impacts of irrigation water use for domestic purpose on water quality and quantity and health outcomes. Again, the health impacts are analyzed both at the individual and household level.

The impact of irrigation water use for domestic purposes such as drinking and cooking on POU water quality is presented in the Appendix A (columns 4—5, Table A3). The results do not provide a strong evidence that suggests domestic use of irrigation water considerably deteriorates the microbiological quality of household storage water. The results further indicate that the distance between a household and irrigation water source is rather a stronger predictor of storage water quality than actual usage of irrigation water for domestic purposes. That is, the farther the irrigation water source from home, the better the storage water quality. This is more intuitive, but the nonsignificant relationship between domestic use of irrigation water and storage water quality is surprising. It might be the case that one-time water quality test result could not actually reflect the average storage water quality for a given household for a long time; consequently, the effects of domestic use of irrigation water on storage water quality might not be captured. Moreover, domestic use of irrigation water can be seasonal and/or households can use it only during the field work. In the latter case, the water quality-testing results of storage water could be hardly attributed to irrigation water uses. Generally, this shows the complexity of how the various pathways play out in terms of their influence on domestic water quality and quantity and irrigation infrastructure under various conditions.

Table 5-8 presents the effects of the domestic use of irrigation water on diarrhea incidence. In column 1, 3 and 5, we controlled for POU water quality whereas, in the other columns, we did not control for POU water quality. We assumed that the health effects of the domestic use of irrigation water, if any, is through household storage water quality. That is, if domestic use of irrigation water had significant health effects, we would expect the estimated coefficients associated with it to be statistically significant or have larger effects on health outcome measures whenever we do not control for POU water quality. The result presented in Table 5-8 suggests a lack of evidence that domestic use of irrigation water exacerbates diarrheal illness. Neither does the magnitude of its effect on health outcomes change much when we control for POU water quality across all estimated models. On the other hand, the impact of domestic use of irrigation water on other water-related illness and overall morbidity has a larger and significant effect size at the household level across all model specifications (Table A6 & Table A7). However, again, the effect of POU water quality is limited to diarrheal illness only.

Table 5-8: Effects of domestic use of irrigation water on diarrhea

Dependent variable: Diarrhea prevalence (%) among household members older than 5

	PROBIT				POISSON	
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Irrigation water use (dummy)	0.005	0.013	-0.019	0.002	0.991	1.072
	(0.018)	(0.020)	(0.063)	(0.069)	(0.170)	(0.196)
Water quality (1=no *E.coli*)	-0.057***		-0.212***		0.532***	
	(0.014)		(0.052)		(0.111)	
Water collection time (dummy)	0.016	0.011	0.073	0.054	1.183	1.120
	(0.019)	(0.021)	(0.067)	(0.071)	(0.255)	(0.253)
Pit latrine (dummy)	0.028*	0.028*	0.106**	0.101*	1.350**	1.374**
	(0.015)	(0.015)	(0.054)	(0.053)	(0.201)	(0.201)
Age in years: reference (5—6)						
7—9 years	-0.128**	-0.125**				
	(0.051)	(0.051)				
10—15 years	-0.209***	-0.207***				
	(0.041)	(0.041)				
16 years or older	-0.230***	-0.227***				
	(0.036)	(0.036)				
Gender (*male=1*)	-0.014	-0.013				
	(0.015)	(0.015)				
Average HH member age	0.012**	0.012**	-0.023***	-0.024***	0.902***	0.900***
	(0.005)	(0.006)	(0.007)	(0.007)	(0.025)	(0.025)
Household size	-0.001	0.001	0.081***	0.077***	1.361***	1.356***
	(0.005)	(0.005)	(0.017)	(0.019)	(0.073)	(0.074)
Household density	-0.008***	-0.009***	0.001	0.012	0.953	0.976
	(0.003)	(0.003)	(0.020)	(0.020)	(0.046)	(0.047)
Highest education comp.	0.005	0.005	-0.027***	-0.029***	0.923***	0.913***
	(0.003)	(0.003)	(0.009)	(0.009)	(0.027)	(0.028)
Distance to health center	0.008	0.014***	0.015*	0.016*	1.046	1.047
	(0.005)	(0.005)	(0.009)	(0.009)	(0.033)	(0.033)
Livestock holding	-0.014	-0.019*	0.022	0.046**	1.130**	1.188***
	(0.010)	(0.010)	(0.019)	(0.019)	(0.063)	(0.065)
Log of assets value	-0.079***	-0.093***	-0.056	-0.075*	0.825*	0.796*
	(0.029)	(0.031)	(0.041)	(0.043)	(0.091)	(0.096)
Proportion of irrigated land	-0.128**	-0.125**	-0.265***	-0.318***	0.321***	0.281***
	(0.051)	(0.051)	(0.090)	(0.098)	(0.095)	(0.087)
Constant					3.166	3.234
					(3.125)	(3.255)
Observations	1455	1455	302	302	302	302
Model Chi2			92.73	83.96	190.44	124.06
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1
Coefficients in columns 1—4 are in average marginal effects while in columns 5—6 are in IRR.

Our results do not suggest that domestic use of irrigation water (for drinking and/or cooking) exacerbates diarrhea incidence among non-preschool household members in the study areas. Moreover, the effects of domestic use of irrigation water on diarrheal diseases could be significantly lower where access to improved drinking water supply is low. Irrigation technologies, however, generally result in poor household health in terms of water-related diseases. A study in Ghana found that a headache, blurred vision, and nausea or vomiting illness symptoms were higher among irrigator workers (Clarke *et al.* 1997). They argued that this negative health effect comes from increased pollution due to pesticide use. This indicates that the quality and quantity of drinking water can easily become affected through irrigation agricultural practices due to increased use of pesticides and agrochemicals and inappropriate water withdrawals methods (Eriksson 2012; Horgby & Larson 2013). Moreover, irrigation might serve as a vector-breeding habitat which affects people's health (Ersado 2005; Ghebreyesus *et al.* 1999). Although we did not estimate the health production function for malaria, Table 5-1 clearly indicates that malaria incidence is significantly higher among irrigator households.

Moreover, in addition to more sick time, the negative health impacts associated with irrigation may increase household medical expense for health care. Table A9 shows estimated medical expenditure functions controlling for irrigation and other few exogenous variables. Households with irrigation technology spend significantly more money on medical expenses than households without irrigation. This might be because irrigator households are generally less healthy than non-irrigator households, which in turn increases their medical expenditures. In contrast, Asayehegn *et al.* (2012) argued that healthy households are more likely to adopt irrigation technologies, implying that households with irrigation technologies are generally healthier than households without irrigation. On the other hand, high medical expenditure might be associated with high household income, which is also associated with irrigation practices. But, this might not be always true. Burney *et al.* (2010) found that health-care expenditure between irrigator and non-irrigator households are statistically nonsignificant.

Another important link between domestic use of irrigation water and health outcome is through increased water quantity and household's time allocation. Hutton and Haller (2004) showed that the time-saving associated with water supply and sanitation generates the greatest economic benefits. Our results confirm a strong positive association between time spent for domestic water collection and access to irrigation, implying irrigator households spend significantly less time than non-irrigator households controlling for distance to drinking water source and other household characteristics (Table A4). This indicates that availability of irrigation water considerably reduces the burden of water collection which is mostly borne by women and children.

Climate change and unpredictable weather poses a challenge and aggravates the vulnerability of farmers to food insecurity. Considering the key role of agriculture in the country's economy, expanding SSI can bring many benefits to farmers through several pathways. Small-scale irrigation technology raises income through increasing production and productivity and reducing risks induced by climate variability. In the study areas, most households with access to irrigation produce more than once per year by extending production in the dry season, which provides additional household income. Asayehegn *et al.* (2012) reported that farmers in Ethiopia with access to irrigation plant crop multiple times per year compared to rain-fed production. Moreover, productivity (gross revenue per hectare) is higher with access to irrigation (FAO 2000). Small-scale irrigation may be instrumental in reducing poverty as incidence and depth of poverty were found to be lower among households with irrigation technologies (Gebregziabher 2008).

Where rainfall is scarce and erratic, access to sufficient quantity and reliable water resource is critical to enhancing agricultural production. In keeping with the ministry of water resources (MoWR), the country could tap only 5 percent of its total water resources for irrigated agriculture and other uses due to lack of technology and finance. The potential for expanding irrigated agriculture in Ethiopia is still large. Of the estimated 3.7 to 4.3 million hectares of potentially irrigable land, less than 10 percent of this area is currently irrigated, and more than half of this area is irrigated by traditional practices (MoARD 2009). Given that agricultural households constitute the vast majority of rural households in the country, expansion of SSI farming is becoming the priority of the government to improve small-scale agricultural production. In its Growth and Transformation Plan (GTP), the government is keen to expand the use of groundwater for irrigation by supporting smallholder farmers in the adoption and use of private hand-dug wells and appropriate water-lifting technologies. Such interventions may generate higher returns if multiple-use of water is incorporated into the design to improve WASH and agricultural production where access to improved domestic water supply is inadequate.

Our result highlights that irrigation significantly increases women's agricultural work load as irrigation requires more labor than rain-fed agriculture. On the other hand, it also substantially reduces women's time for water collection (Table A4). Furthermore, it revealed that the benefits of the domestic use of irrigation water use may be more significant in terms of reducing women's water collection time and increasing the availability of domestic water consumption than its negative health impacts via poor POU water quality. Although our results are robust to various model specifications, they do not mean 'causal' relationships between the outcome and our variables of interest. The variable irrigation or domestic use of irrigation water is more likely to be endogenous due to measurement errors and/or unobserved household characteristics. Our results, however, show strong correlations that, in statistical parlance, are too robust to ignore. The study may also be contaminated by the long recall and under-report bias for any health symptoms, particularly for diarrhea. As diarrheal disease is not considered as serious health issues, it may go unreported especially among adults. In addition, all household members were not available during the interview, and in most cases, the household head and primary caretaker were responsible for responding the questionnaires.

5.6 Conclusions and Recommendations

Small-scale irrigation interventions can impact health and nutrition outcomes in several pathways, including increased food availability (in quality and quantity), increased agricultural productivity and production and thus household income from market sales. With irrigation, households become less dependent on rain and can grow and sell high-value crops throughout the year. On the other hand, poorly designed irrigation system has the potential to increase the burdens of diseases through an increased incidence of vector-borne diseases, such as malaria, and it also affects the quality and quantity of domestic water supply. Rural households often use irrigation water for domestic purpose where access to improved source is inadequate. Similarly, although the primary objective of increasing access to improved rural water supply is for human consumption, rural water supplies are often used for a range of additional services such as water for livestock, home gardens, and SSI activities for the production of crops and vegetables. Such non-exclusive water supply (through multiple water use), however, presents both threats and opportunities. Availability of irrigation water substantially reduces women's time for domestic water collection; nevertheless, irrigation provides another pathway for domestic water contamination (both chemical and microbiological), as irrigation largely requires the application of agro-chemicals.

Our results show that irrigation and household health are significantly associated though there might be a self-selection problem to attribute the poor health outcomes to irrigation. We could not find any evidence, however, to support our initial hypothesis that irrigation can increase diarrhea incidence through its impact on domestic water quality. The impacts of irrigation on domestic water quality may not be substantial to increase the risk of poor water quality to cause diarrhea. On the other hand, irrigation reduces women's time for domestic water collection and increases domestic water availability. Moreover, although domestic use of irrigation water generally deteriorates the health status of households, we could not find a significant difference in terms of diarrhea incidence between the groups.

This shows that the linkage between rural water supply, sanitation practices, and agriculture is complex. In this complexity, interventions might work best when they draw on a range of approaches and disciplines rather than working on a single intervention. The situation may be improved if rural water supplies can be constructed to accommodate a range of services in addition to the basic domestic water supply to link with income generating activities, such as livestock rearing, homestead irrigation, where only one water source is available for all the needs of a community. Similarly, interventions in SSI water management systems should acknowledge the multiple uses of water where access to improved domestic water availability is limited. If multiple-use of water systems is designed by considering the human health and environmental risks, it would help to optimize water availability and quality for domestic and productive use of this limited resource. Moreover, promoting improved WASH from 'farm to fork' to reduce agro-chemical and microbiological contamination as irrigation water can be a source of contamination. Ensuring rural households do not use irrigation runoff for drinking is vital to avoid water-related diseases. This needs to build behavioral changes for sustained improvements in water and sanitation services and key hygiene practices. Lastly, SSI intervention should incorporate nutrition and health aspects through training programs and awareness campaigns. This might help to maximize the potential gains from SSI and to minimize the risk associated with it in terms of nutrition and health. Generally, if the multiple-use of irrigation water is recognized where water availability is limited, and both WATSAN and agriculture are managed in an integrated and indirect support for improved health and nutrition outcomes, multiple benefits, such as improved health and nutrition outcomes, might be achieved and trade-offs reduced.

6. Determinants of Child Nutrition Outcomes

6.1 Introduction

In developing countries, a significant percentage of children are suffering from malnutrition and micronutrient deficiency. It is estimated that malnutrition alone is responsible for more than one-third of child deaths globally (Black *et al.* 2008; UNICEF 2013). Ethiopia is not an exception in this regard, and the problem of child undernutrition and substandard child growth attainment in the country is among the highest in the world. Nationally, 40 percent of under-five children are stunted (low height-for-age), which often used as an indicator of chronic malnutrition), and 21 percent of children are severely stunted (CSA 2014). The proportion of child malnutrition is even much higher in rural areas.

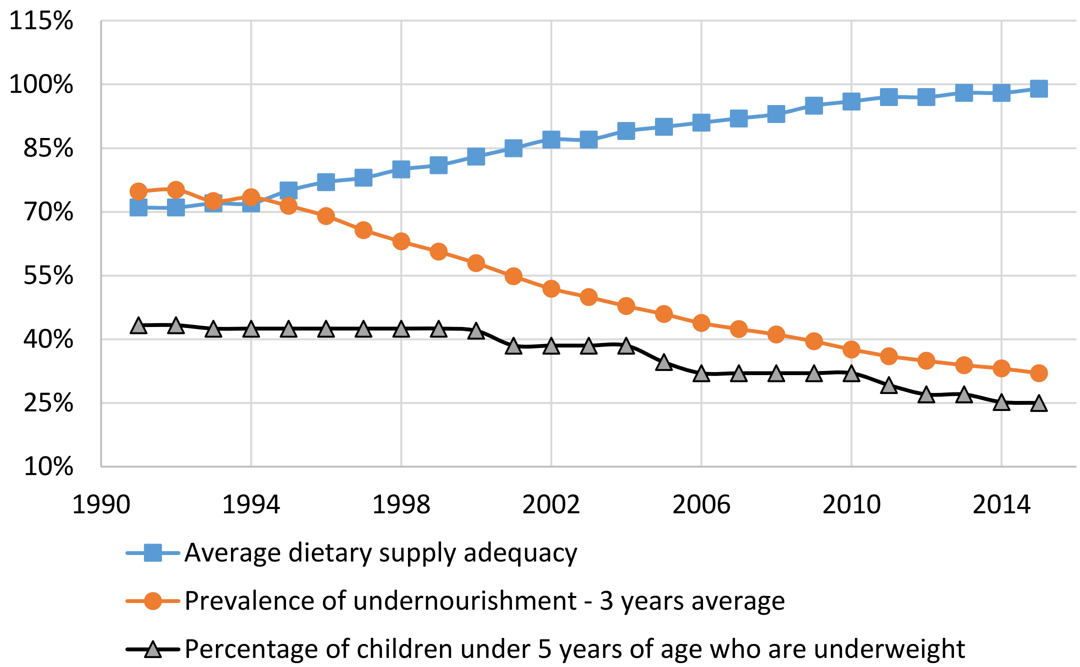


Figure 6-1: Percentage of undernourished children and average dietary supply adequacy trend over time

Source: Author's illustration using data from FAOSTAT 2015.

Figure 6-1 shows the percentage of under-five children who are underweight over time and average dietary supply adequacy between 1992 and 2014. The figure indicates that the percentage of under-five children who are underweight gradually reduced by less than a percentage point per year between this period. Although child undernutrition has dramatically declined over the last decade; the prevalence rate is however still unacceptably high.

The problem of chronic child malnutrition in Ethiopia has been there for many years, and the GoE has recognized the gravity of the problem. To this end, several strategies have been devised by the government to improve the overall nutritional and health status of the most vulnerable group of the population, that is, infants and young children, and mothers. It launched various nutrition and health programs to promote health education and environmental sanitation, provision of micronutrients and treatment of extremely malnourished children (CSA & ICF International 2012). In 2008, the government launched the National Nutrition Programme (NNP) to address the immediate and fundamental causes of malnutrition (UNICEF 2013). However, the government should do much more if the prevalence of chronic malnutrition is to be substantially reduced in the country.

The nutritional status of children is an important indicator of children's health. It is the result of complex interactions between feeding practice and the overall status of health and health-care access and utilization (CSA & ICF International 2012). Several socioeconomic and cultural factors influence child feeding practices and thereby the nutritional status of the child. The first two years of life is understood to be important for children's optimal growth and development. Childhood illnesses, such as diarrhea, pneumonia, and micronutrient deficiencies, however, impede on children's path to optimal growth and development. The nutritional status of under-five children can be evaluated using anthropometric data on height and weight. Based on this evaluation children that are at increased risk of faltered growth can be identified.

Access to improved WATSAN is also important not only for child health and well-being but also for child growth outcomes. A wide range of empirical evidence shows that lack of access to improved WATSAN services is cause for poor child health (Bose 2009; Checkley *et al.* 2004; Esrey 1996; Günther & Fink 2010; Jalan & Ravallion 2003; Kumar & Vollmer 2013). The empirical evidence base showing that lack of these services, especially sanitation, are causes of child malnutrition is also growing and has received renewed attention in recent years.

Irrigated agriculture is also closely linked with nutrition and health and has long been considered as a major driving force to fight acute malnutrition in developing countries (Kennedy & Bouis 1993). The link between irrigated agriculture and nutrition may seem intuitive and simple: growing more and diversified crops provide households with more quality and quantity of foods for a healthy and active lifestyle. A study of child nutrition in Kenya found evidence that there are higher energy intakes and lower chronic malnutrition in children where there is access to irrigation as compared to communities without access (Kirogo *et al.* 2007). The potential of irrigation to improve nutrition and health outcomes, particularly in Africa, has been recently well-documented (for a detailed review and discussion see, Domènech 2015; Domenech & Ringler 2013).

In line with the earlier discussion, the objective of this chapter is to assess the association between drinking water quality and sanitation practices and child nutritional outcomes.

Identifying the major factors that influence child growth outcome where a significant portion of the population is malnourished will help policy makers and practitioners to design the right intervention to improve the public health at large.

6.2 WASH and Child Nutrition Outcomes

Unimproved drinking water and unsafe sanitation practices are common realities for a substantial percentage of people in the developing countries. Empirical studies that examine the relationship between WATSAN infrastructure and child nutritional outcomes are scarce and existing knowledge is limited. Hebert (1985) shows that water quantity had a significant effect on the growth and nutritional status of children above age three while water quality is more important at younger ages. A study conducted in Southern Punjab, Pakistan provides supporting evidence for this pattern. After controlling for potential confounding factors, the study finds a strong correlation between quantity of water available in households and the prevalence of diarrhea and stunting (van der Hoek *et al*. 2002).

Water supply and sanitation interventions can play a major role in fighting malnutrition, which is an underlying cause of an estimated 2.6 million death of under-five children each year (Save the Children 2012). Most of these children live in developing countries. More than 50 percent of the chronic malnutrition among children in developing countries is due to repeated diarrhea and/or intestinal infections as a result of unsafe drinking water, inadequate sanitation and insufficient hygiene (Prüss-Üstün *et al.* 2008). Furthermore, episodes of repeated diarrhea due to inadequate WASH and childhood undernutrition had significant negative long-term impacts on cognitive development, and was linked with poorer school performance, lower adult economic productivity, and increased mortality risk (Black *et al.* 2008; Humphrey 2009; Lorntz *et al.* 2006).

The causality between malnutrition and severe diarrheal diseases is still contentious in the literature. Studies show that malnourished children are more susceptible to severe diarrhea incidence and duration. On the other hand, repeated diarrhea can lead to malnutrition (Briend 1990; Checkley *et al.* 2008; Checkley *et al.* 2003; Dewey & Mayers 2011; Patwari 1999; Schorling *et al.* 1990; Ulijaszek 1996). This suggests that diarrhea and malnutrition operate in a vicious cycle. Reducing the prevalence of diarrhea and other infectious diseases has an impact on nutritional status. That is interventions which improve WATSAN break the cycle and result in better child nutrition directly and indirectly (Fenn *et al.* 2012; Guerrant *et al.* 2008; Lin *et al.* 2013; Prüss-Üstün & Corvalán 2006; Spears 2013).

The WHO classified malnutrition into three broad categories based on the degree of severity and the prevalence rate. Table 6-1 presents the WHO classification of malnutrition. Based on this classification, the prevalence of child wasting is moderate although the prevalence of underweight and stunting in Ethiopia can be termed as high and very high, respectively. Unless the root causes of child malnutrition can be addressed timely, child malnutrition will remain a great public health problem in the country.

Table 6-1: WHO classification of severity of malnutrition prevalence

Indicator	Severity of malnutrition by prevalence ranges (%)			
	Low	Medium	High	Very high
Stunting (low height-for-age)	<20	20-29	30-39	>=40
Underweight (low weight-for-age)	<10	10-19	20-29	>=30
Wasting (low weight-for-height)	< 5	5-9	10-14	>=15

Source: WHO (n.d).

Trends in the nutritional status of children for the period 2000, 2005, 2011 and 2014 are shown in Figure 6-2. It displays a declining trend in the proportion of children stunted, wasted and underweight over the period. Stunting prevalence decreased by 31 percent (from 58% to 40%), wasting reduced by 25 percent (from 12% to 9%), while underweight prevalence reduced by 39 percent (from 41% to 25%) over the last 15 years. Despite all the efforts made to address the problem and the improvement achieved in the last two decades, the severity and prevalence of chronic malnutrition is still quite high in the country.

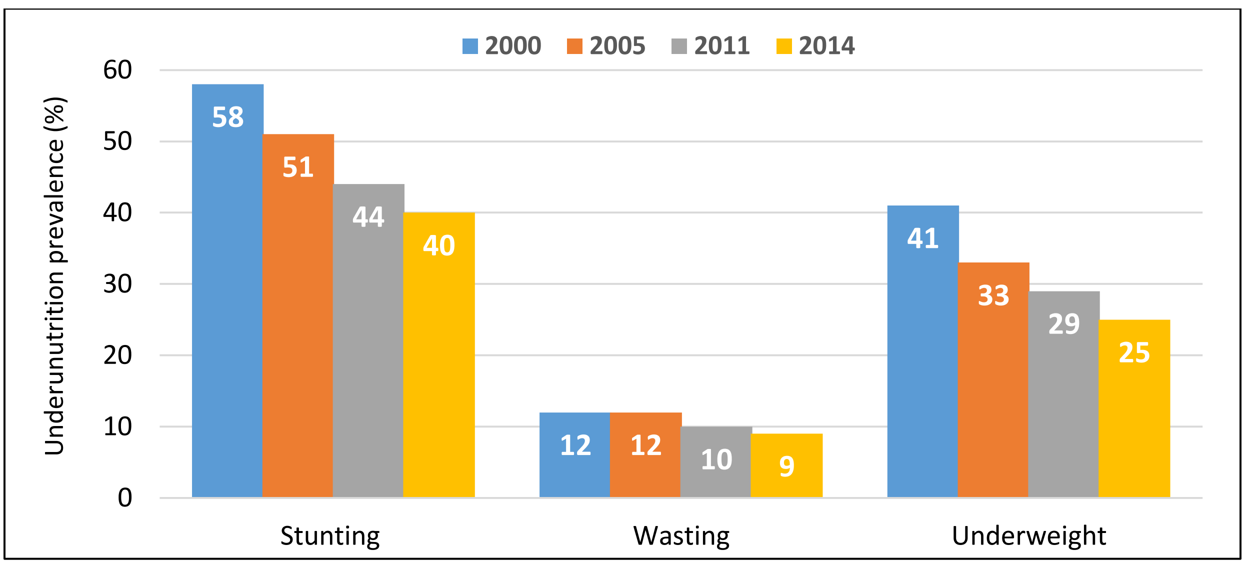


Figure 6-2: Trends in nutritional status of under-five children, 2000-2014

Source: Ethiopian mini-demographic and health survey (CSA 2014).

6.3 Data and Methods

For this analysis, we use the same primary household survey data described in chapter 2. In addition to a wide range of demographic and health variables, the survey collected data on height and weight of all under-five children to evaluate their nutritional status. Based on height and weight measures, three indices of anthropometric indicators—weight-for-age, height-for-age, and weight-for-height were calculated. A total of 565 under-five children were eligible to be weighed and measured; however, height measurements for most children under six months old were not obtained. As a result, data are presented for 547 of these children for weight-for-age and 480 children for height-for-age, and weight-for-height measurement indices. The focus of this analyses, therefore, is exclusively for children under-five years of old.

Anthropometric measurements are often used as indicators to measure under-five child nutritional status. To form the standardized measures, weight and height/length measurements converted to weight-for-age z-scores (WAZ), height-for-age z-scores (HAZ), and weight-for-height z-scores (WHZ) for each child.[34] Z-scores are generated using the new WHO child growth standards using the *perc* Stata package (WHO Multicentre Growth Reference Study Group 2006). The z-score is calculated as $z_i = \frac{y_i - y_{50}}{\delta_y}$ where y_i is the anthropometric outcome, y_{50} is the median of the WHO reference population, and δ_y is the standard deviation of the WHO reference population. The z-scores indicate the number of standard deviations a child is below or above what should be normal for his/her age in comparison to a reference child who was fed and raised in an environment that favored optimal growth.

Measurement of nutritional outcomes

In our empirical analysis, we focus on two anthropometric measures: underweight and stunting indicators of nutritional outcomes—which are often considered as a good indicator for child nutrition outcomes. Child nutritional status is measured by weight-for-age and height-for-age z-score. Underweight and stunting also measured as indicator variables: underweight (measured by a dummy variable equal to 1 if the child's WAZ score is less than -2, otherwise 0), and stunting (measured by a dummy variable equal to 1 if the child's HAZ score is less than -2, otherwise 0). These indicator variables are measured as standard deviations from the median of the reference population to describe whether a child was underweight or stunted. A weight-for-age z-score of minus two standard deviations (-2 SD) from the reference population median is considered underweight. A low weight-for-age (underweight) measurement can be used as an objective

[34] The weight-for-height anthropometric indicator also used as to identify the proportion of population who are overweight and obese. Children more than two standard deviations (+2 SD) above the median weight-for-height are considered overweight or obese. A recent report shows that a small proportion (about 2%) of children below age five years are classified as overweight or obese (+2 SD) in Ethiopia (CSA & ICF International 2012).

indicator for both form of malnutrition, that is, either chronic or acute malnutrition (Gray *et al.* 2006). On the other hand, a child with a low height-for-age measurement below the minus two SD is regarded as stunted compared to the median of the reference population. The anthropometric indicators of the nutritional status of children were calculated using new growth standards published by the WHO in 2006 based on a new reference population collected in the WHO Multicenter Growth Reference Study (2006). The new child growth standards show how children grow under favorable environments all over the world, regardless of any social and economic influences.

Control variables

As we are interested in examining the correlation between storage drinking water quality and sanitation practice on child nutritional status, the key independent variables in this analysis are drinking water quality and availability of a pit latrine, child stool disposal behavior, and irrigation agriculture. In addition to child-specific and maternal characteristics, we also have controlled for a range of household and village-level variables potentially correlated with both child malnutrition and household's WATSAN services. The variable delivery is a dummy variable for whether a mother delivered her baby with the help of a health professional such as a doctor, nurse or health extension worker. The variable antenatal care (ANC) indicates the number of visits from a health professional during pregnancy period of her child. Dietary diversity score measures the mean number of food groups (six food items) consumed in the last 24 hours before the survey. Table 6-2 presents the descriptive statistics of the main variables for this analyses. All the remaining variables are as defined in the preceding chapters.

Table 6-2: Descriptive statistics

Variables	Obs.	Mean	SD
Prevalence of underweight	547	0.26	0.44
Prevalence of stunting	480	0.41	0.49
Prevalence of wasted	480	0.08	0.27
Weight-for-age Z score	547	-1.32	0.99
Height-for-age Z score	480	-1.70	1.20
Weight-for-height Z score	480	-0.62	0.98
Dietary diversity score (6 food items)	505	0.34	0.15
Delivery with health professionals	565	0.16	0.37
Number of antenatal care visits (ANC)	565	1.93	1.50

Source: Author's estimates using own survey data.

6.4 Results and Discussion

Figure 6-3 shows the relationship between different anthropometric indicators. The graphs indicate that height-for-age and weight-for-height are not correlated, whereas there tends to be a positive correlation between height-for-age and weight-for-age. Besides, the distributions of the z-scores for the three anthropometric indicators and the overall prevalence of malnourishment are presented in Figure 6-4. The distribution of z-scores presented in Figure 6-4 provides strong visual evidence of malnourishment in all anthropometric indicators. It is easy to see from the figures that the problems of low weight-for-age and height-for-age z-scores are highly visible.

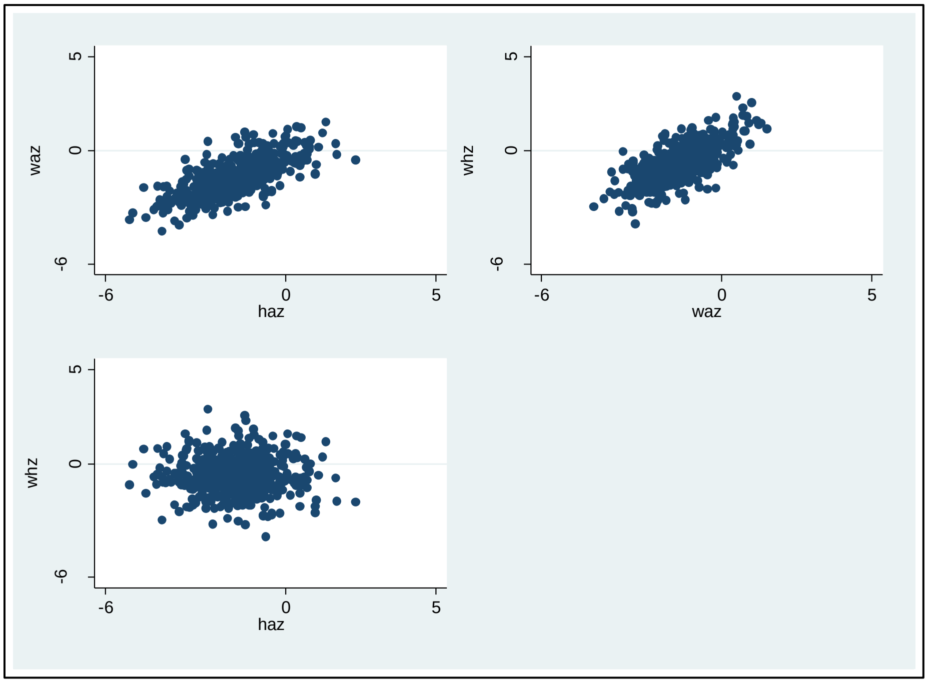


Figure 6-3: Correlation between different anthropometric indicators

Source: Author's computation using own survey data.

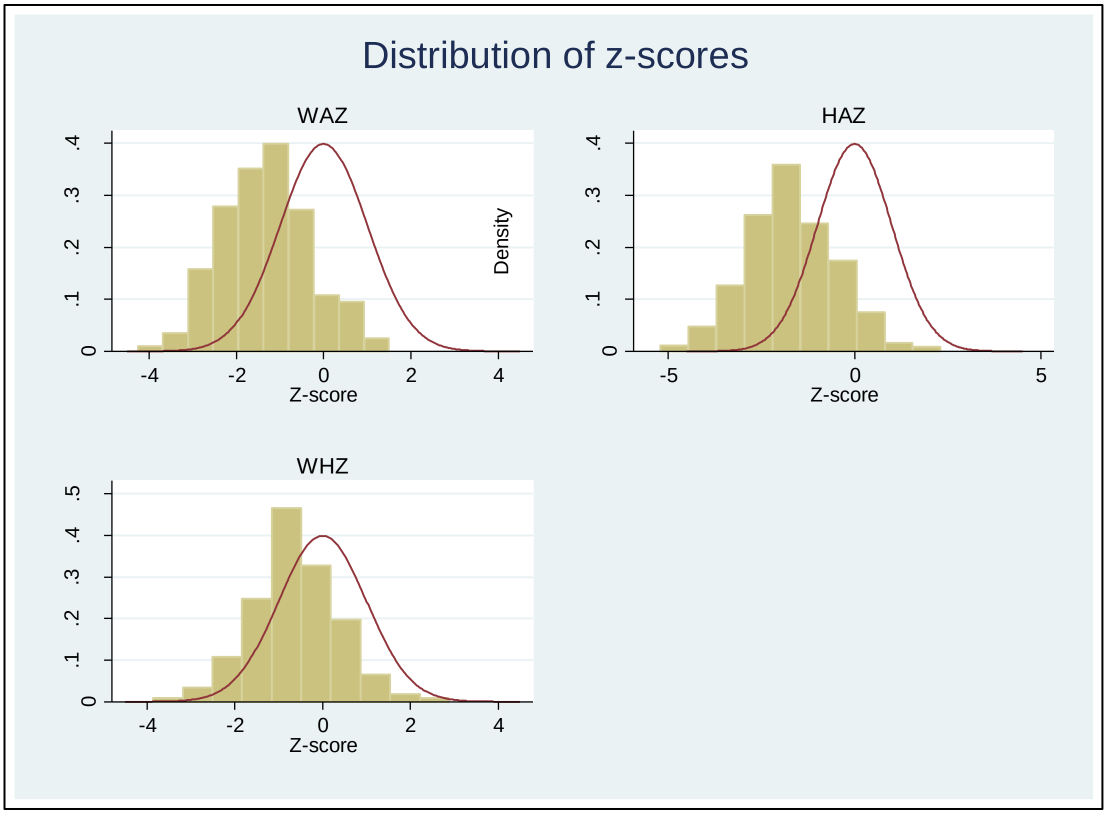


Figure 6-4: Distribution of z-scores for under-five children

Source: Author's computation using own survey data.

Table 6-3 shows the percentage of under-five children in our sample classified as malnourished based on the three anthropometric indices of nutritional status: height-for-age, weight-for-height, and weight-for-age. The table shows that 29 percent of under-five children are underweight (have low weight-for-age), 41 percent of children are stunted (low height-for-age), and 8 percent of children are wasted (low weight and height). The results generally indicate that child underweight and wasting is high while stunting is considered as very high in the study areas. These results are also pretty much comparable to the rural national average prevalence rate, which is estimated at 30.4 (underweight), 46.2 (stunted), and 10.2 (wasted) (CSA & ICF International 2012, p. 159).

Table 6-3: The prevalence of malnutrition based on the WHO 2006 reference group

Variables	Total		Male		Female	
	Obs.	%	Obs.	%	Obs.	%
Underweight	547	26.32	252	29.36	295	23.73
Stunted	480	40.63	223	43.05	257	38.52
Wasted	480	8.13	223	8.97	257	7.39

Source: Author's estimates using own survey data.

Table 6-4 presents the prevalence of child malnutrition by household demographic characteristics. The result shows that children older than 11 months are more likely to be underweight and stunted. Also, there was a significant difference in child malnutrition by sex of the child; boys were more likely to be underweight, stunting and wasted than girls. The proportion of undernourished children varies by housing characteristics too. There is also a marked difference in the prevalence of child malnutrition by districts. Children from Fogera district are more likely to be undernourished than children from Mecha district. A potential reason is that Fogera is often prone to flooding during the rainy season and open defecation is more widespread, which can easily affect the water quality.

Table 6-4: Malnutrition prevalence in under-five children by demographic characteristics

Variables	Obs.	Underweight (%)	Obs.	Stunting (%)	Wasting (%)
Age of child (months)					
6 - 11	55	23.64	47	19..15	8.51
12 - 23	100	31.00	98	34.69	16.33
24 - 35	130	26.15	123	49.59	4.88
36 - 47	122	30.33	120	42.50	5.83
48 - 59	92	29.35	91	43.96	6.59
Sex of child					
Male	295	29.37	223	43.05	8.97
Female	252	23.73	257	38.52	7.39
Housing roofing material					
Corrugated iron sheet	499	26.05	435	41.15	8.05
Thatch	48	29.17	45	35.56	8.89
Districts					
Fogera	347	28.24	307	41.69	10.10
Mecha	200	23.00	173	38.73	4.62

Source: Author's estimates using own survey data.

The bivariate correlation between child nutritional status and household WATSAN characteristic are also briefly discussed below. Table 6-5 presents the prevalence of malnourishment in under-five children by WASH characteristics. The variation in child malnutrition based on improved or unimproved water sources and types of drinking water sources is not systematic. However, the prevalence of child malnutrition variation by household storage water quality is substantial. Children from households whose storage water is contaminated with *E.coli* are more likely to have inferior nutrition outcomes than children of households whose storage water is not contaminated. A surprising result which comes out from Table 6-5 is that children of irrigating households are more likely to be undernourished than children of non-irrigating households across all anthropometric indicators. This finding is counter to what we hypothesized in the earlier discussions. The common understanding is that irrigated agriculture is likely to improve household food security and nutrition. Irrigation helps farmers to produce more and grow more micronutrient foods. However, the environmental impact of irrigation infrastructures that influence child health status may not be captured at the household level. On the other hand, poor child nutritional outcome among irrigated households could be partly explained by low child care due to high labor demand for irrigated agriculture. It might be also the case that the increase in household income due to irrigated farming might not be spent on consumption that improves child nutrition outcomes.

Table 6-5: Malnutrition prevalence in under-five children by WASH characteristics

Variables	Obs.	Underweight (%)	Obs.	Stunting (%)	Wasting (%)
Water source based on WHO					
Improved	267	27.34	235	37.45	8.94
Unimproved	280	25.36	245	43.67	7.35
Primary drinking water source					
Private-protected dug well	30	33.33	26	46.15	7.69
Shared-protected well/spring	237	26.58	209	36.45	9.09
Unprotected well/spring	218	27.06	191	41.88	7.85
Surface water	62	19.35	54	50.00	5.56
Storage water quality					
Contaminated	321	28.97	289	41.52	10.03
Uncontaminated	226	22.57	191	39.27	5.24
Handwashing with soap					
Yes	152	29.61	128	39.06	9.38
No	395	25.06	352	41.19	7.67
Latrine					
Yes	222	25.68	188	37.23	6.91
No	325	26.77	292	42.81	8.90
Irrigation farming					
Yes	368	30.42	323	45.20	9.29
No	179	17.88	157	31.21	5.73

Source: Author’s estimates using own survey data.

The variation of child malnutrition can be influenced by household income level. Improved household income could be associated with improved diet and better access to health services, which in turn can develop children growth outcomes. As shown in Table 6-6, the correlation of household income with child nutritional status is not much clear. We can see that children from the top 40 percent of the income distribution are relatively better off, however.

Table 6-6: Malnutrition prevalence in under-five children by income distribution

Nutrition indicator	Income quintile					Total
	Poorest	Poorer	Average	Richer	Richest	
Underweight (%)	30.84	25.23	26.36	25.93	23.42	26.33
Stunting (%)	41.57	44.33	42.11	35.71	39.60	40.63
Wasted (%)	8.99	11.34	11.34	7.14	4.95	8.13

Source: Author's estimates using own survey data.

6.4.1 Multivariate regression results

Having investigated the bivariate correlation between storage water quality and sanitation practices, and child nutritional status, this section employs multivariate regressions to control for various confounding factors such as child and maternal-specific, and household and community-level characteristics. The regression results for two anthropometric measures of interest, WAZ (underweight) and HAZ (stunting) are reported in Table 6-7 and Table 6-8, respectively. The OLS results are presented in columns 1—3, while estimated results for the probit models are presented under columns 4—6 in each table. Furthermore, the dependent variable for the OLS regression is the negative of the z-score such that a positive coefficient indicates a negative correlation with weight/height. Robust standard errors adjusted for clustering at village level are reported in each model. We start the estimation from the most parsimonious specification, i.e. in the first column, the model is controlled only for the main variables of interest, and then we showed progressively a more comprehensive specification. In this case, we can see how the estimated coefficients remain stable to a full-blown model specification, which is our preferred model. The explanatory power of the model is relatively modest for nutritional outcomes. Finally, we discuss the results concurrently by each measure of anthropometric indicators next.

Results for weight-for-age z-score and underweight

The regression results presented in Table 6-7 indicate that storage water quality is positively associated with weight-for-age z-scores, but this correlation is not statistically significant when we controlled for health facility indicators (columns 3 and 6, Table 6-7). On the other hand, though the sign is not expected, water collection time is robustly correlated with weight-for-age z-score and underweight in all model specifications. We expected better child nutrition outcomes when a household has access to a nearby drinking water source. Moreover, safe stool disposal is statistically significant in the weight-for-age z-score but not in the preferred underweight model. As expected, on average, it suggests that children living in villages with a low concentration of child stools had improved weight-for-age z-score. In the parsimonious model, household's pit latrine is not strongly correlated with child nutrition outcomes, but in the subsequent model specifications, pit latrine marginally associated with poor child nutritional status. This indicates that pit latrine is associated with other control variables. For instance, this variable is moderately correlated with distance to health facility—households are more likely to build latrines if they live close to a health facility. It indicates that children living in households with a pit latrine are 8 percentage points increase in the likelihood of being underweight compared to children living without a pit latrine (column 6, Table 6-7). This result may not be surprising as we have already shown in the preceding chapter that pit latrines are not protective against diarrhea.

The other variables of interest, irrigation and livestock, are also significantly associated with child nutrition outcomes, particularly in the underweight model (columns 4—6, Table 6-7). Unpredictably, children from irrigating households are 13 percentage points more likely to be underweight than children from non-irrigating households (column 6, Table 6-7). This can be partly explained by lower child care due to high labor demand for irrigated agriculture (Komatsu *et al.* 2015; Miller & Urdinola 2010). Normally, irrigated agriculture is more labor-intensive than rain-fed agriculture (Namara *et al.* 2011). Moreover, irrigator households often produce twice a year and demand more family labor than conventional farming households. On the other hand, livestock ownership significantly improves child weight-for-age z-scores. Livestock improves child nutritional outcomes by supplying richer animal proteins, such as cow milk, which may be the only important source of animal protein and micronutrients for children in rural areas. Livestock, however, may also be associated with poor sanitary environment.

Regarding other control variables, child age is negatively correlated with weight-for-age z-scores (young children are less likely to be underweight than older children). Male children are slightly more likely to be underweight than female children. The weight of a boy child is likely to be 0.14 z-scores lower than that of a girl (column 3, Table 6-7). Mother's age, household size and level of education appear not to have a significant correlation with child weight-for-age. As expected, dietary diversity score and household assets are positively correlated with child nutritional status in both model specifications.

In terms of health control variables, we find a strong positive association between weight-for-age z-score and the number of antenatal care (ANC) visits. The effect of ANC appears large and robust, and this could be that this variable may capture health knowledge of the primary caretaker and household wealth. Also, children delivered by the help of a health professional are 15 percentage points lower in the likelihood of being underweight than children delivered without the help of any health professionals. We could also not be surprised about the non-significant influence of the variable distance to the health center, as this variable could not capture the effects of quality of health services. Moreover, its effect may have been already partially captured by the other health indicator variables. Because distance to health facility can also influence the variable ANC and delivery.

Table 6-7: Multivariate regression model for weight-for-age/underweight

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) PROBIT	(5) PROBIT	(6) PROBIT
Water quality (1= no *E.coli*)	-0.199*	-0.183*	-0.081	-0.104**	-0.102**	-0.069
	(0.100)	(0.097)	(0.100)	(0.043)	(0.041)	(0.042)
Water collection time (1=30min/less)	0.222*	0.190*	0.220**	0.153***	0.155***	0.142**
	(0.115)	(0.112)	(0.106)	(0.058)	(0.056)	(0.056)
Safe stool disposal (village mean)	-0.901***	-0.911***	-0.612***	-0.164*	-0.159*	0.015
	(0.193)	(0.190)	(0.189)	(0.091)	(0.089)	(0.108)
Pit latrine (dummy)	0.083	0.122	0.162*	0.058	0.067*	0.080**
	(0.095)	(0.090)	(0.087)	(0.038)	(0.038)	(0.036)
Irrigating households (dummy)	0.211**	0.164*	0.182*	0.120***	0.112***	0.128***
	(0.105)	(0.098)	(0.092)	(0.041)	(0.039)	(0.040)
Livestock holding	-0.073**	-0.055	-0.008	-0.060***	-0.055***	-0.027**
	(0.032)	(0.035)	(0.037)	(0.012)	(0.013)	(0.013)
Child age in months		0.044***	0.006		0.013***	-0.005
		(0.009)	(0.010)		(0.004)	(0.004)
Child age square (/100)		-0.054***	-0.006		-0.018***	0.005
		(0.015)	(0.016)		(0.006)	(0.006)
Child is male		0.154*	0.136*		0.055	0.067**
		(0.079)	(0.074)		(0.039)	(0.030)
Mother age		-0.010	-0.005		-0.006	-0.007**
		(0.008)	(0.008)		(0.004)	(0.003)
Highest education completed		-0.032**	-0.022		-0.005	0.001
		(0.015)	(0.014)		(0.008)	(0.008)
Household size		0.030	0.038		0.015	0.019
		(0.033)	(0.032)		(0.016)	(0.016)
Dietary diversity score			-2.263***			-1.178***
			(0.293)			(0.133)
Log of assets value			-0.110**			-0.052***
			(0.049)			(0.018)
Delivery with health professional			-0.080			-0.147***
			(0.110)			(0.052)
Number of ANC visits			-0.117***			-0.052***
			(0.026)			(0.010)
Distance to health center			0.001			0.005
			(0.013)			(0.006)
Constant	1.589***	1.029***	3.043***			
	(0.171)	(0.255)	(0.448)			
Observations	547	547	494	547	547	494
R-squared	0.07	0.14	0.27	0.07	0.09	0.30
Model F-stat/Chi2	7.127	6.700	14.16	33.13	41.75	136.74
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1, and Probit in average marginal effect
Note: the dependent variable for the OLS regression is negative of the z-score.

Results for height-for-age z-score and stunting

The regression results presented in Table 6-8 indicate that there is no statistically significant association between storage water quality and sanitation variables and child height-for-age outcomes in our data. Studies show that environmental factors, such as access to improved WATSAN, matter for child height (Dangour *et al.* 2013; Fenn *et al.* 2012; Kabubo-Mariara *et al.* 2009; Spears 2013). For instance, Fenn *et al.* (2012) showed that WASH interventions reduce the prevalence of stunting by 12 percent in Ethiopia. Similarly, Lin *et al.* (2013) indicated that children living in households with improved sanitation environment and proper hygiene are taller for their age compared to children living in contaminated environment. However, others do not find a statistically significant correlation between child nutritional outcomes and WATSAN (Kabubo-Mariara *et al.* 2009). This might be because these variables sometimes may not measure well the environmental quality that children grow up. Height-for-age (stunting) is a cumulative indicator of slow physical growth and reflects long-term malnutrition (Glewwe *et al.* 2002). It is worth pointing that household storage water quality can change frequently and cannot capture/predict the actual water quality being consumed over a long time. Again, distance to drinking water sources and irrigated agriculture are negatively associated with child height-for-age while dietary diversity score is positively correlated.

Regarding the other control variables, child age and gender are negatively correlated with height-for-age z-scores. For instance, the height of male children, on average, is 0.25 z-scores lower than female children; older children are more likely to be stunted than younger ones. This is consistent with some studies that show that girls have relatively better nutritional status than boys (CSA & ICF International 2012; Kabubo-Mariara *et al*. 2009). Furthermore, the health-related control variables, again the results are robust, statistically significant and fairly large nutritional gains to the number of ANC visits and delivery by a health professional. Although access to or utilization of health facility is limited in many rural areas of the country, a study by Headey (2014) shows similar results that four or more ANC is strongly associated with better height-for-age z-score.

Generally, our results suggest that there is some degree of correlation between WATSAN and child nutritional status, particularly the impact of water collection time is robust to any model specifications. As discussed above, the negative impact of water collection time is not actually expected. We showed, in the previous chapters, that water collection time is negatively correlated with household drinking water quality and child diarrhea incidence. In the same line of arguments, children living with households having closer water source point should have better nutritional status than children living with households having a faraway water source. This could however be partly explained by poor quality of drinking waters, that is, households have to travel long distance to get access to improved water sources.

The impact of irrigation agriculture on child nutrition outcomes is also counterintuitive. Although irrigation is expected to improve household food availability and dietary diversity, which in turn improves nutritional outcomes of the households (Olney *et al.* 2009; von Braun *et al.* 1989), child nutritional outcomes may not be improved. The positive impacts of irrigation on household nutritional status may not occur automatically. Irrigation helps farmers not only to grow and sell high-value crops throughout the year and increases their income but also to improve the food base available to them. We also show that irrigator households report higher income from agriculture than non-irrigator households, but we do not find a significant difference in terms of dietary diversity score between irrigator and non-irrigator preschool children. As most of the common staple foods in many communities do not provide sufficient micronutrient, such as vitamins, minerals, for younger children, emphasizing dietary diversity and nutritional content of the available food base may be vital to children's growth and mental development.

The association between nutritional outcomes and health indicator variables are also robust across all model specifications and show fairly large nutritional gains than improved WATSAN services. In this analysis, we are only able to explain a small portion of the variations in child nutrition outcomes. It is worth pointing that child nutrition outcome is a result of complex interaction of different variables, and WATSAN is one of the many ingredients for improved child growth outcomes.

The economic burden of malnutrition is estimated to be huge and its health effect is last long. Malnourishment can impair proper cognitive and physical development, increase susceptibility to infectious diseases, which in turn affects health outcomes, school performance, and productivity. Investing in programs that improve child nutrition outcomes would more likely to produce large returns in the long term, particularly in areas where the prevalence of malnutrition is high as the case in rural Ethiopia.

This analysis may be suffered from omitted variables such as mother's nutritional status and child's birth weight and order. For instance, a child's birth weight is an important indicator of the child's nutritional status and child's vulnerability to infectious diseases and survival. Children who are small at birth are more likely to be malnourished than children who are average or larger in size at birth (CSA & ICF International 2012). Birth weights however were not known for many babies as most of them delivered at home and not weighted at birth. On the other hand, the mother's nutritional status is also a good predictor of her child's nutritional outcomes. Empirical studies show that children of thin mothers are more likely to be stunted than the children of overweight mothers. Improving maternal nutrition is, therefore, vital for improving children's health and nutrition status.

Table 6-8: Multivariate regression model for height-for-age/stunting

VARIABLES	(1) OLS	(2) OLS	(3) OLS	(4) PROBIT	(5) PROBIT	(6) PROBIT
Water quality (1= no *E.coli*)	-0.123	-0.124	-0.064	-0.037	-0.037	-0.007
	(0.129)	(0.128)	(0.116)	(0.054)	(0.054)	(0.047)
Water collection time (1=30min/less)	0.640***	0.601***	0.611***	0.174***	0.162***	0.142***
	(0.148)	(0.146)	(0.126)	(0.062)	(0.063)	(0.051)
Safe stool disposal (village mean)	-0.758**	-0.673**	-0.388	-0.193	-0.155	-0.009
	(0.287)	(0.259)	(0.266)	(0.131)	(0.125)	(0.121)
Pit latrine (dummy)	0.075	0.080	0.119	-0.010	-0.011	-0.001
	(0.111)	(0.112)	(0.109)	(0.049)	(0.047)	(0.042)
Irrigating households (dummy)	0.251*	0.206	0.205	0.107**	0.086*	0.094**
	(0.145)	(0.137)	(0.124)	(0.053)	(0.052)	(0.040)
Livestock holding	-0.053	-0.038	0.029	-0.021	-0.018	0.020
	(0.047)	(0.050)	(0.049)	(0.018)	(0.019)	(0.017)
Child age in months		0.058***	0.046***		0.019***	0.013**
		(0.015)	(0.015)		(0.007)	(0.006)
Child age square (/100)		-0.079***	-0.069***		-0.023**	-0.018**
		(0.024)	(0.023)		(0.011)	(0.009)
Child is male		0.231**	0.249**		0.043	0.057*
		(0.114)	(0.102)		(0.046)	(0.034)
Mother age		-0.020*	-0.012		-0.010**	-0.006
		(0.012)	(0.011)		(0.004)	(0.004)
Highest education completed		-0.039**	-0.024		-0.012	-0.003
		(0.017)	(0.016)		(0.009)	(0.008)
Household size		0.083*	0.053		0.038**	0.024
		(0.044)	(0.041)		(0.016)	(0.015)
Dietary diversity score			-2.361***			-1.461***
			(0.361)			(0.154)
Log of assets value			-0.014			-0.037
			(0.071)			(0.024)
Delivery with health professional			-0.230*			-0.105**
			(0.134)			(0.053)
Number of ANC visits			-0.155***			-0.060***
			(0.035)			(0.013)
Distance to health center			0.005			-0.001
			(0.014)			(0.006)
Constant	1.450***	0.665*	1.686***			
	(0.252)	(0.379)	(0.624)			
Observations	480	480	476	480	480	476
R-squared	0.07	0.12	0.26	0.03	0.06	0.29
Model F-stat/Chi2	6.569	6.132	16.18	15.61	29.40	177.45
Model p-value	0.000	0.000	0.000	0.000	0.003	0.016

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1, and Probit in average marginal effect.
Note: the dependent variable for the OLS regression is negative of the z-score.

6.5 Conclusion and Implications

Ethiopia has made a remarkable progress in reducing child undernutrition; however, a substantial portion of the population is still malnourished, and the country remains one of the most undernourished populations in the world. The country also lags behind the rest of the world in terms of access to improved drinking water and adequate sanitation facilities (WHO/UNICEF 2015). This deficiency can contribute to increased child morbidity and mortality, poor nutritional outcomes, lower social and economic development. Using a primary household survey data and anthropometric measurements, this chapter investigates the degree of association between WATSAN variables and nutritional status of preschool children in rural areas of Ethiopia.

This analysis contributes to the limited literature on child malnutrition and WATSAN services. The results reveal that preschool children in rural Ethiopia have a lag in height-for-age and weight-for-age relative to the WHO reference populations and support previous evidence. Indeed, our results explain a small portion of the variations in child nutrition outcomes which is possibly influenced by a range of interconnected variables and often difficult to control for and disentangle their effects using cross-sectional data. To improve nutritional outcomes in rural Ethiopia, it needs a great effort to improve access to and utilization of health service and micronutrients in children's diets on top of improving the WATSAN ladders. As the results suggest, the quality and quantity of complementary feeding practices for children should be promoted. Providing diverse food groups that supply all the vital micronutrients helps meeting the requirements for optimal child growth and healthy lives. Furthermore, it is shown that parental education is an important determinant of nutrition outcomes and can produce reasonably large effects on child growth outcomes (Behrman & Wolfe 1987; Thomas *et al.* 1991); nonetheless, as discussed earlier, both maternal and paternal levels of education are extremely low in the study areas. In the long-term, maternal educational improvement could be an important channel to improve child malnutrition.

7. General Conclusions and Policy Recommendations

In the developing world, lack of access to improved WATSAN services are major causes of morbidity and mortality for large portions of the population. Expanding the provision of access to improved WATSAN services is, therefore, a priority among government and development partners in many developing countries. Increasing investments in WATSAN infrastructures and promoting key hygiene practices are generally expected to improve the health, social and economic benefits of the population—especially by reducing the risk of many communicable diseases among young children.

Inadequate access to improved WATSAN services remains a major cause of health problems in Ethiopia—particularly in the rural areas. Lack of clean drinking water and unsafe sanitation practices are the main causes of diarrheal diseases among under-five children (CSA & ORC Macro 2006; Usman *et al*. 2016). The negative health impact of contaminated water is worsening because most rural households obtain their drinking water from unprotected sources, and they often consume the water without any prior treatment. Moreover, many rural households have poor understanding of the importance of proper hygiene practices, which further increases the risk of contracting infectious diseases. Household water sample tests also indicate that poor POU water quality is a significant problem in the study areas. Besides the evidence that most of the so-called 'improved' water sources in rural areas do not provide safe water for consumption, the problem of lack of improved drinking water is compounded by POU water contamination due to unsafe water storage and handling practices. Although access to clean water and pit latrines has increased significantly during the last decade, many of the surveyed households did not regard the progress as satisfactory in terms of access to clean water supply. Rural households complained about a lack of access to improved water sources, poor water quality, and having to travel long distances to access drinking water.

The GoE defines 15 liters of water per capita per day within 1.5 km of their home as a primary indicator for access to improved rural water supply. However, this does not include water safety at POU and water continuity throughout the year. As discussed earlier, most rural water supply often contains water unsafe for drinking; in some instance, water sources do not distribute water continuously throughout the year due to limited capacity and maintenance and repair problems (MoW 2007; UNDP 2006; Beyene 2012). This implies that households may be forced to find out alternative water sources which are of poor quality or less convenient and more distant sources. As this stand-alone indicator conceals various inequalities, a broader approach should be developed that take into account the basic pillars of access to improved water supply in rural areas. While achievement on improved water supply coverage over the last decade has been applauded, investments should be made to make sure that existing services are sustainable while improving its quality.

According to the WHO/UNICEF (2015) JMP progress report on WATSAN over the last two decades clearly indicated that sanitation coverage is lagging far behind water supply coverage. To meet the SDG-6 which aims at ensuring access to WATSAN for everyone there should be more concerted and coordinated actions. Unless efforts to increase access to improved WATSAN services are intensified and implemented in conjunction with the promotion of proper hygiene practices, communicable diseases will continue to remain a major cause of morbidity and mortality in the country.

The study relied on a primary household survey data from rural areas in Ethiopia where water-related diseases are quite prevalent health problems due to lack of access to clean water and basic sanitation facilities. The household survey was conducted over a five month period between February and June 2014. The survey collected a range of information on demographic and socioeconomic characteristics including water quality sample testing at household's water storage and sources to determine the level of *E.coli* bacteria (CFU/100ml water). In addition, anthropometric measurements, such as height and weight, were also collected for all under-five children.

7.1 Potential Intervention Areas

The study suggests that the AG-WATSAN nexus requires a mix of instruments to address the problem of health and nutrition outcomes in the study areas. That is, there is no one silver bullet for the problem. It needs a more integrated cross-sectoral approach from various sectors such as agriculture, WASH, health, nutrition, and education from different actors such central and local government, and NGOs. Creating an enabling environment to facilitate the multi-sectoral approach (i.e. working together by avoiding sectoral thinking about the problem) may bring long-term and sustainable solutions for the problem. Based on our empirical findings, we highlight the key policy implications coming from this work. We discussed four main potential intervention areas, which can be targeted, to improve the existing poor WASH services and health and nutritional status in the study areas, and we discussed them below one after the other.

7.1.1 Rural water supply

About 74 percent and 58 percent of the water sample from sources and household storage were positive for *E.coli* bacteria, indicating that most rural population is at high risk of waterborne diseases. Access to an improved drinking water source is low in the study areas—only 50 percent of the surveyed households have access to protected or 'improved' water sources; however, more than 43 percent of these households' POU water was contaminated with fecal matters. The findings indicate the rampant drinking water problems both at the POS and POU. The following recommendations are made to bring immediate health benefits by addressing the problem of poor POS and POU water quality.

Efforts should be increased to further expand the provision of improved drinking water supply to increase access for the unserved rural population. Improving access to clean water supply not only increases the quantity of clean water available for households but also allows households to save time by reducing the distance between each household and the nearest water access point. The available time from water collection may be used to look after the children and to engage in other productive activities to generate income. The study also shows that shortening the distance to water source points improves not only POU water quality but also health outcomes. However, such infrastructure investments require many years of financing which might be only feasible in the long-term for a country like Ethiopia. The following interventions can improve the overall situation of poor water quality both at the POS and POU in the short-term. Such simple interventions substantially reduce avoidable morbidity and mortality caused by lack of access to improved WASH services.

Available water source points should be properly protected because protection of water source points is a first-step to lessen the risk of contamination. Private-well water sources should not be developed close to or downslope from household's latrine to prevent potential seepage. Many of the private-wells in the study areas are bucket-wells and they are often shallow and inadequately protected and thus they can be contaminated easily by microorganisms and other external pollutants such as latrine, animal droppings, dirty ropes and buckets and households waste. Our results show a significant positive correlation between the presence of a pit latrine and the POU water quality for households with own private-wells water source. Moreover, most community water sources considered to be 'improved' showed the presence of *E.coli* which is not in compliance with both the national and the WHO guideline standards.

Promoting household water treatment methods and products to address POU water quality concerns. Given that most rural households obtain their drinking water from unprotected sources, a simple household drinking water treatment practices substantially avoids the risk of contaminated water. There is, however, a lack of awareness of the need to treat household drinking water. POU water treatment on regular basis is almost negligible among the study households because households' perception regarding drinking water quality is that clean water is 'clean' water. Promoting HWTS and the health risks of drinking contaminated water can, therefore, bring significant progress in the provision of safe drinking water from source to mouth. Increasing the provision of rural water supply alone may not be enough if households do not treat their water or practice safe water storage and handling. The study suggests that uncontaminated POU drinking water can reduce childhood diarrhea by 15 percentage points and up to 6 percentage points for adults. We, therefore, recommend all rural households to develop the habits of HWTS to ensure safe water quality—particularly for drinking.

The study also indicates the importance of WUA in the provision of safe water supply in rural areas. Households belong to a village with WUA have better storage water quality that who do not. The provision of drinking water supply through community water scheme is the only existing conventional approach to increasing access to clean water in many rural areas. Building the capacity of WUA to enable them to repair and manage available water sources, and providing training in water source protection and environmental sanitation is, therefore, critical in the provision of sustainable water supply.

Establishing a water quality monitoring system which can monitor a set of common drinking water quality indicators for rural water supply systems is essential to safeguarding public health. Determining the public health risk associated with drinking water quality is useful; however, in practice routine monitoring of pathogens is generally not carried out in many rural areas.

Community variations and household behavioral and sanitary factors are also key determinants of household POU water quality. Unsafe sanitation practices, improper disposal or storage of household wastes and poor environmental sanitation could be the primary causes of drinking water contamination. Moreover, keeping domestic animals separately from household dwellings and out of water source catchment areas can improve household water quality. 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 disease-causing pathogens.

7.1.2 Sanitation infrastructure and practices

In terms of sanitation, we found that 42 percent the households have access to a simple pit latrine while the rest of households defecate in the open. Such sanitation technology is considered unimproved based on the commonly used WHO definition. In most cases, these latrines are not fly-proof and do not have handwashing stations, squat-hole covers, and proper structures; and become dysfunctional for many reasons, including the evidence that they are not connected to any sewerage system and they can also easily collapse due to flooding.

Pit latrines should be therefore fly-proof equipped with a squat-hole cover and should be hygienically maintained. The study reveals that availability of pit latrine increases the risk of diarrhea incidence and the probability of a child being underweight. This indicates that improperly build or poorly located and/or maintained latrines will not generate positive health. Nevertheless, we are not encouraging open defecation per se, but rather arguing that existing pit latrines are not good enough to achieve the desired health benefits of sanitation. Eliminating human feces in the open through the construction of pit latrine alone is not enough to combat diarrheal diseases if the oral-fecal transmission pathway is not completely blocked. Pit latrines should be adopted if only adequate hygiene can be maintained, otherwise, they can pose a serious health risk—especially if they are not fly-proof or insufficiently away from drinking water sources.

7.1.3 Hygiene behavior awareness

Interventions targeting people's behavior in WASH sector can be effective in the provision of safe WATSAN services and in the fight against most infectious diseases. For instance, the provision of improved water supply alone sometimes does not bring positive health gains primarily due to household's unsafe water storage and handling behavior which causes re-contamination at the POU (Clasen 2015; Wright *et al.* 2004). Addressing the following points are instrumental in improving individual and household level behaviors, which in turn improve health outcomes and WASH environment.

Promoting handwashing with soap—a defensive mechanism for preventing germs from getting into mouths and food, and avoiding diarrhea in young children. The results point towards the importance of handwashing with soaps at critical times because unhygienic practices are key pathways in the transmission of pathogens. As the study revealed, when primary caretakers practice handwashing with soap at critical times, the risk of young children contracting diarrhea was reduced by 6 percentage points. Proper hygiene practice is critical to realize the greatest benefits of improved WATSAN services as well as to combat most communicable diseases. Yet, again, inadequate water supply may cause households to limit their handwashing practices.

Promoting safe handling and disposal of child stools. The study also highlights that proper child stool disposal behavior can reduce childhood diarrhea by 23 percentage points. However, the behavior of safe child stool disposal is lacking in the study areas. Our findings also indicate that household level variations alone do not appear to be appropriate to capture children's potential exposure to poor WATSAN services. Rather, the type of sanitation technologies and the practice of child stools disposal at their neighbors are also important determinants of children's health outcomes. Direct contact with human feces can lead to diarrheal diseases. The safe disposal of children's feces is therefore tremendously important in preventing the spread of diseases. However, most of the households perceived child feces to be less harmful than adult ones, and child feces were therefore often left around or disposed close to a household's living area where children are often roaming and playing. This further highlights the lack of awareness among the study households about the causes of diarrhea and the necessary remedial measures. Moreover, many primary caretakers do not consider diarrhea to be a serious health problem as it is common among young children. Education and public awareness campaigns could be an effective channel to disseminate information that can improve child health associated with inadequate WASH services. This is particularly important in many rural areas of the country, where mothers usually have little education.

Promoting safe water vessels/containers. The study finds that 84 percent of the surveyed households use jerrycan for water collection and storage; however, their storage water quality is poorer than households using traditional clay vessel. Providing either safer storage containers or promoting how to clean jerrycan properly would avoid substantial risk of water contamination.

Moreover, since adult women and girls are largely responsible for household water collection and cleaning, targeting them in the provision of key hygiene education campaign will generate substantial improvement in POU water quality.

On top of that, our findings indicate that WASH interventions are also required to make households aware of the importance of safe WASH through educational campaigns so as to help them change their long-held habits and hygiene behaviors. Primary caretakers often undermine the critical role that good hygiene plays in improving overall health outcomes. Educating rural communities on the potential sources of water contamination, proper water treatment methods, safe disposal of child feces away from the domestic environment, and good hygiene practices (for instance; handwashing with soap at critical times such as before preparing and eating foods, after defecation and/or disposing of child stools) can result in significant health gains to the rural population. Households should also be encouraged to have appropriate storage containers where water continuity is not guaranteed or water is scarce but at the same time, containers used for collecting/storing water need to be cleaned regularly using detergents to ensure safe water quality.

7.1.4 Small-scale irrigation agriculture

Irrigation water is used for various domestic purposes in addition to its prime purpose of agricultural uses. Domestic use of irrigation water includes drinking, cooking, washing and bathing, livestock and aquaculture. This multiple-use of irrigation water is not planned by design in most contexts, however. In rural areas where improved water supply is inadequate, drawing drinking water directly from irrigation sources might serve to meet adequate water for domestic needs. In such an environment, domestic and productive water uses are often not exclusive to each other and the quality of the water is compromised as irrigation water can be a source of drinking water contamination. An integrated effort on drinking water supply and irrigation water management may bring an impact on the health and quality of life of those it benefits. Our result indicates that although irrigation water use for domestic purposes does not deteriorate the microbial quality of stored drinking water, it generally results in poor health outcomes. Addressing the following concerns will be instrumental in maximizing the benefits of multiple-use of irrigation water.

Constructing rural water supplies to accommodate a range of services to link with irrigated agriculture in addition to the basic domestic water supply. Similarly, interventions in SSI should acknowledge the multiple-use of water where improved domestic water availability is limited. If multiple-use of water systems are designed by considering the health and environmental risks, it would help to optimize the limited water resource availability and quality for domestic as well as for productive uses. This further encourages a more integrated, cross-sectoral approach that could deliver a greater and more sustainable impact of any intervention that targets health and nutrition in rural areas. However, more research may be needed to generate the costs and benefits of various intervention options and to identify the right technical and institutional arrangements under which agriculture-WATSAN nexus could work to exploit the opportunities opened up to change and improve human health and livelihood of rural households at large. As a caveat, we should also be more careful that cross-sectoral approach might even worsen the situation if the right institutional setup is not in place.

Promoting improved WASH services from 'farm to fork' to reduce agro-chemicals and microbiological contamination as irrigation water can be a source of contamination. Most households lack awareness about the detrimental health impacts of poor water quality, unsafe sanitation, and inadequate hygiene practices. Promoting improved WASH in the field and ensuring that households do not use irrigation runoff for drinking without appropriate POU water treatment is, therefore, vital to avoid water-related diseases. Moreover, small-scale irrigation promotion should incorporate nutrition and health aspects through training programs and awareness campaigns. This helps to maximize the potential gains from SSI and to minimize the risks associated with it in terms of nutrition and health.

Generally, agriculture, WASH, and nutrition are closely interlinked and complex. These complex interactions are inextricably linked and in such a complex environment a single intervention approach will not work. For instance, providing safe drinking water without safe stool disposal and key behavioral changes will not work. Furthermore, improving nutrition without safe WASH environment, then the latter will undo much of the good gained from improved diets. This complexity, therefore, requires a mix of instruments needed to end hunger, to achieve food security, to improve nutrition, to promote sustainable agriculture (SDG-2) as well as to ensure access to water and sanitation for all (SDG-6) in the next decade. However, achieving the SDG-2 and SDG-6 targets in the next decade will require large economic resources, new-cost effective and sustainable technologies and engagement of various actors at different levels.

Lastly, most SSI systems, such as shallow wells, tend to be developed and managed by farmers using their own knowledge and skills. Providing technical and/or financial supports for such households who desire to develop or improve their own groundwater supply could be an alternative policy approach to link rural water supply and SSI, which in turn increases access to improved rural water supply.

7.2 Limitations of the Study and Future Research Directions

One of the main limitations of the study is our reliance on the self-reported prevalence of diarrhea and other illness symptoms, which are not clinically verified for our data. The study would have given more insights if actual medical records were collected from the districts health centers/posts. However, reliable morbidity data for such communicable diseases are difficult to obtain from local health centers/posts due to lack of adequate health-care services in rural areas.

The study would have been also benefited if water sample quality tests were repeated for certainty. Although one-time sampling information is useful, high level of *E.coli* may be a one-time event occurrence, which does not allow us to capture seasonal impacts on groundwater quality. Since the sampled households entirely rely on non-piped water supply sources, seasonal changes could likely affect water quality in the household, which could also influence the level of water quality measured. Conducting subsequent water sample testing over time can provide a more representative water quality indicator. The study could have been also improved if water samples had been taken from all possible community water sources and matching with household water sample test results.

The other possible drawback of this study is that we did not look into the gender implications of irrigation and the roles of women in irrigated agriculture. It is hypothesized that "improving women's access to and ownership of irrigation technologies and control over irrigated produce would have a positive multiplying effect on nutrition and health outcomes." Integrating gender into future policy designs is essential to enhance the full potential impacts of irrigation interventions on nutrition and health. An ongoing project in Ethiopia, Ghana, and Tanzania: "The Feed the Future Innovation Lab for Small-Scale Irrigation and the Impact of Irrigation on Agricultural Productivity, Nutrition, Health and Women's Empowerment" has been working on the gender dimension of impacts of irrigation on health and nutrition outcomes.[35] We hope it would shed some light on this regard.

In summary, we acknowledged the limitations of analyzing causal studies using cross-sectional data; consequently, drawing such critical policy implications on the basis of it may be questioned. However, in statistical parlance, the empirical results are too robust to ignore due to strong correlations. Future studies may consider using a randomized control-trial (RCT) or panel dataset to address this limitation. We also recommend future research to focus on assessing seasonal changes in rural water supply and how it impacts storage water quality under multiple-use water systems. Furthermore, it should focus on exploring on how individual level of behaviors related to WASH affects both POS and POU water quality. Most importantly, future studies should look at what kind of local institutional arrangements are more appropriate to facilitate an integrated multi-sectoral approach to maximize the synergies and minimize the trade-offs in the nexus among WASH-agriculture and nutrition.

[35] The Feed the Future Innovation Lab for Small- Scale Irrigation, a project of the U.S. Government's Feed the Future Initiative, is a five- year project in Ethiopia, Ghana and Tanzania aimed at benefiting the region's farmers by improving effective use of scarce water supplies through interventions in small-scale irrigation.

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Appendix A

Table A1: Impact of latrine on household water quality: Number of *E.coli* (CFU/100ml water)

VARIABLES	(1) OLS	SE	(2) OLS	SE	(3) PROBIT	SE
Pit latrine (dummy)	23.088***	6.597	15.368**	6.467	0.098	0.100
Drinking water source (1=protected)	-15.885**	7.048	-8.711	6.852	0.185	0.125
Container (1=jerrycan)			19.255**	8.428	0.675**	0.323
Irrigating households (dummy)			-0.796	8.107	0.885**	0.374
Handwashing with soap(dummy)			-0.044	7.207	0.090	0.088
Number of adult female			-7.078	7.699	-0.052	0.100
Household density			2.851	2.648	0.120*	0.063
Household size			-1.274	2.769	0.006	0.033
Number of children aged 6/younger			8.539	5.357	-0.430**	0.186
Garbage disposal (reference burning)						
Throw in the yard			17.857**	8.458	0.559***	0.062
Throw away outside the yard			-2.414	10.019	-0.222***	0.079
Used as fertilizer			6.601	9.586	0.416***	0.073
Livestock holding			5.407*	2.704	0.052	0.035
Log of assets value			-5.720	4.459	-0.393**	0.191
Constant	16.187***	5.105	16.169	38.671		
Observations	71		71		71	
Pseudo/R-squared	0.20		0.51		0.75	
Model F-stat	8.363		4.232			
Model Chi2					71.88	
Model p-value	0.000		0.000		0.000	

Note: the dependent variable for column 1 and 2 is the log of E.*coli* while for column 3 is binary.
Significance *** p<0.01, ** p<0.05, * p<0.1

Table A2: Impact of irrigation and domestic use of irrigation water on p/c/d water consumption

VARIABLES	(1) Model	(2) Model	(3) Model	(4) Model	(5) Model
Irrigating households (dummy)	0.577**	0.391	0.436**		
	(0.274)	(0.252)	(0.214)		
Domestic use of irrigation water (dummy)				0.425	0.735**
				(0.313)	(0.277)
Container size in liters		0.208***	0.248***	0.203***	0.247***
		(0.0397)	(0.033)	(0.051)	(0.043)
Minutes to water source (1=30min/less)		1.232***	1.065***	1.343***	1.327***
		(0.228)	(0.186)	(0.368)	(0.327)
Proportion of adult women		9.109***	2.277*	9.386***	2.112
		(1.593)	(1.293)	(1.979)	(1.549)
Household size			-0.686***		-0.731***
			(0.059)		(0.070)
Log of assets value			0.213		0.323**
			(0.135)		(0.138)
District (1=Fogera)			0.545***		0.815***
			(0.189)		(0.269)
Constant	8.387***	0.979	3.232***	1.168	2.233*
	(0.219)	(1.001)	(1.170)	(1.245)	(1.254)
Observations	454	454	454	302	302
R-squared	0.01	0.19	0.38	0.19	0.40
Model F-stat	4.418	28.45	43.08	15.86	30.09
Model p-value	0.0398	0.000	0.000	0.000	0.000

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

Table A3: The impact of domestic use of irrigation water on POU water quality

VARIABLES	(1) OLS	SE	(2) PROBIT	SE
Irrigation water use (dummy)	-0.110	0.209	-0.092	0.058
Water source (1=protected)	-0.202	0.150	-0.074	0.052
Minutes to water source (1=30min/less)	-0.890***	0.293	-0.176*	0.097
Container (1=jerrycan)	1.151***	0.162	0.231***	0.066
Number of adult women	-0.192	0.144	-0.076*	0.044
Household density	0.297***	0.060	0.072***	0.018
Garbage disposal (reference burning)				
Throw in the yard	1.107***	0.213	0.346***	0.074
Throw away outside the yard	0.205	0.359	0.032	0.099
Used as fertilizer	0.730**	0.285	0.208**	0.095
Handwashing with soap (dummy)	-0.326**	0.152	-0.104**	0.045
Highest education completed	-0.052	0.032	-0.015**	0.006
Livestock holding	0.273***	0.059	0.066***	0.017
Log of assets value	-0.321***	0.081	-0.051**	0.020
Water user association(dummy)	-1.123***	0.187	-0.354***	0.063
Distance to irrigation water (hours)	-0.686**	0.274	-0.237***	0.090
Constant	3.024***	0.808		
Observations	302		302	
Pseudo / R-squared	0.48		0.41	
Model F-stat	46.30			
Model Ch2			142.66	
Model p-value	0.000		0.000	

Robust standard errors adjusted for clustering at the village level;
Significance *** p<0.01, ** p<0.05, * p<0.1
Probit in average marginal effects
Note: the dependent variable for column 1 is log of E.*coli* while for column 2 is binary.

Table A4: The effect of irrigation on primary caretaker time use

VARIABLES	(1) Water fetching	SE	(2) Agriculture	SE
Age in years	-0.306	0.198	-0.135	0.159
Irrigating households (dummy)	-13.565***	3.318	4.552**	1.828
Household size	-2.135**	0.924	-1.278*	0.685
Proportion of adult women	-43.337**	18.674		
Number of children age 6/younger	2.303	2.546	2.440*	1.230
Water collection time (1=30min/less)	-16.123***	4.073	2.277	1.851
Container size	-0.558	0.501		
Log of off-farm income	1.128***	0.418	0.207	0.196
Own land holding	-3.644**	1.639	1.135	1.098
Livestock holding	1.270*	0.652	0.471	0.444
Proportion of irrigated land			5.840**	2.900
Constant	86.177***	14.818	18.176***	4.434
Observations	453		453	
R-squared	0.19		0.09	
Model F-stat	10.98		5.026	
Model p-value	0.000		0.000	

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

Note: Water fetching time is reported in minutes for the day before the interview day while agricultural activity is reported in the last 7 days before the survey and reported in hours.

Table A5: Health effects of irrigation—Water-related and morbidity

	Water related			Morbidity		
VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Irrigating households (dummy)	0.039**	0.110*	1.458**	0.110***	-0.023	1.448***
	(0.018)	(0.060)	(0.245)	(0.031)	(0.050)	(0.160)
Water quality (1= *no E.coli*)	-0.011	-0.024	0.920	-0.043*	-0.060	0.880*
	(0.017)	(0.054)	(0.138)	(0.022)	(0.042)	(0.065)
Water collection time (1=30min/less)	-0.001	-0.051	0.975	-0.006	-0.046	0.994
	(0.017)	(0.067)	(0.149)	(0.026)	(0.052)	(0.088)
Pit latrine (dummy)	-0.032**	-0.136***	0.751**	0.039*	-0.031	1.145*
	(0.014)	(0.044)	(0.104)	(0.022)	(0.037)	(0.083)
Age in years: reference (5—6)						
7—9 years	-0.002			-0.200***		
	(0.021)			(0.048)		
10—15 years	0.034			-0.255***		
	(0.023)			(0.047)		
16 years/older	0.060***			-0.171***		
	(0.020)			(0.044)		
Gender (male=1)	-0.003			-0.037		
Average household member age		-0.000	1.000		-0.002	0.976**
		(0.006)	(0.013)		(0.004)	(0.011)
Household size	-0.008	0.047**	1.107**	0.005	0.061***	1.209***
	(0.005)	(0.018)	(0.048)	(0.008)	(0.014)	(0.033)
Household density	0.013**	0.026	1.118**	0.017*	0.045***	1.045
	(0.006)	(0.019)	(0.050)	(0.009)	(0.016)	(0.030)
Highest education completed	-0.002	-0.006	0.993	-0.011***	-0.018***	0.966***
	(0.002)	(0.008)	(0.022)	(0.003)	(0.006)	(0.012)
Distance to health center	0.001	0.005	1.007	0.009***	0.011**	1.027***
	(0.002)	(0.004)	(0.014)	(0.003)	(0.004)	(0.009)
Livestock holding	0.004	0.006	1.052	0.004	0.007	1.032
	(0.005)	(0.020)	(0.052)	(0.009)	(0.015)	(0.029)
Log of assets value	0.012	0.034	1.131	0.008	0.038	1.035
	(0.010)	(0.036)	(0.104)	(0.015)	(0.028)	(0.049)
Proportion of irrigated land	-0.009	-0.073	0.927	-0.105**	-0.044	0.700***
	(0.026)	(0.085)	(0.204)	(0.041)	(0.062)	(0.090)
Constant			0.053***			0.370**
			(0.040)			(0.176)
Observation	2149	454	454	2149	454	454
Pseudo R-squared	0.03	0.07		0.05	0.15	
Model Chi2	54.00	46.16	59.62	147.10	74.06	266.74
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1;
Probit in average marginal effects and Poisson in incidence-rate ratios.

Table A6: Health effects of irrigation water use—Water related

VARIABLES	(1) PROBIT	(2) PROBIT	(3) PROBIT	(4) PROBIT	(5) POISSON	(6) POISSON
Irrigation water use (dummy)	0.046***	0.046***	0.127**	0.126**	1.475***	1.476***
	(0.017)	(0.016)	(0.052)	(0.051)	(0.205)	(0.199)
Water quality (1= *no E.coli*)	-0.002		0.014		0.992	
	(0.023)		(0.069)		(0.179)	
Water collection time (1=30min/less)	-0.010	-0.010	-0.149	-0.146	0.927	0.926
	(0.022)	(0.021)	(0.096)	(0.093)	(0.149)	(0.144)
Pit latrine (dummy)	-0.021	-0.021	-0.093	-0.093	0.854	0.855
	(0.019)	(0.019)	(0.066)	(0.066)	(0.142)	(0.142)
Age in years: reference (5—6)						
7—9 years	0.005	0.005				
	(0.027)	(0.027)				
10—15 years	0.046	0.046				
	(0.029)	(0.029)				
16 years/older	0.076***	0.076***				
	(0.025)	(0.025)				
Gender (male=1)	0.007	0.007				
	(0.018)	(0.018)				
Average household member age			-0.009	-0.009	0.987	0.987
			(0.006)	(0.006)	(0.014)	(0.014)
Household size	-0.013*	-0.013*	0.021	0.021	1.062	1.062
	(0.007)	(0.007)	(0.023)	(0.023)	(0.056)	(0.055)
Household density	0.026***	0.026***	0.071***	0.070***	1.200***	1.201***
	(0.006)	(0.006)	(0.020)	(0.020)	(0.049)	(0.048)
Highest education completed	-0.004	-0.004	-0.002	-0.002	0.985	0.985
	(0.004)	(0.004)	(0.012)	(0.012)	(0.028)	(0.029)
Distance to health center	-0.000	-0.000	0.004	0.004	0.999	0.999
	(0.002)	(0.002)	(0.005)	(0.005)	(0.017)	(0.016)
Livestock holding	0.008	0.009	0.032	0.030	1.085	1.086*
	(0.007)	(0.007)	(0.023)	(0.022)	(0.055)	(0.055)
Log of assets value	0.017	0.017	0.032	0.033	1.171	1.170
	(0.013)	(0.013)	(0.041)	(0.042)	(0.119)	(0.123)
Proportion of irrigated land	0.005	0.004	-0.059	-0.055	0.997	0.995
	(0.029)	(0.030)	(0.090)	(0.093)	(0.232)	(0.241)
Constant					0.057***	0.057***
					(0.053)	(0.053)
Observation	1455	1455	302	302	302	302
Pseudo R-squared	0.04	0.04	0.11	0.11		
Model Chi2	52.10	51.94	53.25	53.63	76.18	70.07
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1,
Probit in average marginal effects and Poisson in incidence-rate ratios.

Table A7: Health effects of irrigation water use—Morbidity

VARIABLES	(1) PROBIT	(2) PROBIT	(3) PROBIT	(4) PROBIT	(5) POISSON	(6) POISSON
Irrigation water use (dummy)	0.084***	0.086***	0.132***	0.131***	1.263***	1.270***
	(0.027)	(0.027)	(0.042)	(0.042)	(0.114)	(0.114)
Water quality (1= *no E.coli*)	-0.033		0.005		0.922	
	(0.030)		(0.039)		(0.085)	
Water collection time (1=30min/less)	-0.022	-0.026	-0.151***	-0.149***	0.968	0.959
	(0.036)	(0.034)	(0.053)	(0.053)	(0.104)	(0.098)
Pit latrine (dummy)	0.074***	0.074***	0.064	0.064	1.247**	1.249**
	(0.028)	(0.028)	(0.047)	(0.047)	(0.109)	(0.110)
Age in years: reference (5—6)						
7—9 years	-0.116**	-0.116**				
	(0.057)	(0.058)				
10—15 years	-0.146***	-0.145***				
	(0.052)	(0.052)				
16 years/older	-0.069	-0.068				
	(0.048)	(0.048)				
Gender (male=1)	-0.049	-0.048				
	(0.031)	(0.031)				
Average household member age			-0.009**	-0.009**	0.963**	0.963**
			(0.004)	(0.004)	(0.016)	(0.016)
Household size	0.001	0.001	0.047***	0.047***	1.182***	1.182***
	(0.011)	(0.011)	(0.017)	(0.018)	(0.042)	(0.041)
Household density	0.035***	0.036***	0.054**	0.053**	1.082**	1.086***
	(0.012)	(0.012)	(0.022)	(0.022)	(0.035)	(0.034)
Highest education completed	-0.017***	-0.017***	-0.020***	-0.020***	0.960**	0.959**
	(0.005)	(0.005)	(0.007)	(0.007)	(0.017)	(0.016)
Distance to health center	0.007**	0.008**	0.017***	0.017***	1.021**	1.022**
	(0.004)	(0.004)	(0.006)	(0.006)	(0.011)	(0.011)
Livestock holding	0.013	0.016	0.015	0.014	1.058*	1.067*
	(0.011)	(0.011)	(0.017)	(0.016)	(0.035)	(0.036)
Log of assets value	0.012	0.009	0.015	0.016	1.045	1.040
	(0.018)	(0.018)	(0.032)	(0.032)	(0.057)	(0.057)
Proportion of irrigated land	-0.087**	-0.095**	-0.048	-0.046	0.714***	0.700***
	(0.043)	(0.045)	(0.056)	(0.056)	(0.091)	(0.094)
Constant					0.548	0.544
					(0.343)	(0.338)
Observation	1455	1455	302	302	302	302
Pseudo R-squared	0.05	0.04	0.20	0.20		
Model Chi2	108.21	100.65	71.91	71.80	238.45	211.23
Model p-value	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors adjusted for clustering at village level in parentheses;
Significance *** p<0.01, ** p<0.05, * p<0.1,
Probit in average marginal effects and Poisson in incidence-rate ratios.

Table A8: Health effects of irrigation and irrigation water use—any illness except injury

VARIABLES	(1) POISSON	SE	(2) POISSON	SE
Irrigating households (dummy)	1.529***	0.175		
Irrigation water use (dummy)			1.299***	0.123
Water quality (1=no *E.coli*)	0.872*	0.065	0.925	0.087
Water collection time (1=30min/less)	1.059	0.089	1.058	0.113
Pit latrine (dummy)	1.175**	0.087	1.262**	0.120
Average household member age	0.962***	0.010	0.951***	0.012
Household size	1.208***	0.032	1.172***	0.039
Household density	1.034	0.030	1.076**	0.032
Highest education completed	0.965***	0.013	0.964**	0.017
Distance to health center	1.031***	0.009	1.029**	0.011
Livestock holding	1.044	0.031	1.070**	0.036
Log of assets value	1.008	0.048	1.016	0.056
Proportion of irrigated land	0.672***	0.094	0.710**	0.100
Constant	0.523	0.235	0.751	0.427
Observations	454		302	
Model Chi2	326.04		223.55	
Model p-value	0.000		0.000	

Robust standard errors adjusted for clustering at village level;
Significance *** p<0.01, ** p<0.05, * p<0.1,
Regression confidents are in incidence-rate ratios.

Table A9: The association between irrigation and medical expenditure

VARIABLES	(1) Medical Expenditure (last 2 months)	(2) Medical Expenditure (last one year)
Irrigating households (dummy)	48.372***	91.534***
	(14.693)	(30.300)
Household size	12.294**	34.337***
	(4.882)	(7.428)
Highest education completed	4.010	1.716
	(2.816)	(5.270)
Log of non-farm income	2.385	10.822**
	(2.004)	(4.530)
Distance to health center	1.553	10.757**
	(2.278)	(5.108)
Constant	-49.081	-83.992*
	(31.884)	(49.484)
Observations	454	454
R-squared	0.05	0.07
Model F-stat	4.780	10.47
Model p-value	0.001	0.000

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

Table A10: Agricultural production estimates

VARIABLES	(1) Farm productivity	SE	(2) Farm productivity	SE
Irrigating households (dummy)	0.528***	0.078	0.371***	0.100
Agricultural equipment	0.045*	0.025	0.001	0.029
Total family male labor days	0.245***	0.031	0.220***	0.031
Total family female labor days	0.102**	0.045	0.077	0.049
Total hired male labor days	0.091***	0.022	0.086***	0.022
Total family female labor days	0.044**	0.018	0.034**	0.017
Total variable inputs	0.101***	0.022	0.110***	0.023
Proportion of irrigated land	-0.284**	0.118	-0.196	0.122
Land quality index	-0.191	0.118	-0.172	0.118
Livestock holding	0.080***	0.021	0.061***	0.021
Average distance to plot (minutes)	-0.003*	0.002	-0.003**	0.002
Highest education completed			-0.018*	0.009
Off farm labor participation (dummy)			-0.074	0.069
Household size			0.043**	0.019
Assets value			0.087**	0.037
Altitude			-1.518**	0.594
Constant	6.541***	0.323	17.716***	4.490
Observations	454		454	
R-squared	0.54		0.56	
Model F-stat	50.14		39.80	
Model p-value	0.000		0.000	

Robust standard errors; Significance *** p<0.01, ** p<0.05, * p<0.1,
Variables are transformed into logarithm except level of education, household size and the dummy variables.

Appendix B

Participation Information Sheet and Informed Consent Form

Name of Project: Water, Sanitation, and Hygiene Nexus under a Multi-Use Water System: Synergies, Thresholds, and Trade-offs for a Better Health and Nutritional Outcomes in Ethiopia.

Part I: Information Sheet

Introduction

My name is________ and I am conducting a survey for the AG-WATSAN-Nexus project. The center for Development Research (ZEF), University of Bonn, Germany in collaboration with the Ethiopian Economics Association (EEA), Addis Ababa, are now implementing the project to address basic health needs including household drinking water supply, sanitation, and knowledge and practices concerning hygiene in the selected villages of Fogera and Mecha *Woredas.* The project is funded by the *Bill and Melinda Gates Foundation* and this study will examine the synergies and trade-offs between domestic *water supply* (*quality* and *quantity*), *sanitation*, *hygiene* (WASH) and their linkage with irrigation and drainage systems.

As part of the planning process, we are conducting a survey of households in villages that are being considered for participation in the project. We have sampled certain households randomly to collect information about the household and the people living there; the current situation of water supply and sanitation facilities; knowledge and practices concerning hygiene; other health care and household practices; agricultural production, household consumption and expenditures; household time and labor use, and anthropometric measures for under-five children. You are one of them and invited to participate in this research and we would appreciate your contribution to our understanding on WASH in your area.

If you have any questions regarding this research project or anything you do not understand during the interview, you are free to ask and the interviewer will take time to explain to you to the best of his/her knowledge.

Purpose of the Research

The main purpose of this research is to analyze the impacts of use of different water sources and various sanitation facilities on health and their linkage with irrigation and drainage systems so that the findings will help the government or other stakeholders to plan better water supply, sanitation and essential health-care services for this areas.

Type of Research Intervention

This survey will involve different member of your household and the entire interview will take approximately not more than 60 minutes. However, households which have under-five children will be revisited every fortnightly for about five or six times (three months) to collect information about the prevalence of diarrheal diseases for last two-week period.

Voluntary Participation

Your participation in this research is completely voluntary. If for any reason you do not wish to participate, you can chose not to, and you can object to answering any specific question or questions in the questionnaire. There are no disadvantages to deciding not to participate or not to answer certain questions. It is entirely your choice whether to participate or not. However, we would greatly appreciate your cooperation.

Benefits of Participation

There will be no direct benefit to you, but your participation is likely to help us find out more about the present burden of water, sanitation and hygiene related diseases and eventually identify better strategies of linking domestic water uses for 'WATSAN' and irrigation and drainage systems to improve health and nutrition status in your area. Apart from acknowledging your contribution in sparing time for us in answering the questions, we will also give you some present to compensate the loss of your time.

Confidentiality

Any information we obtain from you during the research will be kept strictly confidential and your answers will never be shared with anyone other than our project team and partner and will be kept private. Names and addresses of participants will not be included in the analysis or report, nor will information about a person's household be shared with anyone else. The results of the study will be published in academic journals, policy briefing issues and as discussion papers.

Right to Refuse or Withdraw

You do not have to take part in this research if you do not wish to do so, and choosing to participate will not affect you in any way. You may stop participating in the interview at any time you wish. I will give you an opportunity at the end of the interview/discussion to review your remarks, and you can ask to modify or remove portions of those, if you do not agree with my notes or if I did not understand you correctly. You can also ask me any more questions about any part of the research study if you wish to.

Part II: Certificate of Consent

Participant Statement:

I have read (had someone read to me) this consent form. I have discussed with the research staff the information in this consent form. I have been given the opportunity to ask questions. I understand that I may refuse to participate in this study and that if I refuse to participate, this will not result in negative personal repercussions. I also understand that if, for any reason, I wish to stop participating, I will be free to do so. I have understood the purpose of the study and I am willing to participate in the interview.

Do you agree to participate?

☐ *Yes ⇨ THEN BEGIN THE INTERVIEW.* ☐ *No ⇨ DISCUSS THIS RESULT WITH YOUR SUPERVISOR AND GO TO THE NEXT HOUSEHOLD.*

Name and Signature of Participant: ____ Date: _____________________

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands. I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered to the best of my ability. I confirm that the individual has not been forced into giving consent, and the consent has been given freely and voluntarily.

Signature of Researcher /Person taking the consent: _______________________ Date: ______________________

REMARK: *PREPARE 2 COPIES, AND ONE COPY SHOULD BE GIVEN TO THE PARTICIPANT!*

Whom to Contact

If you feel you have been treated unfairly, or you have questions or concerns you may contact:

Ethiopian Economics Association, Ethiopian Economic Policy Research Institute (EEA/EEPRI),

P.O.Box: 34282

Addis Ababa, Ethiopia

Tel: 251-11-645-3200/3091