Zentrum für Entwicklungsforschung

Investment in health within the agriculture, water, sanitation and hygiene nexus for rural households in Bangladesh

Inaugural-Dissertation

zur

Erlangung des Grades

Doktor der Agrarwissenschaften

(Dr. agr.)

der

Landwirtschaftlichen Fakultät

der

Rheinischen Friedrich-Wilhelms-Universität Bonn

vorgelegt von

Mohammad Monirul Hasan

aus

Tangail, Bangladesch

Bonn 2018

Referent:	Prof. Dr. Joachim von Braun
Korreferent:	Prof. Dr. Jan Börner
Tag der mündlichen Prüfung:	19.12.2017

Angefertigt mit Genehmigung der Landwirtschaftlichen Fakultät der Universität Bonn

Abstract

Water, sanitation and hygiene (WASH) related burden of disease is one of the most important aspects of human capital formation. As WASH is a system issue, it needs to be investigated with many other complementary factors to establish the possible synergy effects with nutrition and human capital. By identifying the possible linkage between WASH and nutrition, this thesis strives to identify the impact of improved water infrastructure and behavioural change investment on health and nutrition. In doing so, it investigates the impact of publicly supplied piped water on water and food quality, health, and child nutrition for rural households in north-western Bangladesh. Having examined the ineffectiveness of the piped water on health and nutrition, this study applies a Randomized Controlled Trial (RCT) experiment of Food Hygiene Education (FHE) to the rural households to evaluate how behavioural change investment towards WASH could benefit health and nutrition.

Using a nationally representative panel data of rural Bangladesh, the first analytical chapter finds that improved water and sanitation infrastructure is found to reduce diarrhoea related morbidity and the level of malnutrition in children under-five. Moreover, education, household dietary diversity score and water purification are found to improve diarrhoea and child nutrition but are sensitive to the maintenance of proper hygiene and cleanliness. In addition, irrigating poses some risks and increases diarrhoea incidence, possibly because the situation is worsened if adequate hygiene and water purification are not practiced. Having livestock in the household plays a positive role in reducing malnutrition if and only if the personal, food and environmental hygiene standards are maintained properly. Therefore, it is the hygiene level which mostly matters for reduction of malnutrition even after controlling for the other household characteristics such as household size, income, education and location. For maintaining proper hygiene, investment is required for personal, food and environmental cleanliness.

One such investment is in the area of access to clean drinking water. In the next chapter, the study uses propensity score matching to investigate the association between a public piped water infrastructure programme (BMDA) and gains in water-sanitation, hygiene and health outcomes in north-western Bangladesh. In terms of food safety, there is no evidence of improvement in the quality of drinking water, measured by *E. coli* count per 100 ml of water at the point of use (i.e. the pots and jars used to store it). Food utensils were tested positive for *E. coli* in both the control and treatment group, thus showing no improvement through the BMDA intervention. Hygiene behaviour such as handwashing with soap after defecation or before feeding children also does not improve. In addition, the study finds no evidence of health benefits, such as decreased diarrhoea incidence in children under-five or improved nutritional outcomes such as stunting, underweight and wasting. Although access to BMDA piped water in the premises is subject to a fee, it seems this incentive mechanism is not strong enough to improve water behaviour or its outcomes: treated households are as poor as the non-treated in terms of maintaining hygiene and water quality, possibly because of a lack of information.

Consequently, the final chapter presents an RCT experiment of FHE. It aims to fill the information gap between the households and identify potential changes in water, sanitation and hygiene related behaviour in the marginalized rural households in the same communities of north-western Bangladesh. The treatment combines three elements - microbiological test results of contamination from *E. coli* bacteria in drinking water and on food preparing utensils, training to maintain food hygiene at the household level and a poster of hygiene messages to be hung in the dining area. The evidence suggests that the FHE treatment has a positive impact on the microbiological quality of drinking water and kitchen utensils. The percentage of households with *E.coli* in the drinking water was reduced after one and two months of intervention, compared with the control group. Households' hygiene practices and cleanliness have increased significantly in the treated households without significant increases in the costs of water, sanitation infrastructure and related investment. In this randomized phased-in evaluation, the former treated households reduced the incidence of child diarrhoea and significantly reduced child wasting by 5% in the two month period compared to the later treated households. The FHE experiment thus results in positive health and nutritional gain for children under-five in the rural households. However, the study only investigates the impact over a two month period. The long term outcomes of FHE are unknown and require further research.

Zusammenfassung

Krankheitslasten, die im Zusammenhang mit Wasser, Sanitäranlagen und Hygiene (WASH) stehen, sind einer der wichtigsten Aspekte von Humankapitalbildung. Um potentielle Synergieeffekte zwischen Ernährung und Humankapital zu identifizieren, muss WASH als ganzheitliches System durch die Betrachtung verschiedener und sich komplementierender Faktoren untersucht werden. Durch die Beleuchtung der potentiellen Beziehung zwischen WASH und Ernährung prüft die vorliegende Dissertation den Einfluss verbesserter Wasserinfrastruktur einerseits und geänderter menschlicher Verhaltensweisen andererseits auf Gesundheit und Ernährung. Konkret untersucht die Arbeit den Einfluss öffentlicher Wasserversorgung auf die Wasser- und Lebensmittelqualität, die Gesundheit und die Kinderernährung in ländlichen Haushalten im Nordwesten Bangladeschs. Nachdem die Wirkungslosigkeit öffentlicher Wasserversorgung für eine verbesserte Gesundheit und Ernährung herausgearbeitet wird, nutzt die Dissertation ein randomisiertes kontrolliertes Experiment ("Randomized Controll Trial (RCT)“) – die Ausbildung ländlicher Haushalte im Bereich Lebensmittelhygiene („Food Hygiene Education (FHE)“) – um zu evaluieren, ob Gesundheit und Ernährung von der Investition in veränderte menschliche Verhaltensweisen profitieren können.
Auf Grundlage einer national repräsentativen Panelbefragung im ländlichen Bangladesch stellt das erste Kapitel fest, dass verbesserte Wasser- und Sanitärinfrastruktur Durchfallerkrankungen und das Ausmaß von Mangelernährung bei Kleinkindern unter fünf Jahren verringern kann. Zusätzlich mindern zwar Bildung, Nahrungsvielfalt in Haushalten und Wasseraufbereitung die Anfälligkeit für Durchfallerkrankungen und verbessern die Ernährung von Kleinkindern, allerdings sind diese Faktoren abhängig von geeigneter Hygiene und Sauberkeit. Zusätzlich stellen Bewässerungssysteme ein Risiko dar, da sie die Anzahl von Durchfallerkrankungen erhöhen, wenn hierbei nicht auf adäquate Hygienemaßnahmen geachtet wird. Dagegen verbessert Tierhaltung im Haushalt die Ernährung, allerdings nur unter der Voraussetzung, dass entsprechende personelle, ernährungsrelevante und ökologische Hygienestandards eingehalten werden. Folglich stellen hohe Hygienestandards den wichtigsten Faktor zur Reduzierung von Mangelernährung dar. Diese Beziehung hält auch der Kontrolle bezüglich Haushaltsgröße, Einkommen, Bildung und Standort der Haushalte stand. Entsprechend muss für die notwendige Hygiene in personelle, ernährungsrelevante und ökologische Sauberkeit investiert werden.
Ein möglicher Investitionsbereich stellt der Zugang zu sauberem Trinkwasser dar. Entsprechend verwendet das nächste Kapitel die Methodik des Propensity Score-Matchings, um den Zusammenhang zwischen einem Infrastrukturprogramm zur öffentlichen Wasserversorgung und verbesserten Wasser-, Hygiene- und Gesundheitsstandards im Nordwesten Bangladeschs zu untersuchen. Mit Blick auf Lebensmittelsicherheit lässt sich durch das Infrastrukturprogramm keine Verbesserung der Trinkwasserqualität, gemessen an der Anzahl von E. Coli-Bakterien pro 100ml, feststellen. Küchengeräte wurden sowohl in der Kontroll- als auch in der Versuchsgruppe positiv hinsichtlich E. Coli-Bakterien getestet. Darüber hinaus stieg das Hygieneverhalten, zum Beispiel Händewaschen mit Seife nach dem Stuhlgang oder vor dem Füttern von Kindern, ebenfalls nicht an. Schlussendlich findet die Arbeit auch keinen Nachweis für gesundheitliche Vorteile wie verringerte Durchfallerkrankungen bei Kleinkindern unter fünf Jahren oder verbesserte Ernährungssicherheit, zum Beispiel durch die Abnahme von körperlichen Entwicklungshemmnissen, Untergewicht oder Auszehrungserscheinungen. Obwohl der Zugang zur Wasserversorgung durch das Infrastrukturprogramm kostenpflichtig ist, gibt es aufgrund des fehlenden Zusammenhangs demnach nicht genügend Anreize, das Programm zu nutzen.

Infolgedessen präsentiert das abschließende Kapitel ein RCT im Bereich Lebensmittelhygiene das FHE. Das Experiment zielt darauf an, Informationslücken bei den Haushalten zu schließen, indem es mögliche Verhaltensänderungen hinsichtlich WASH bei den benachteiligten ländlichen Haushalten im Nordwesten Bangladeschs identifiziert. Die FHE-Versuchsgruppe kombiniert drei Elemente: mikrobiologische Testergebnisse zur Kontaminierung von E. Coli-Bakterien in Trinkwasser und Küchengeräten, Training zur Hygienesicherung von Nahrungsmittel auf Haushaltsebene sowie Plakate mit praktischen Hinweisen zu verbesserter Hygiene im Esszimmer. Die Ergebnisse legen nahe, dass das FHE-Verfahren einen positiven Effekt auf die mikrobiologische Qualität von Trinkwasser und Küchengeräten hat. Im Vergleich zur Kontrollgruppe reduzierte sich der Anteil von Haushalten mit E. Coli-infiziertem Trinkwasser nach ein bis zwei Monaten nach der FHE-Intervention. Zusätzlich erhöhten sich die Hygienepraktiken und die Sauberkeit in der Versuchsgruppe signifikant, ohne dabei die Kosten für Wasser- und Sanitätsinfrastruktur sowie damit verbundenen Investitionen zu steigern. Schlussendlich reduzierte die Versuchsgruppe die Anzahl von Durchfallerkrankungen bei Kindern sowie deren Auszehrungserscheinungen um 5% in den ersten zwei Monaten im Vergleich zu den später behandelten Haushalten. Die Ergebnisse des FHE-Experiments zeigen demnach positive Gesundheits- und Ernährungsentwicklungen bei Kleinkindern unter fünf Jahren in ländlichen Haushalten. Anzumerken ist, dass die Studie diese Effekte ausschließlich über einen Zeitraum von zwei Monaten untersucht. Die langfristigen Effekte von FHE sind noch unbekannt und erfordern weitere Forschung auf diesem Gebiet.

Table of content

List of figures

List of Tables

List of Abbreviations

AG-WATSAN	Agriculture, water, sanitation, and hygiene
ATE	Average Treatment Effect
BDT	Bangladeshi Taka
BIHS	Bangladesh Integrated Household Survey
BMDA	Barindra Multi-purpose Development Authority
BMI	Body Mass Index
CBA	Cost Benefit Analysis
CDDS	Child Dietary Diversity Scores
cfu	Colony Forming Units
DALY	Disability-Adjusted Life Year
DFID	Department for International Development
E. coli	Escherichia Coli 0157
EED	Environmental Enteric Dysfunction
EUR	Euro
FHE	Food Hygiene Education
FNS	Food and Nutrition Security
GoB	Government of Bangladesh
HDDS	Household Dietary Diversity Score
IFPRI	International Food Policy Research Institute
ILO	International Labor Organization
IRR	Incidence Rate Ratio
MDG	Millennium Development Goals
NGO	Non-Government Organization
OECD	Organization for Economic Co-operations and Development
OLS	Ordinary Least Square
POS	Point of Source
POU	Point of Use
PSM	Propensity Score Matching
RCT	Randomized Controlled Trial
SD	Standard Deviation
SDG	Sustainable Development Goals
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
U5	Under-five
U10	Under-ten
WASH	Water, sanitation and hygiene
WATSAN	Water, sanitation and hygiene
WHO	World Health Organization
WSP	Water and Sanitation Programme
YLD	Years Lost due to Disability
YLL	Years of Life Lost

Acknowledgement

I would like to express my deep gratitude to almighty Allah for his love, grace, and mercy for endowing me strength, courage and good health for completing this dissertation. This work would never be completed without the kind support of many individuals to whom I am indebted to. First, I would like to express my gratitude to my supervisor Professor Dr. Joachim von Braun for kind support and guidance throughout my PhD research at the Center for Development Research (ZEF). His excellence in the economic research and positive inspirational behaviour shaped my academic and research career and I am very fortunate to be his doctoral student. My gratitude also goes to Prof. Dr. Jan Börner for giving his consent to be my second supervisor and allocating his valuable time to read my dissertation.

I would also like to expresses my gratitude to my advisor at ZEF, Dr. Nicolas Gerber for his kind support and guidance throughout my PhD journey. His insightful and critical comments on my several drafts of the thesis were extremely helpful and appreciated. I am also indebted to Dr. Evita Hanie Pangaribowo for assisting in questionnaire preparation and also coordinating field research works in Bangladesh. For her proper guidance and co-ordination, I was able to conduct a Randomized Controlled Trial (RCT) experiment in Bangladesh. I am also grateful to the office of the doctoral studies at ZEF especially to Dr. Günther Manske and Mrs. Maike Retat-Amin for their various forms of support during the whole time of my doctoral study including the arrangement for family support.

I am grateful to the German Federal Ministry for Economic Cooperation and Development (BMZ) via the DAAD, and to the Fiat Panis Foundation for partially funding this research. I also thank the Bill and Melinda Gates Foundation for financially supporting the fieldwork leading to this study through the ZEF AG-WATSAN project. I do acknowledge the Institute of Biological Science (IBSc) lab of Rajshahi University in Bangladesh for their excellent support during the microbiological tests. Special thanks go to Dr. Akhter Ahmed of IFPRI Dhaka office for hosting me during the field research period and BRAC-RED for letting me borrow some of their data collection equipment. I would like to thank Dr. Zahid Hayat Mahmud of icddr,b Dhaka office, for allowing their laboratory to be used for training the laboratory research assistants. I am grateful to Dr. Ariful Haque of Rajshahi University for arranging their laboratory facility to be used for microbiological tests, especially when considering the difficult political situations. This study is benefited from the comments of Dr. Doris Wiesmann on the nutritional outcome of children under-five. I would also like to thank ZEF WATSAN-agriculture team especially for their continuous support and comments on my works. I am thankful to my ZEF colleague Muhammed Abdella Usman for his assistance and brotherhood. I also thank Christian Sebaly at ZEF for assisting me to generate GIS maps of the study areas. I am also indebted to my ZEF colleague Johanna Rapp for her help in German translation.

Most importantly, none of my PhD works would have been possible without the support of my family. I am greatly indebted to my wife Trisa Khan for being an excellent mother to my new born daughter Mahia during my PhD field work. It is she who gave me courage and support to continue my work in so many difficult times. She did invaluable sacrifice for my doctoral research. I am immensely benefited from my parents, the ultimate mentor of my life, for their lifelong support and encouragement throughout my life. The continuous support from my parents, in-laws, my siblings and Bangladeshi friends and family in Bonn greatly helped me to achieve my goal. I am thankful to all who helped me doing my doctoral research. Thank you all.

Chapter One

1 Introduction

1.1 Background and motivation

The world has achieved significant progress towards the Millennium Development Goals (MDGs) but a significant portion of the population is still suffering from a lack of proper sanitation and safe drinking water in many regions. More than 0.7 billion people (9% of the world's population) do not have access to improved drinking water sources and about 2.4 billion people (33% of the world's population) do not have access to improved sanitation (United Nations 2015). Among the unimproved sanitation users, about 40 percent live in South Asia. Although a significant improvement has been made in terms of reducing open defecation, it is still practiced by a substantial portion of the population (946 million, 13% of the world's population) and could cause sanitation-related health problems, and hence the Sustainable Development Goals aim to ensure water quality, sanitation and hygiene for all by 2030 (UNDP 2016).

Having access to water may not guarantee that the water is potable at the point of use (POU) because water quality at the source often differs from POU water quality. For domestic purposes, especially for drinking, water quality plays a vital role and water needs to be handled properly. Globally, at least 1.8 billion people (24% of the world's population) use drinking water from a source which is faecally contaminated (UNDP 2016). It is widely found that even water from improved sources are frequently contaminated during water collection, transportation and storage in the household because of improper handling (Rufener et al. 2010; Shields et al. 2015; Wolf et al. 2014; Wright, Gundry, and Conroy 2004). In addition, most of the south Asian and African countries still have unimproved sanitation facilities and less than 50% of the population on average use the improved sanitation facilities in those countries (Figure 1.1).

Water, sanitation and hygiene related burden of disease is one of the most important aspects of human capital formulation. Inadequate water, sanitation and hygiene are among the greatest global health related challenges which account for global economic losses of USD 260 billion every year generated from lost time and productivity (WHO 2012). Basic water-sanitation and hygiene services at home and the workplace play a vital role in making a robust economy through a healthy and productive labour force, and possibly have a benefit-to-cost ratio as high as 7:1 in developing countries (OECD 2011). Furthermore, water and its related services should be considered as the fundamental driver for green growth (OECD 2012). To ensure green growth, water governance should be strengthened by an integrated programme of education, knowledge, capacity building and skill development, including a focus on youth and women (UN-WATER 2015). It is noted that the estimated rates of return on water and sanitation investment are striking:

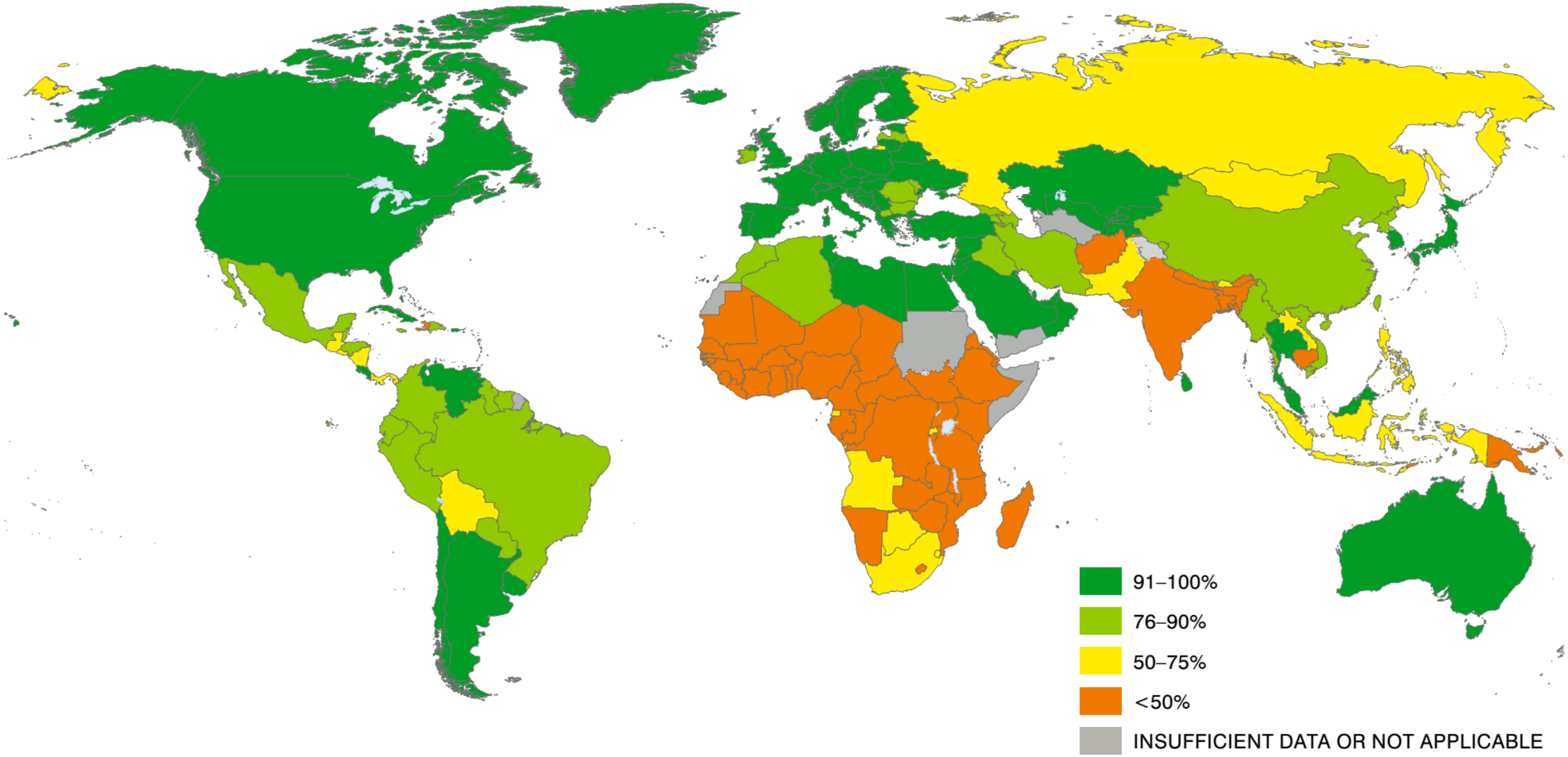


Figure 1.1: Proportion of the population using improved sanitation facilities in 2015.
Source: (Unicef and WHO 2015)

Indeed, USD 1 invested in WASH could generate a return of USD 3 - 34 depending on the geography and associated technology (Hutton and Haller 2004). Increased investment in water, sanitation and hygiene is needed through infrastructure development, effective communication and hygiene education strategies to reduce the mortality and morbidity especially for the marginalized people living in hard-to-reach areas (WSP 2012). A high return for the economy and the environment is generated not only by the investment in infrastructure - water, agriculture and energy - but also by the provision of service in these sectors (UNEP 2012). A lack of good governance and investment failure in water can lead to economic slowdown (ILO 2012, 2014). Therefore, to bring down the mortality and the morbidity rates, water and sanitation facilities are not enough (Unicef and WHO 2015); rather, those facilities linked with hygiene behaviour is what generates more productive and sustainable practices (Assefa and Kumie 2014; Dube and January 2012; Kinley 2011; van Wikj and Murre 2003). Even the presence of improved sanitation may expose the high level of pathogens from faecal materials if their neighbours have no improved sanitation (Baker and Ensink 2012; Root 2001) or the on-site sanitation is not managed hygienically (Wolf et al. 2014).

Malnutrition, which is partly caused by inadequacy of water, sanitation and hygiene infrastructure, could impair the immune system and makes children more vulnerable to diarrhoea (Esrey 1996; van der Hoek, Feenstra, and Konradsen 2002; Javaid et al. 1991). Diarrhoea has a long term negative impact on cognitive development in young children (Keusch et al. 2006). To break the vicious cycle of diarrhoea and malnutrition by reducing the transmission of pathogens, it is important to increase the use of safe water and improved sanitation (Esrey 1996). Maintaining good health is regarded as human capital. Health, which is a value in itself and a precondition for economic prosperity, impacts the economic outcomes of productivity, labour supply, human capital and public spending (European Commission 2013). Health expenditure is accepted as growth-friendly investment and cost-effective, efficient health expenditure can increase the quantity and productivity of labour through increasing life expectancy (European Commission 2013).

The socio-economic consequences of malnutrition are enormous and it affects the productivity of the individual and also slows down the growth of a country (World Bank 2006). Malnutrition is a long term chronic problem of a country and could cost on average almost 2 to 3% of Gross Domestic Product (GDP). A malnourished child starts schooling with an average delay of 7 months, losing 0.7 grade during their study and earning 10 to 17 percent less in lifetime earnings than a healthy child (World Bank 2012). Malnourished children are also at risk of developing chronic health problems in adulthood such as diabetes, hypertension and cardiovascular disease. Improving the nutritional status of under children under five is essential to break the vicious cycle of poverty and to accelerate the economic growth of a country. It is calculated that a one dollar investment in nutrition generates a benefit of USD 8- 138 and preventing a child from having a low birth weight could save almost USD 580 (World Bank 2006).

The multipurpose characteristics of water use, especially for irrigation and domestic purposes, encounters health issues which is possibility inherited in the trade-offs in terms of water quantity and quality. The quality of water for domestic purposes, especially for drinking, is crucial and needs proper handling, as the quality at source differs from the POU. Irrigated agriculture being contaminated by problematic WASH situations affects human health through crops as well as domestic water use from open irrigation canals, traditional furrow and open drainage ditches (Tsegai, Mcbain, and Tischbein 2013). A significant level of waterborne pathogens was found in fruits and vegetables when irrigation water came from untreated waste water because human wastewater is of very poor microbial quality which requires extensive treatment before irrigating crops (Steele and Odumeru 2004). In addition, having livestock and poultry in the household could increase the probability of faecal contamination of water and food through improper hand washing. Several studies have found that households who keep their poultry and livestock inside their living room or in the vicinity are found to have an increase in stunting in children under five (George et al., 2015; Headey et al., 2016; Headey & Hirvonen, 2016). As a result, agricultural activities could impair the benefits from water and sanitation infrastructure if personal and environmental hygiene is not properly maintained. The issue of water, sanitation and hygiene, and irrigated agriculture might compete for quality water resources because of the increasing demand (from an increased population, increased income and change of nutrition behaviour in favour of more water demanding food items), the supply of quality water resources and increasing threat of climate change (Tsegai et al. 2013).

Therefore, to generate sustainable growth and productive human capital, a continuous investment in health is required. The endowment of health capital at birth depreciates with age but can be raised through investment (Cawley and Ruhm 2011). Increased investment in water, sanitation and hygiene is needed to reduce mortality and morbidity, especially for marginalized people in low and middle income countries. Interventions for improving water quality, sanitation and hygiene behaviours fall mainly into four major categories (Tsegai et al. 2013) which are: institutions (capacity building, gender), financial (technology, financial resources), cultural (society, hygiene behaviour) and physical (infrastructure, design). Despite a substantial role being played by the macro level interventions, the micro-level interventions, such as from households and the community, play a major role in determining the health benefits. Household interventions such as proper water management, using latrines in an appropriate way and maintaining hygiene especially for food are the major determinants of good health of the household members (Curtis et al. 2011). By maintaining the water, sanitation and hygiene related practices, people may ensure the utilization of the food and nutrition they get. Hygiene interventions are the third most productive methods to prevent diarrhoea related morbidity (Martines, Phillips, and Feacham 1993; Webb et al. 2006). A hygiene intervention typically includes hygiene and health education and the encouragement of certain behaviours (Fewtrell et al. 2005a). But when interventions involve information about bacterial contamination in their drinking water and food preparing utensils, the effects of the intervention are expected to be multiplied. Individuals take action when the urgency of the prescribed work is clearly revealed to them with the necessary information. General education of hygiene produces less of an impact until they are affected by the incidents (van Wikj and Murre 2003).

Consumers' low demand for health prevention measures may be a result of their low perception of the possible benefits which might come many months or years after the intervention. When such an underestimation of the health benefits of certain behaviours is observed, the natural response should be to provide them with the information of prevention measures (Kremer and Glennerster 2011). Among the other channels, one possible effective channel through which health education affects behaviour is information. It is common for people to have imperfect information and interventions are expected to work on the assumption that they are the rational processors of information. The frequency of less hand washing might be attributed to the unavailability of water and hygiene enabling infrastructure and time. Some households might consider it an extra cost that they can't sufficiently manage. Whenever a household pays for the water they drink and uses it for household purposes, it is rational that they should manage the water properly. The payment for the water works as a signal to the household to preserve the quality of the water. If the household does not uphold the quality of the water they buy, it is reasonable to assume that they have insufficient knowledge for preserving water hygienically. Less knowledge of possible risks originating from improper water, sanitation and hygiene would make them less likely to follow the health prevention measures. In this regard, providing education could work to improve this channel. Again, people follow the health prevention measures based on their salience (Luoto, Levine, and Albert 2011). So rather than being a Bayesian decision maker (individual having prior information of a certain event) and rationally processing information, people may respond to intervention based on the salience of the contamination under a human capital model. But in a limited attention model, when an individual is made aware of the level of contamination in their storage container, they are expected to show a greater response.

In Bangladesh, despite having plenty of rivers, safe drinking water is becoming scarcer because of water pollution, salinity and the widespread arsenic contamination. In the 1990s, 97% of the population had access to safe water, while the arsenic-adjusted figure was 86% in 2009 (GoB 2012). According to the Joint Monitoring Program 2015 report, 87% of households in Bangladesh have access to improved drinking water, 61% have improved sanitation facilities and only 1% defecate openly (Unicef and WHO, 2015). In Bangladesh, people mostly depend on ground water for potable water. Groundwater is the world's largest source of high-quality fresh water (Shiklomanov and Rodda, 2003; Taylor, 2013). But ground water depletion, especially in arid and semi-arid areas, has recently been detected because of intensive abstraction for irrigation purposes (Konikow, 2011; Rodell, Velicogna, and Famiglietti, 2009). A part of the depletion phenomenon has also been observed in the north-western part of Bangladesh. The aquifer level in this part is below the country's average because of high extraction as a result of drilling boreholes or setting up tube-wells that do not provide sufficient water; rather, deep tube-wells are necessary for accessing pure drinking water (Chen et al. 2007; Escamilla et al. 2011). Households in this area are marginalized[1] in terms of access to fresh groundwater. Therefore, the Barindra Multipurpose Development Authority (BMDA), a public body, has started an initiative to supply water for irrigation and household uses using pipelines. It has covered an extensive area in northern-western Bangladesh based on an analysis of water needs in that area. As of 2014, 15,054 deep tube wells have been built, supplying irrigation water to 255,256 hectares of land used for cultivating rice. Besides irrigation water, the authority also supply drinking water to many parts of its working areas. By 2014, they had established 1,100 overhead water tanks, each containing 25,000 litres of water. The water flows from the overhead tanks to the households through a network of pipes.

1.2 Research questions

The general objective of this research is to identify how the agriculture, water, sanitation and hygiene (AG-WATSAN) nexus matters for the health outcomes in the marginalized rural areas of Bangladesh and how household and community investment can benefit the economic and health outcomes of these people. The study strives to identify the possible linkages of the AG-WATSAN nexus in terms of their synergies and trade-offs in determining household health. Investment in technological and institutional arrangements from the public intervention for the multipurpose water system and human health will also be the focus of the present study. By exploring the randomized experiment, the study tries to identify the impact of food hygiene education on the water quality, sanitation, hygiene and health outcomes of the households. To be more precise, the study seeks to achieve three objectives which can be identified by three specific research questions, as follows:

Specific research questions:

1. To what extent does the agriculture, water, sanitation and hygiene nexus affect household health outcomes in rural Bangladesh?
2. To what extent does the public piped water supply affect the food and water quality, sanitation, hygiene and health outcomes of rural households in north-western Bangladesh?
3. To what extent does behaviour change investment through Food Hygiene Education (FHE) affect water quality, sanitation, hygiene and health in the rural households of north-western Bangladesh?

1.3 Overall conceptual frameworks

For a broad conceptualization of the relationships between the research questions in this study, the conceptual frameworks revealing the proximate and underlying factors influencing water, sanitation, hygiene and health are shown in Figure 1.2 and Figure 1.3. The overall system approach of agriculture, water resources, WASH, food and nutrition security, and economic development are depicted in Figure 1.2, in which the inter-related flows of different services are revealed. It is clearly evident from this figure that the role of WASH in Food and Nutrition Security (FNS) is obvious and crosscutting. Environmental safety, especially hygiene, plays a major role in retaining nutritional value and energy in the human body and hence hygiene could be the determining factor of food and nutrition security. Adequate knowledge and practice of hygiene could enhance the function of food intake, increasing productivity. Figure 1.3 shows how food hygiene education can play a role as an underlying determining factor for child nutritional status. Food hygiene education regarding improved water, sanitation and hygiene functions as a resource for health and care, and determines the nutritional status of children.

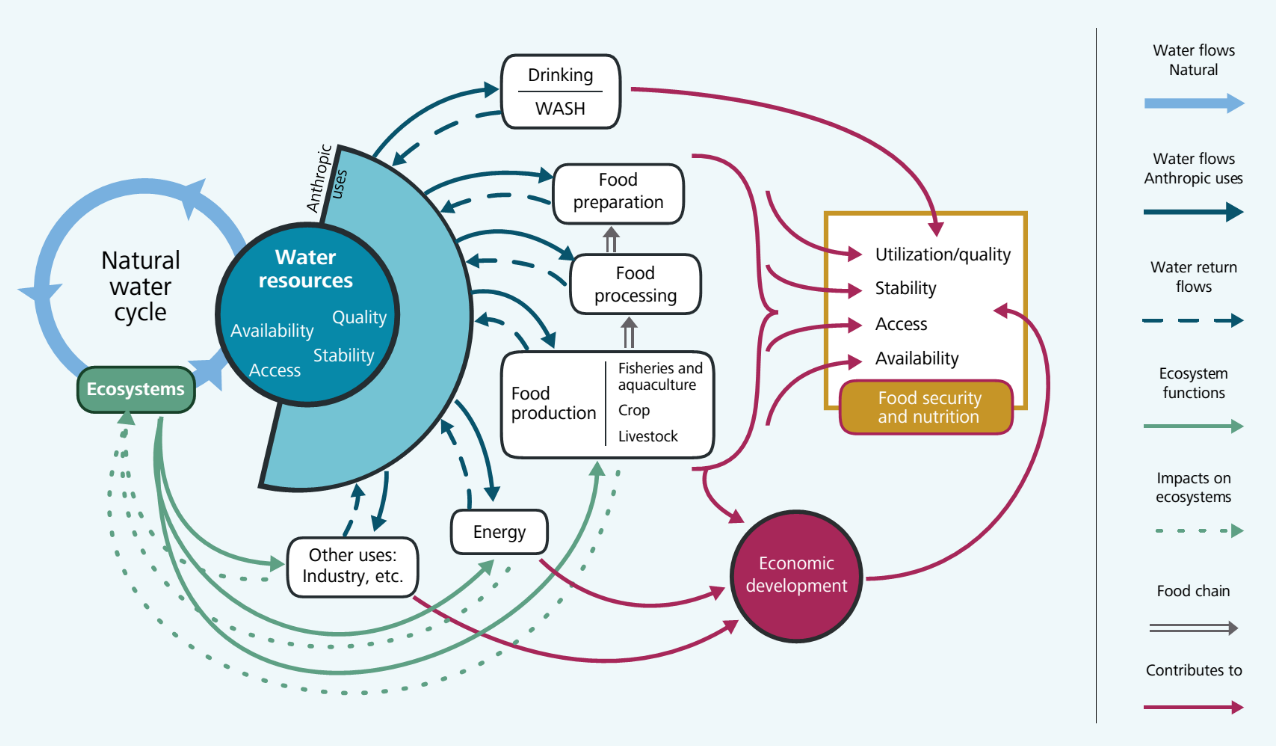


Figure 1.2: Multiple interfaces between agriculture, WASH, and food and nutrition security.
Source: (HLPE 2015)

Water resources determine FNS in numerous ways, especially by functioning as the lifeblood of ecosystems (including lakes, wetlands and forests) and providing essential input in the food value chain (food production, processing and preparation). Appropriate quality and adequate quantity of water is essential for human health, especially for providing vital conditions for the absorption of nutrients from foods. It also provides energy to all animals including humans. Figure 1.2 clearly depicts the functions of water for the ecosystem, food value chain, WASH, Energy, Industrial uses, FNS and the economic development as a whole. The role of water, sanitation and hygiene is of primary importance to the FNS as a whole, where security means availability, access, stability and the utilisation of food and nutrition. Hygiene plays a crosscutting role in the food value chain (especially in food processing and preparation) and affects the food and nutrition security. So it is in our interest to explore how the WASH sector is affecting the food and nutrition security at the household level.

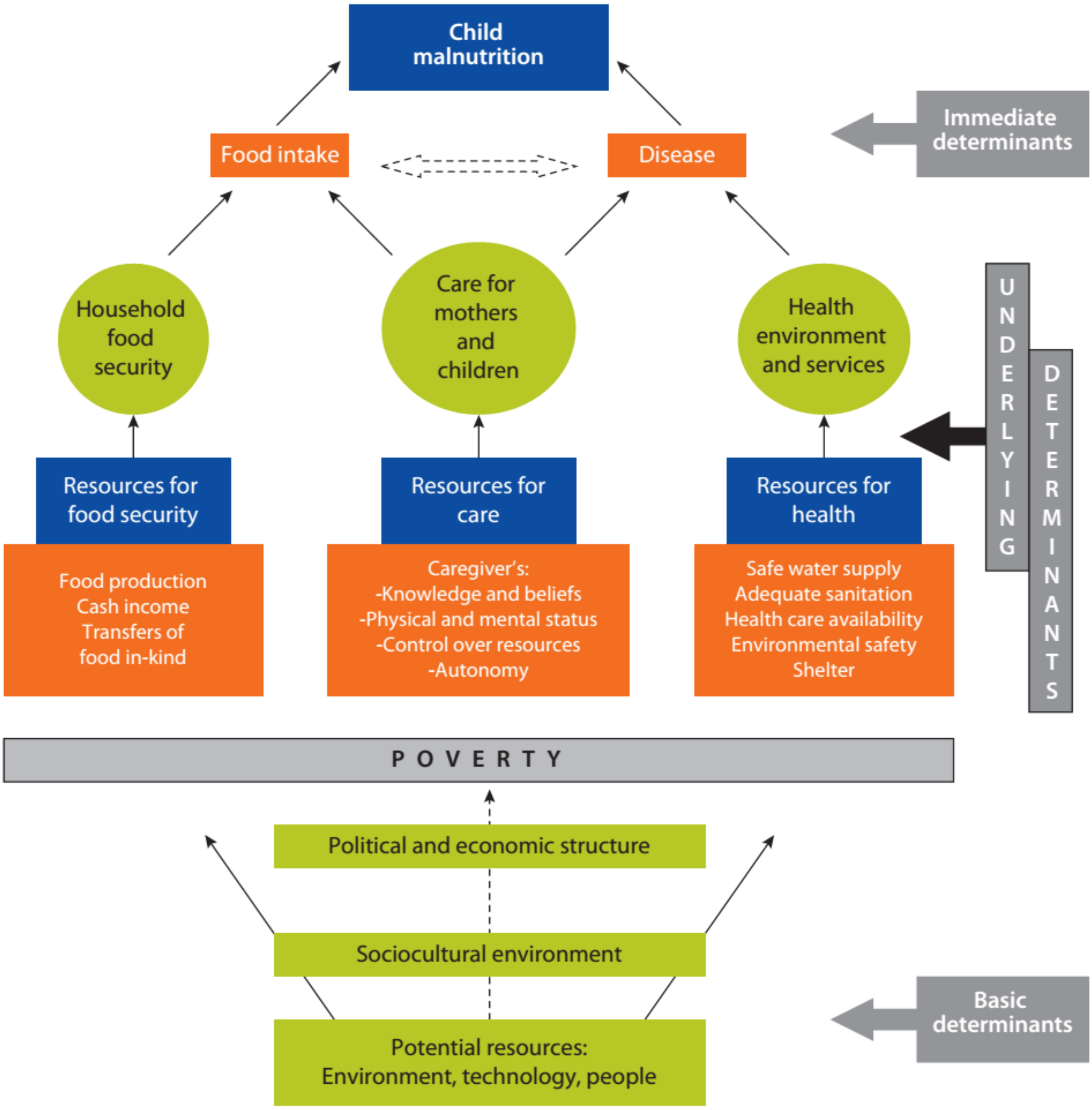


Figure 1.3: Conceptual framework Child nutritional outcome with possible interventions.
Source: Adapted from (Mahmud and Mbuya 2015) and (Engle, Menon, and Haddad 1999; UNICEF 1990)

Child malnutrition is a consequence of multifaceted factors operating across several levels and sectors, which can be classified as *immediate*, *underlying* and *basic* potential causes. The conceptual framework of child malnutrition is depicted in Figure 1.3, which is adopted from UNICEF (1990) and the subsequent works of Engle, Menon, & Haddad (1999) and Mahmud & Mbuya (2015). In the *immediate* causes of undernutrition, inadequate dietary intake and disease are often assumed to be the determining factors. They are also assumed to affect each other forming the vicious cycle. The lack of household food security, inadequate care for mother and children, and poor health and environmental conditions are assumed to be the main *underlying* causes of child malnutrition. These three factors are established on the availability of socio-economic resources for the individuals as well as households. Poverty plays a significant role in determining these underlying factors as well. Care generally means mother's pregnancy support and nutrition, appropriate infant feeding practices and health seeking behaviour etc. The caregiver's knowledge and belief, his/her physical and mental condition and control over the resources may influence the status of adequate care for children. Another underlying factor – health - is influenced by the adequacy of water, sanitation, health care availability and the environmental safety, including proper hygiene. The *basic* causes comprise the sufficiency and the distribution of available resources in the community and country level, based on socio-political and economic conditions. These *basic* causes influence both the formal and informal institutions that provide services to the community.

1.4 State of the art and contribution

The three papers of this thesis aim to contribute to the development economics literature. According to the conceptual framework, it is revealed that agriculture, water, sanitation and hygiene contribute to health. There are a handful of studies that have focused on water, sanitation and hygiene separately but none of these have focused on integrated investment in all three, which could be more cost or outcome effective than more isolated approaches. Furthermore, the connection of these three factors to agriculture is even more scant in the literature (Tsegai et al. 2013). Although the fact that WATSAN are upstream interventions that are likely to have a broad impact on wellbeing and health is hardly an esoteric point, (Hunter, MacDonald, and Carter 2010; Mara et al. 2010), little research has been carried out on the causal pathways through which WATSAN may impact health (Schmidt 2014). The link between agriculture and WATSAN is even less discussed and almost absent in the economic literature. Our aim is to discover the impact of the agriculture-water-sanitation-hygiene (AG-WATSAN) link to human health, especially the health development of children under-five in rural Bangladesh.

In the second research question, the thesis considers the technological and institutional arrangement of the water supply for marginalized rural households, and deals with the impacts of piped water on child health. There are a handful of studies that investigate the relationship between improved water and health gains (Esrey et al. 1991b; Fewtrell et al. 2005b; Hoque et al. 1996; Waddington et al. 2009; Wolf et al. 2014). The impact of piped water on health has been documented in several studies under different conditions (Devoto et al., 2012; Gamper-Rabindran, Khan, and Timmins, 2010; Jalan and Ravallion, 2003; Klasen, Lechtenfeld, Meier, and Rieckmann, 2012). Gamper-Rabindran et al. (2010) showed that access to piped water reduced child mortality in Brazil by 20% from 1970 to 2000. This paper differs from the previously mentioned papers in terms of its setting and scope; it studied the health impact of using and handling piped water in a marginalized rural setting and investigated the microbiological quality of water and kitchen utensils, which is a unique aspect of this study. To study the health effects of piped water connection in a water-scarce area of Bangladesh, the following variables were investigated: the level of the faecal bacteria *E. coli* in drinking water and on kitchen utensils, water, sanitation and hygiene infrastructure and behaviour, and various health outcomes (such as diarrhoea incidence and child anthropometrics).

The third research question considers the food hygiene education intervention for rural households in Bangladesh. It is well established that safe hygiene is the single most cost-effective means of preventing infectious disease but the investment in hygiene is low both in the health and water-sanitation sector (Curtis et al. 2011). A study in Vietnam reported that risk of diarrhoea was significantly higher for the children of those mothers who prepared food for cooking somewhere other than the table than for those who prepare on the table, based on a longitudinal study (Takanashi et al. 2009). Another study in Indonesia highlighted the role of food hygiene maintenance in reducing diarrhoea incidence in low-socioeconomic people, based on a cross sectional study (Agustina et al. 2013). However this study doesn't establish the causal link and does not consider endogeneity issues. Evidence and the observational studies show that improved hand-washing and safe stool disposal benefit health outcomes like diarrhoea. Although there is a growing understanding of the drivers of hygiene behaviour, some important gaps exist in the literature. It is noted that almost no trials of the effectiveness of an intervention to improve food hygiene in developing countries are available (Curtis et al. 2011; DFID 2013). Hence, the scope for conducting a Randomised Controlled Trial (RCT) of Food Hygiene Education (FHE) is promising to discover how food-hygiene practice matters in the daily routine to achieve major gains to household health outcomes. The research makes at least some contributions by identifying how food hygiene education affect health outcomes as well as water quality and hygiene practices in rural households. To our knowledge, we are the first to analyse the stand-alone impact of Food Hygiene Education (FHE), providing the households with microbiological test results of water and kitchen utensils, training and a poster in a marginalized rural setting. A randomised Controlled Trial (RCT) experiment of food hygiene education eliminates the possible endogeneity and biasness of the intervention in order to discover the impacts on water quality, hygiene practices and health outcomes.

1.5 Organisation of the thesis

The study is structured into five chapters. The current chapter represents the introductory chapter of the study which mainly highlights the background and motivation, research questions, conceptual framework, contribution of this study to the development economics literature, and approach and methods employed for this research.

The second chapter of the study deals with the first research question and reviews how the agriculture-water-sanitation-hygiene nexus impacts on the health outcomes of the rural households. This chapter basically focuses on the possible linkages of agriculture-water-sanitation and hygiene and health outcomes such as morbidity, child nutrition and health related investment. Two years' worth of panel data from the Bangladesh Integrated Household Survey (BIHS), a national representative sample survey, is used here. Different econometric regressions, namely ordinary least squares (OLS), logistics regression, probit regression and Poisson regression are also used in this chapter.

Chapter three is based on the second research question, in which the role of a public intervention such as piped water provision from a government agency is evaluated in terms of water and food utensil quality, sanitation and hygiene practices for the benefit of child nutritional outcomes. This chapter follows the quasi-experimental setting to discover the impacts of piped water on bacterial contamination of water and food utensils and child health outcomes. The chapter is based on the primary sample data of 512 households from north-western Bangladesh where the BMDA operates. The Propensity Score Matching (PSM) technique is applied here to investigate the impacts of piped water.

Next, Chapter four considers the third research question, in which the randomized controlled trial experiment of food hygiene education is evaluated. This experiment aims to measure households' behavioural change regarding the water and food utensil quality, proper hygiene maintenance, hygiene related investment and overall hygiene indexes. Child nutritional and health outcomes are also measured to observe the impact of food hygiene education. Like Chapter three, this chapter also uses the same sample of 512 households in north-western Bangladesh with the addition of an experimental set up. A randomized phased-in experiment was applied whereby half of the sample received treatment in the beginning and the second half received it at a later stage. A Difference-in-Difference (D-i-D) regression equation is used here to discover the possible experimental outcomes in this chapter. Chapter four also considers the cost benefit analysis (CBA) of the RCT experiment of food hygiene education. For the CBA calculation, data from the national representative sample and experimental sample are used to construct the possible cost and benefit related variables.

Finally, Chapter five provides an overall summary of the three chapters. This chapter also outlines the key policy recommendations, possible areas of scaling up and the areas of potential future research.

Chapter Two

2 Understanding the nexus of agriculture, water, sanitation and hygiene: impacts on health in rural Bangladesh

2.1 Introduction

The aim of this chapter is to discover the impact of the AG-WATSAN linkage on human health, especially the health development of children under-five in rural Bangladesh. This chapter strives to identify the association of water quality and sanitation infrastructure with household morbidity and nutritional status in the presence of agricultural components (irrigation, livestock and poultry) in rural Bangladesh.

Agriculture and health are closely related in many ways yet the health and agricultural sectors remain poorly coordinated and there is greater scope for health and agriculture researchers to work together. Agriculture benefits human health by providing food, fibre and materials for shelter; on the other hand, it can also cause poor health such as malnutrition, malaria, food borne illness, livestock related disease, chronic disease and occupational ill-health (Hawkes and Ruel 2006). The link between health and the agricultural sector is presented in Figure 2.1. The agricultural supply chain has three sectors: agricultural producers, agricultural systems and agricultural output, which are closely related to each other. The link between the agricultural supply chain and health outcomes works through an intermediate process which involves the mechanism of economics. Labour supply and income from agriculture is highly correlated with occupational health risk and agricultural outputs. Irrigated water and surface water can cause water related vector borne diseases which may cause under nutrition and chronic disease. The role of agriculture in WATSAN mainly works through water and waste management. Households draw water from the hydrological cycle and dispose of it openly to the surface water which is used for agriculture. There are households who use drinking water for irrigation and irrigated water for drinking. Therefore, the relationship works in both ways with regards to the AG-WATSAN nexus.

WASH and nutrition are interlinked through the environmental conditions by direct and indirect pathways. There exists synergies and trade-offs among the three domains of water, sanitation, and hygiene; and the effect of a specific domain to cause malnutrition is very much dependent on the other domains. To address the nexus of WASH and nutrition, there are three direct channels to be addressed (Yosef 2016). The first channel is through diarrhoea, the leading global cause for under-five mortality and morbidity. Diarrhoea ruins the appetite, immune system, the absorption of nutrients, and the physical and cognitive development of children under-five. Better water quality can reduce the incidence of reported diarrhoea but its impact in reducing diarrhoea is challenged by the presence of inadequate facilities of water quantity, sanitation infrastructure and proper hygiene maintenance. Agriculture also plays a vital role in providing hygienic environmental conditions. The synergy of the three domains works when each of them are positively working, otherwise one domain reduces the effect of another. For example, if water quality is present in the household, but the household does not have proper sanitation infrastructure or does not use it properly, and does not maintain adequate hygiene including food hygiene, the effect of a better quality of water will not be felt to its fullest extent. But it is not known to what extent the individual impact of water quality is reduced by the inadequate sanitation or hygiene and vice versa. Newman (2013) identified the impact of the different compositions of adequate food, environmental health and care on the percentage of stunting, but not the substitution effect of each domain.

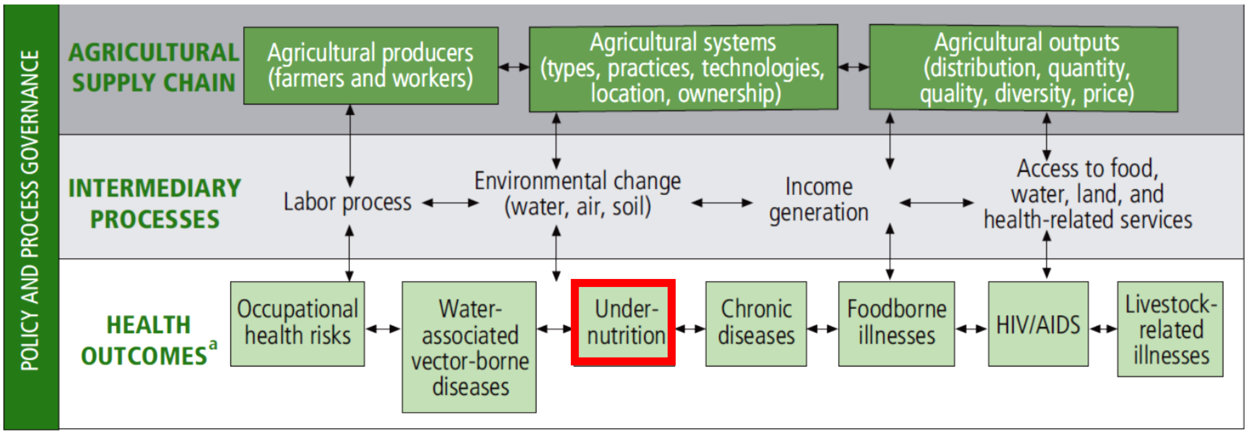


Figure 2.1: Conceptual framework for the nexus of agriculture, sanitation, hygiene and health
Source: (Hawkes and Ruel 2006)
[a] These health conditions are not mutually exclusive – livestock-related illnesses, for example, are also occupational health risks. The list of health outcomes is not necessarily inclusive. Other health conditions are also likely to interact with agriculture, but these have not yet been identified as such in the published scientific literature.

The second link for addressing WASH and malnutrition is different types of infections. Inadequate sanitation facilities such as open defecation or the unimproved sanitation infrastructure possess the risk of infestation of soils by eggs and larvae of helminth (a parasitic worm) which is transmitted into the human body through eating contaminated water and food or walking barefoot on contaminated soil. Entering into the human body, these helminth and fomites (carriers of germs or parasites) cause parasitic infections including hookworm, roundworm and whipworm. These types of infections in the human body, especially in children, impair the physical and cognitive development of children and cause malnutrition.

The third link between WASH and malnutrition is through environmental enteropathy. In the environment of inadequate sanitation infrastructure and poor sanitary conditions, there exist plenty of pathogens. These pathogens are ingested by the children in many ways and may damage the gut and lead to poor absorption of nutrients. This condition is known as environmental enteropathy or environmental enteric dysfunction (EED). Children living in unhygienic sanitation conditions are exposed to pathogens bacteria and thus develop EED. The food they eat cannot be utilized by the body and they do not receive any benefit from it, causing malnutrition. Apart from this systematic direct effect, there are other indirect pathways that exist for the WASH and nutrition relationship. Among these, time for water collection, income, education, market, geographical locations, culture and institutions are the most prominent. In terms of the nutritional outcomes of children under-five, time and money has a significant trade off as the more time is invested in water collection, purification and hygiene maintenance, the less time is left for child care. A significant investment in water and sanitation infrastructure is needed at the household and community level. In addition, there are governance issues which also governs the sustainability of the WASH and nutrition relationship. When there is a lack of demand for sanitation infrastructure from the household and the community and the market access for sanitation products is restricted, then it is the task of the government to intervene so that sanitation infrastructures can be facilitated (Spears and Haddad 2015). Therefore, governance and market also has an indirect relationship with WASH and nutrition.

2.2 Materials and methods

2.2.1 Sample and Data

A panel data set is constructed from two surveys, i.e. Bangladesh Integrated Household Survey (BIHS) 2011-12 (baseline) and BIHS 2015 survey which is cited as (Ahmed 2013; IFPRI 2016). These are the nationally representative data of rural Bangladesh. The households who were in the BIHS 2011-12 are also followed up in BIHS 2015. IFPRI used rigorous statistical methods to calculate the total BIHS sample size of 6,500 households in 325 primary sampling units (PSUs). Two stages stratified sampling adopted for selecting PSUs and the selection of households using the sampling frame of 2001 population census of Bangladesh. Later on sampling weights were adjusted based on 2011 population census. In the first stage, 325 PSUs were allocated among the 8 strata with probability proportional to size. A total of 5831 children and 5503 households were considered for the baseline survey analysis. After matching of households in the first round and second round, a total of 5098 household were identified. Similarly to keep under five children present in round 1 and round 2, 686 children were matched in both rounds.

To make a balanced panel, a household was only used if it was interviewed in both rounds. Those households that are not found in the 2015 survey and new households that are added in 2015 were not considered for this analysis. After matching this criteria, 5098 households in the panel data were interviewed twice. It was also confirmed that the household characteristics of the matched households and the unmatched households in both panels do not represent any differences, as the dropping of the unmatched households does not follow any systematic pattern.

For the anthropometric analysis of children under-five, as proposed by the WHO standard analysis, only children who were measured (height and weight) in both rounds and also remain under-five in the 2015 survey were selected. As a result, children were dropped who were measured in both rounds but were not within the prescribed age range of under-five in 2015. On the other hand, the new-borns in the 2015 survey were also not considered. To ensure a strongly balanced panel of child anthropometrics, only 686 children who were under-five in both rounds were considered.

2.2.2 Methods

To observe the interlinkages among the agriculture, water, sanitation and hygiene, cross tabulation and econometric regression analysis were used. The dependent variables were the water-sanitation disease related morbidity and the nutritional status of children under-five. Morbidity was measured in terms of diarrhoea incidence in children. Incidence rates are the number of days spent under diarrhoea episodes in the previous two weeks. Households reported their frequency of diarrhoea and how many days they experienced diarrhoea in the previous two weeks. Using panel data in the Poisson regression model, the incidence rate ratio of occurring diarrhoea episodes (number of days) was calculated. Incidence is a measure of the probability of occurrence and the incidence rate measures the number of new cases per population at risk in a given period of time. In the Poisson regression, the coefficient was interpreted as the difference between the logs of expected counts; on the other hand, the incidence rate ratio was obtained by exponentiation of the Poisson regression coefficient.

Children's nutritional status in terms of their growth measurements, such as the height and weight of children under-five, was calculated based on the observed measurements in both surveys. Following the WHO standard of growth measurement of children under-five, height-for-age z-scores, weight-for-age z-scores and weight-for-height z-scores were calculated. Based on the cut-off, scores of z-scores stunted (<-2SD) and severely stunted (<-3SD) were generated. Other variables such as underweight and wasted were also calculated in a similar fashion. To observe the impact of improved water and sanitation infrastructure, a fixed effect panel data regression model was used. The panel data regression equation can be expressed as:

$$Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it}$$

Where,

α_i = the unknown intercept for each households

Y_{it}= dependant variables of household i in time t.

X_{it}=independent variables of household i in time t.

β_1= the coefficient of independent variables

u_{it}= error term

Additionally, to observe the effect of water-sanitation infrastructure on the percentage of stunted, underweight and wasted children, a panel data probit model was used. It checks the similarity of patterns of the possible impacts. In the regression, there are independent variables such as improved sanitation, improved water access, household dietary diversity scores and mother's body mass index, which are defined and discussed in the Appendix.

2.3 Descriptive analysis

2.3.1 Access to improved water

Access to improved water can be classified into two groups: for drinking and general use (household core activities). Usually, if a household has a tube-well on the premises, then improved water can be used both for drinking and household purposes.

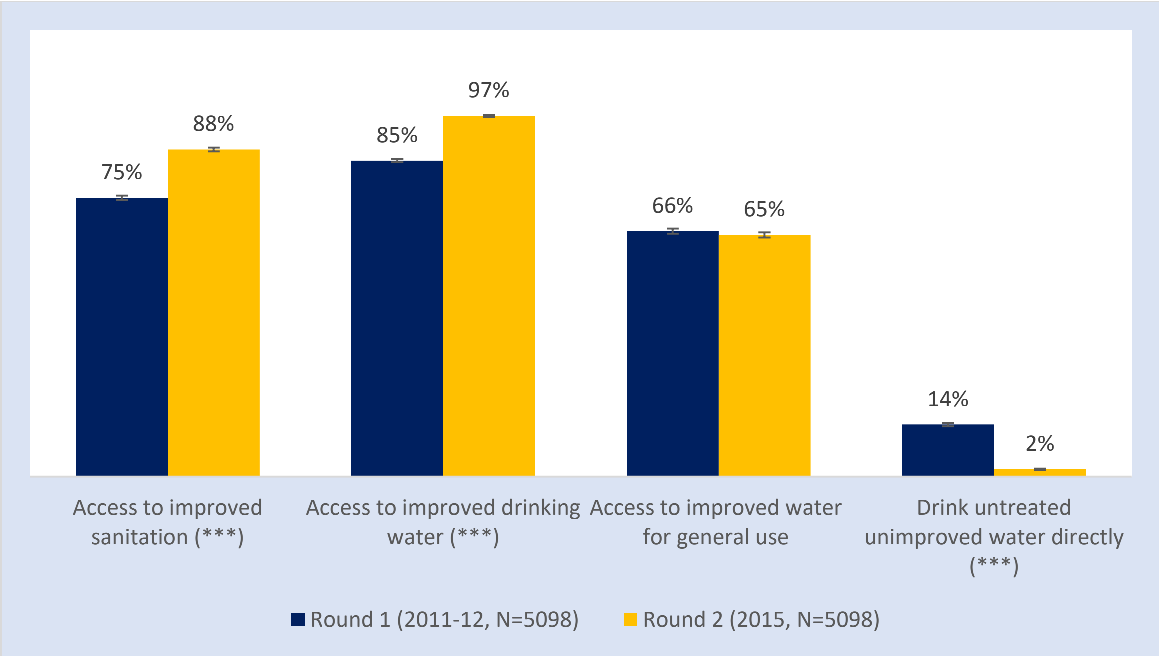


Figure 2.2: Percentage of households with access to water-sanitation infrastructure.
Source: calculation based on IFPRI BIHS data sets
*** represents mean difference at p<0.01

The definition of an improved water source is a piped-water network, private tube-well, community tube well, rainwater, protected springs or protected ring well; an unimproved drinking-water source is defined as a river, pond, canal, or irrigation water from a shallow or deep tube well (Table A. 7.1 in the Appendix). Access to improved water for drinking has increased from 85% in 2011-12 to 97% in 2015. The major change comes from the water purification practices. In 2011-12, 14% of the sample households were reported as using untreated unimproved water directly from source, but in 2015 this figure was only 2% (Figure 2.2). No change is found in the access to improved water for general use in any of those years. In Bangladesh, arsenic contamination or any other heavy chemical contamination is not considered to categorize the water quality, only source of infrastructure is considered.

2.3.2 Access to improved sanitation

Overall access to improved sanitation has improved from 75% in 2011-12 to 88% in 2015 (Figure 2.2). According to WHO guidelines, access to improved sanitation is characterized as a bricked toilet or sanitary toilet with or without flush. On the other hand, open defecation, a hanging toilet, community latrine and other kinds of latrines are regarded as unimproved sanitation infrastructure. Open defecation represents the worst label of sanitation condition anywhere. In the rural areas of Bangladesh, only 3.3% of households were reported to have no sanitation infrastructure and openly defecate in 2011-12; this figure fell to 2.3% in 2015 (Table A. 7.2). The quality of sanitation infrastructure is quite impressive but there is still more scope to do better. Most of the sanitary toilets are without a proper flushing system and sewerage connection.

Table 2.1: Summary of the household characteristics

	Round 1 (2011-12)	Round 2 (2015)	P-value (R1-R2)
Age of household head (year)	43.9	45.9	0.000
Maximum education of household member (year)	6.3	7.1	0.000
Household size	4.2	4.7	0.000
HH total income (BDT)	115794.4	163896.5	0.000
Cultivatable land (Acre)	0.7	0.7	0.206
Irrigating households	52%	51%	0.766
Number of livestock	2.9	2.4	0.000
Percentage of unimproved sanitation in village	24%	11%	0.000
Immunization as of date complete for youngest child	5%	31%	0.000
Child Dietary Diversity Score	3.0	3.2	0.224
Household Dietary Diversity Score	6.0	6.9	0.000
Mother's Body Mass Index (BMI)	20.3	21.3	0.000
Received antenatal service more than once	72%	84%	0.000
Knowledge on exclusive breastfeeding (yes=1)	28%	38%	0.000
When to give supplementary food?(six month=1)	72%	45%	0.000
Tested for arsenic contamination	35%	44%	0.000
Monthly expenditure on HH cleanliness (BDT)	137.5	177.2	0.000
Floor (Square-feet)	350.7	432.1	0.000
Roof: Tin	93%	92%	0.343
Distance: health centre (Km)	4.7	7.0	0.000
Distance: small market (Km)	1.7	1.7	0.095
Distance: nearest town (Km)	9.3	8.7	0.000

Source: Author’s calculation.

Source: calculation based on IFPRI BIHS data sets

2.3.3 Household characteristics

The time difference in the two rounds is 3 to 4 years. Many things have changed during this time. The Bangladesh economy has grown at a 6.5% rate in 2011-12 to a 7.1% in 2015, mainly dominated by private sector investment. Agricultural contribution to GDP is reducing day by day; in 2011-12, agriculture contributed 13.7% to GDP and in 2015, this was reduced to 11.7%. The contribution of crop to GDP fell from 10% in 2012-12 to 8.3% in 2015 (MOF 2016). The age of the head of the household is close to 44 to 46 years, and the maximum years of education was 7.1 in 2015. Household size has increased from 4.2 to 4.7 with income increasing from BDT 116 thousand to 164 thousand annually. There was no change in the cultivatable land and its irrigation status between the rounds. The numbers of livestock declined by 0.5 in 2015. The percentage of households with unimproved sanitation was reduced by half in 2015 and remained at 11%. The rate of immunization complete to date was lower in round 1 but increased to 31% in round 2 (Table 2.1). There was no improvement in the child dietary diversity score (CDDS) between rounds but there was some improvement in the HDDD (Household Dietary Diversity Score). Receiving antenatal care more than once has increased from 72% to 84% with the improved knowledge of exclusive breastfeeding. Households invested more in cleanliness and better housing in round 2 than round 1, so there is a significant increase in the health care facilities and increased knowledge along with the increase in the amount of income and expenditure. The regression results have been controlled for all these household characteristics to observe the possible impact of improved water, sanitation, hygiene and childcare. Some of the noted changes may be due to measurement errors between the two rounds.

2.3.4 Nutritional status of children under-five

The nutritional status of children under-five is a very important indicator for measuring their future productivity and contribution to national income. Malnutrition affects the productivity of the individual and also slows down a country's growth (World Bank 2006). Child nutritional status can be characterized as the growth measurement of children under-five, such as their height and weight. According to the child growth measurement of the WHO, the z-scores of children under-five are calculated based on their observed height and weight. Using WHO guidelines, the height-for-age z-scores, weight-for-age z-scores and weight-for-height z-scores were calculated. Stunted, underweight and wasted are defined as when z-scores are less than -2SD (standard deviation) and its severity is defined as when z-scores are -3SD.

The national level nutritional status of rural children under-five is evident from Table A. 7.3, where all children under-five are covered irrespective of their presence in both survey rounds. This table gives an estimate of the severity of malnutrition in Bangladesh. It shows that the percentage of stunted children has decreased from 47% in 2011-12 to 38% in 2015 and the percentage of severely stunted children was also reduced from 18% in 2011-12 to 12% in 2015. The percentage of underweight and severely underweight children is 33% and 9% respectively, which is unchanged in both rounds. The percentage of wasted children has increased from round 1 to round 2 from 12% to 16%, keeping its severity level of wasted children unchanged (Table A. 7.3).

On the other hand, using only the matched sample where the same children are followed up in both rounds, the percentage of stunted and underweight is much higher in 2015 than in 2011-12. The percentage of stunted children was 37% in 2011-12 and increased to 41% in 2015 (Table 2.2). In round one, these children were 0-24 months old and in round 2 they were 37-59 months old. The percentage of severely stunted children has declined from 14% in 2011-12 to 12% in 2015 at a 10% level of significance. The sharp increase in the percentage of underweight children is significant at a 1% level, which shows that as the children grow up they become underweight according to WHO standards, which may be partly a cohort effect. The severity of underweight children is an alarming situation in Bangladesh, as it reached 40% (Mahmud & Mbuya, 2015).

Table 2.2: Nutritional status of under five children in both rounds (N=686)

	Round 1 (2011-12) Child 0-24 months	Round 2 (2015) Child 37-59 months	P-value
Stunted	37%	41%	0.159
Severely stunted	14%	12%	0.091
Underweight	28%	40%	0.000
Severely underweight	7%	9%	0.276
Wasted	12%	16%	0.030
Severely wasted	4%	3%	0.181

Source: Calculation based on IFPRI BIHS data sets

To discover the nutritional status of under-five children, it is necessary to identify which months of children are pushing the average upwards. To do so, it is important to examine the full sample scenario first. It is observed that nutritional status improves in the first six months after birth and starts to deteriorate after six months. The deterioration of the percentage of stunting is faster than any other measure (Figure A. 7.1 and Figure A. 7.2). The percentage of under-weight children also increases, but slower than the stunted figure. The deterioration of nutritional status continues to rise until the children reach 36 months (3 years) and afterwards, it starts to decrease to the level of almost 17 months old.

The matched sample, in which the same children are followed up in the second round, shows almost the same pattern as the full sample. In the beginning, it starts to deteriorate and then decreases a little bit. The percentage of stunted and underweight children is above 40%, which is an alarming situation. The percentage of stunted children increases rapidly from 6-8 months to 9-11 months (shown in Figure 2.3) when they start to eat solid food. In addition to the biological adoption of the solid food, diarrhoea-related disease also increases. Maintaining hygiene for the children is very important, especially food hygiene.

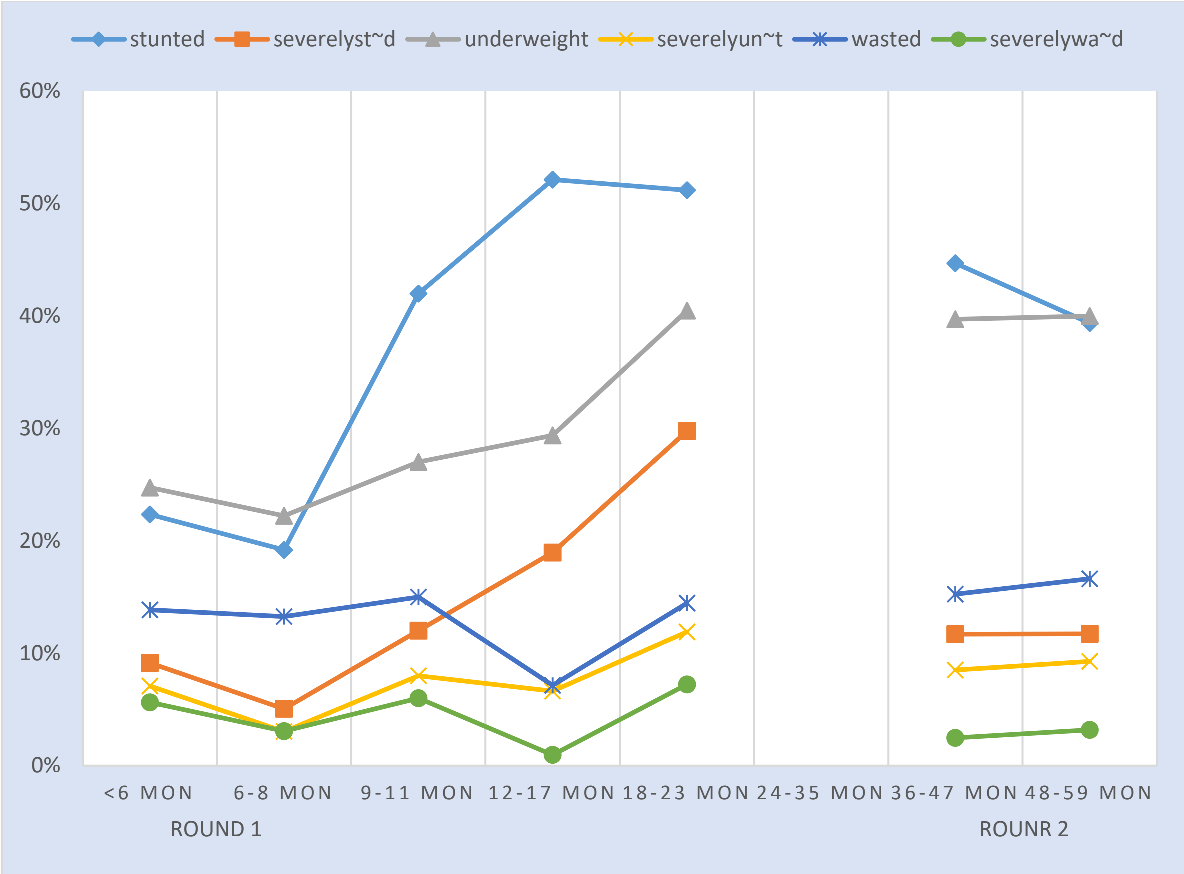


Figure 2.3: Nutritional status of children under-five for matched sample panel
Source: Calculation based on IFPRI BIHS data sets

The high level of malnutrition is partly explained by the economic condition of the household. The level of malnutrition varies in terms of their income quintile. Malnutrition is higher in the lowest income quintile and lowest in the highest income quintile (Table 2.3 and Figure 2.4). In the lowest income quintile (quintile 1), the average height-for-age z-score is -1.658 in round 1 and -1.913 in round 2. Obviously, there is an age effect between rounds. Similarly, the average weight-for-age z-score in round 1 is -1.485 and in round 2 is -1.897 for the quintile 1 group (Table 2.3).

Table 2.3: Child nutrition (z-scores) by income quintile and rounds

Income quintile	Average height-for-age z-score		Average weight-for-age z-score		Average weight-for-height z-score	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
1	-1.658	-1.913	-1.485	-1.897	-0.708	-1.138
2	-1.714	-1.958	-1.358	-1.839	-0.538	-1.004
3	-1.556	-1.937	-1.377	-1.875	-0.651	-1.092
4	-1.327	-1.623	-1.202	-1.604	-0.559	-0.963
5	-1.321	-1.620	-1.143	-1.623	-0.531	-0.992

Source: Calculation based on IFPRI BIHS data sets

The percentage of stunted children in the lowest quintile is 45% in round 1 and 47% in round 2 (Figure 2.4). The percentage of stunted, underweight and wasted children decreases as income level increases. In the highest income quintile (quintile 5), the percentage of stunted and underweight children in round 1 are 28% and 21% respectively and in round 2 are 32% and 33% respectively. It is also observed that the percentage of any nutritional status deteriorates in round 2, which mainly shows the age effect.

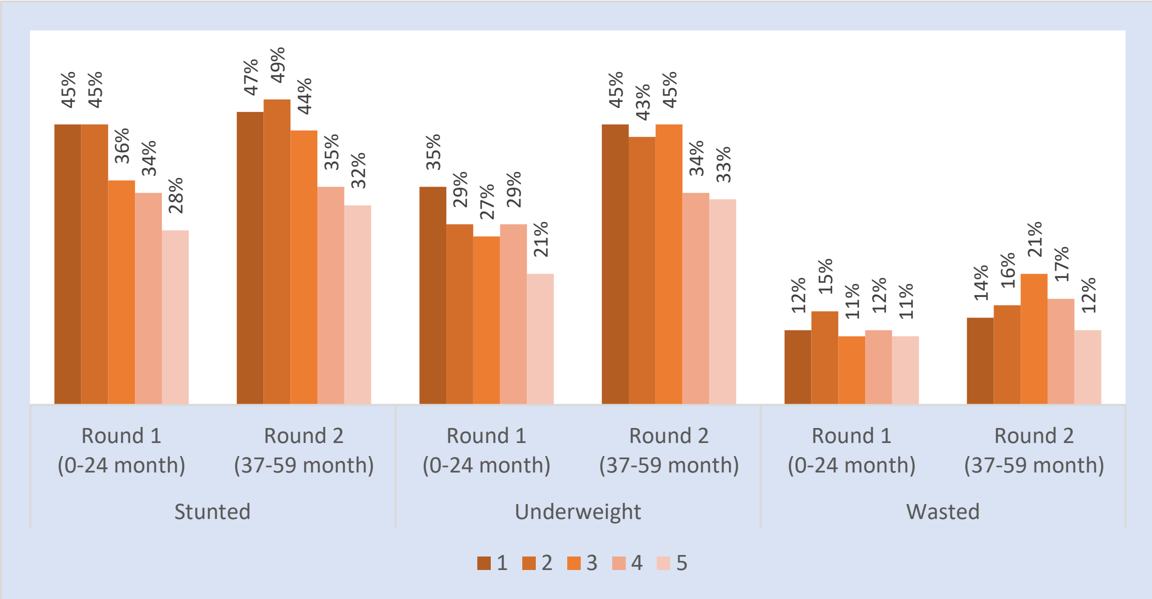


Figure 2.4: Nutritional status of under five children by months and rounds.
Source: Calculation based on IFPRI BIHS data sets

Access to improved sanitation and access to improved drinking water are linked to the nutritional status of the children under-five. The nutritional status is better for those who have access to improved sanitation and improved drinking water in both rounds. In round 1, weight-for-age z-scores of children under-five with improved sanitation infrastructure is -1.273, which is higher than -1.416 (the without-improved-sanitation infrastructure group). Similarly, in round 2, all the nutritional statuses are better for those who have improved water and sanitation infrastructure (Table 2.4). The percentage of stunted, underweight and wasted children is lower for those who have sanitation infrastructure. The percentage of stunted children has increased by 3% (=40% -37%) from round 1 to round 2 for those who have improved sanitation access; which is lower than 9% (=47% -38%) for unimproved sanitation access (Table 2.4). Similarly, households with better access to improved drinking water suffer from malnutrition less than the group with unimproved drinking water. It is quite certain that access to improved sanitation and drinking water contributes to a better nutritional status; however, the conclusion of to what extent this is so cannot be drawn without a proper regression analysis considering all the relevant covariates.

Table 2.4: Average child nutritional status by WATSAN infrastructure

	Access to improved sanitation				Access to improved drinking water			
	Round 1		Round 2		Round 1		Round 2	
	No	Yes	No	Yes	No	Yes	No	Yes
Height-for-age z-score	-1.508	-1.518	-1.929	-1.791	-1.607	-1.493	-1.931	-1.805
Weight-for-age z-score	-1.416	-1.273	-1.933	-1.741	-1.404	-1.291	-1.995	-1.757
Weight-for-height z-score	-0.712	-0.553	-1.167	-1.017	-0.575	-0.603	-1.277	-1.026
Stunted	38%	37%	47%	40%	39%	37%	48%	41%
Underweight	32%	27%	48%	39%	30%	27%	52%	39%
Wasted	15%	11%	15%	16%	9%	13%	27%	15%

Source: Calculation based on IFPRI BIHS data sets

Following the guidelines of WHO nutritional measurement, the level of stunted, underweight and wasted children are defined as having z-scores less than -2SD. The severity of these nutritional levels, such as severely stunted, severely underweight and severely wasted, are defined as having z-scores of less than -3SD. It is important to observe how much of this level of malnutrition is caused by access to improved water, sanitation and hygiene sector. To do so, Figure 2.5 compares the percentage of bad nutritional status (<-2SD) and very bad nutritional status (<-3SD) in terms of access to improved water and sanitation conditions in both rounds. It is evident from Figure 2.5 that the nutritional status without improved water and sanitation is much worse than its counterpart. From round 1 to round 2, there is only a 5% (=54%-49%) increase in malnutrition (<-2SD), despite the improved sanitation; which is lower than the 11% (=62%-51%) of the unimproved sanitation group. Similarly, malnutrition (<-3SD) has dropped from round 1 to round 2 by 2% for those who have an improved sanitation infrastructure.

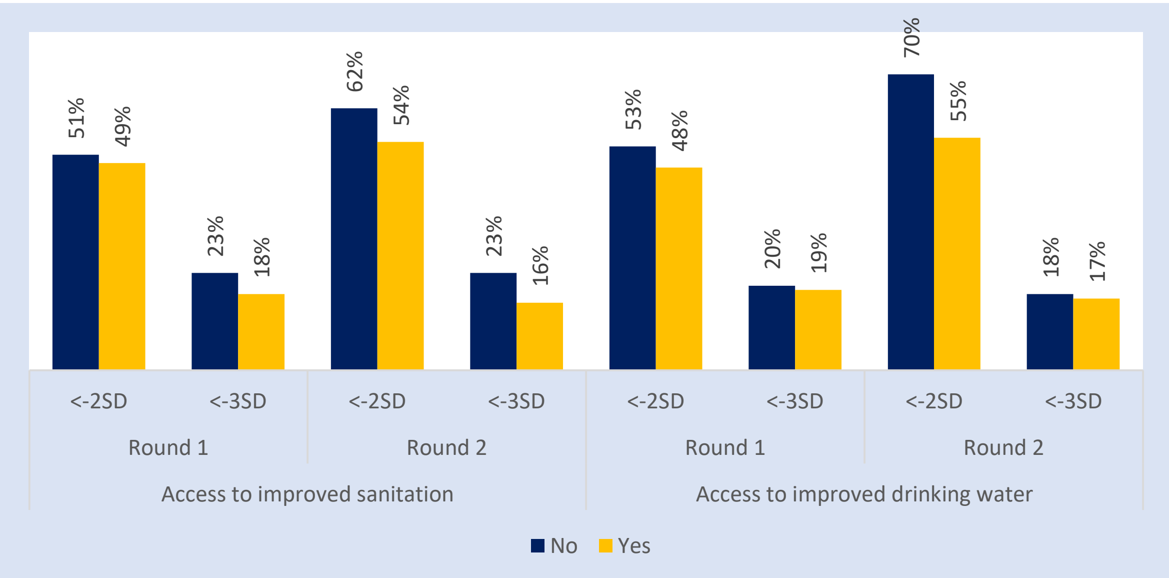


Figure 2.5: Nutritional status of under five children by water and sanitation infrastructure
Source: Calculation based on IFPRI BIHS data sets

2.4 Regression results

The impact of access to an improved water source, and access to improved sanitation and hygiene practices on the household health outcomes of rural Bangladesh were analysed in the regression results. For the health outcomes, household morbidity and child nutritional status was considered. Household morbidity is defined as the number of days affected by the diarrhoea episodes of any member of the household. Similarly, child morbidity is defined as the number of days affected by diarrhoea episodes of any child in the households. The prime object of the regression analysis is to establish how many of the outcome variables are explained by the access to water, sanitation and hygiene after controlling for other households characteristics. A list of household characteristics is shown in the Table 2.1. For finding out the possible determinants of household and child morbidity, panel data Poisson regressions are applied. Incidence Rate Ratio (IRR) for the diarrhoea episodes are counted for this analysis. It measures the number of new cases per population at risk in a given period of time.

To discover the determinants of child nutritional outcomes, fixed effect panel regressions were applied. The prime objective of the regression equation is to establish how many of the variations of the outcome variables are explained by the access to improved water, sanitation and hygiene variables. To do so, it is only the key variables that are shown in the tables, as the detailed list of variables and their impacts are shown in the appendix (Table A. 7.4 and Table A. 7.5). For the continuous variables of the nutritional outcomes such as height-for-age z-scores, weight-for-age z-scores and weight-for-height z-scores, a fixed effect panel was applied and for discrete outcome variables such as stunted, underweight and wasted panel data, a Probit model was applied.

2.4.1 Impact on child morbidity

Child morbidity is defined as the number of days affected by the diarrhoea episodes of children under-five. Households reported the number of days they were affected by diarrhoea for each child over the last one month. The Incidence Rate Ratio (IRR) was calculated to see to what extent it is affected by access to improved water, sanitation and hygiene. Households having access to improved sanitation reduced the number of days of diarrhoea episodes by 34% (=100-0.66) which is significant at a 5% level (Table 2.5). Similarly, having access to improve drinking water reduced the diarrhoea related morbidity of children by 59%, which is significant at a 1% level (Table 2.5). Access to improved water for general use does not improve the situation; rather, it worsens it because water for general use is too often re-contaminated by unhygienic maintenance. Education and household dietary diversity reduced the number of days of diarrhoea episodes by 17%. Households who purified their water before use reduced the diarrhoeal episode days by 86%. On the other hand irrigating a household has a higher rate of diarrhoeal incidence than a non-irrigating household, possibly because of the pathogen contamination of the canal water. Household income and assets do not have a negative impact on the incidence rate of diarrhoeal episodes.

Table 2.5: Households' reported total diarrhoea episode (days) of children under five in last 4 weeks

Panel data Poisson regression	Incidence rate ratio (IRR)	Standard Error
Access to improved Sanitation	0.66**	0.14
Access to improved drinking water	0.41***	0.11
Access to improved water for general use	1.40*	0.26
Age of the household head (years)	0.99	0.01
Years of schooling of the household head	0.83**	0.07
Household Dietary Diversity Score	0.82***	0.06
Expenditure for cleanliness (BDT)	1.00	0.00
Water purification of drinking water (Y=1)	0.14***	0.10
Roof: Tin	1.67	0.65
Irrigating household (Y=1)	1.50*	0.32
Number of poultry in the household	1.00	0.00
Household total assets (BDT)	1.00**	0.00
Per capita income quintile		
Income quintile 2	1.13	0.34
Income quintile 3	2.01**	0.61
Income quintile 4	1.52	0.44
Income quintile 5	3.20***	1.06

Source: Calculation based on IFPRI BIHS data sets. note: *** p<0.01, ** p<0.05, * p<0.1

2.4.2 Impact on child nutrition

Child nutritional status is an important indicator for child growth, defined as the WHO recommended cut off point of z-scores. This study aims to establish the association of improved drinking water, sanitation, hygiene and care variables with the child nutritional status. Table 2.6 highlights the possible linkages with the water and sanitation variables including the household characteristics. A detailed impact of all the variables is shown in Table A. 7.4 and Table A. 7.5. Households with access to improved sanitation improves the height-for-age z-scores by 1.2 points, which is significant at a 1% level. Similarly, access to improved drinking water improves the height-for-age z-scores by 1.58 points at a 10% level of significance. Immunization of children is found to be significantly associated with the increase of height in the analysis, while monthly expenditure on household cleanliness reduces the height-for-age z-scores controlling for the households characteristics, but the amount is very low in terms of its effect. Another reason might be that households spend money on the environmental cleanliness rather than on personal hygiene issues.

Access to improved sanitation is not significantly associated with the increase of weight-for-age z-scores and weight-for-height z-scores of children under-five, but access to improved drinking water sources are significantly associated with the increase of weight-for-age z-scores by 1.7 points, which is a significantly large number. It is not found to be significantly associated with an increase in weight-for-height z-scores.

Agricultural variables such as irrigating households and number of livestock are significantly associated with the increase of height-for-age z-scores and weight-for-age z-scores (Table 2.6). Households with poor housing infrastructure, including a roof of tin, significantly reduce the height-for-age and weight-for-age z-scores (Table A. 7.4). Therefore, it is important to note that water and sanitation variables significantly affect the child's growth even after controlling for the household characteristics.

Table 2.6: Impact of water, sanitation and care on child nutritional outcomes.

	Height-for- age z-score	Weight-for- age z-score	Weight-for-height z-score
	coefficient (SE)	coefficient (SE)	coefficient (SE)
Access to Improved Sanitation	1.194*** (0.433)	0.248 (0.304)	-0.559 (0.388)
Access to Improved drinking Water	1.576* (0.829)	1.711*** (0.664)	0.553 (0.715)
Immunization as of date complete for youngest child (Yes=1)	1.155** (0.560)	0.593 (0.429)	-0.287 (0.304)
Irrigating household (Yes=1)	1.428*** (0.512)	0.757** (0.377)	-0.275 (0.461)
Number of livestock	0.311*** (0.082)	0.193*** (0.068)	-0.023 (0.076)
Household characteristics	Yes	Yes	Yes
_cons	-3.420* (1.943)	-3.822*** (1.014)	-3.303* (1.977)

Source: Calculation based on IFPRI BIHS data sets. note: *** p<0.01, ** p<0.05, * p<0.1

Child growth in terms of stunting, and being underweight and wasted, were also analysed, the results of which are shown in Table A. 7.5. Access to improved drinking water is associated with the 30% reduction in stunted children (at a 5% level of significance) and underweight children by 23% (10% level of significance) after controlling for the household and child characteristics, especially the age and age-squared of children. The level of education significantly reduces the percentage of malnutrition. Water purification for drinking reduces the number of stunted children by 30%, which is significant at a 5% level. The percentage of unimproved sanitation in the village actually worsens the underweight situation of children under-five after controlling for their age and age-squared with other household characteristics. Furthermore, irrigation actually helps to improve the nutritional status of children under-five if other household characteristics are controlled for. Finally, education and expenditure on cleanliness reduces the percentage of severely stunted children.

2.5 Discussion

The study strives to identify the possible linkage of the agriculture, water, and sanitation nexus on health outcomes. Agriculture has a direct link to water quality and hygiene practices which are affected by the sanitation conditions of rural households. Unimproved sanitation contaminates the canal and surface water for agricultural activities. Household food utilization is in a vulnerable situation in the presence of inadequate hygiene practices which are triggered by the unimproved water and sanitation conditions. This study finds that a household's diarrhoea related morbidity can be reduced by improved water and sanitation infrastructure to a greater extent, a conclusion also found in several works (Esrey et al. 1991b; R. Guiteras, Levinsohn, and Mobarak 2015; Lim et al. 2012). The analysis finds that improved sanitation alone can reduce child diarrhoea related morbidity by 34%; a 5% level of significance after controlling for other household characteristics. Furthermore, access to improved water infrastructure could reduce the diarrhoea morbidity for children by almost 58% at a 1% level of significance. A similar result is also found in several studies (Esrey et al. 1991a; Fewtrell et al. 2005a; Waddington et al. 2009). The effectiveness of access to improved water on morbidity is higher in the presence of improved sanitation infrastructure which is also the finding of Esrey (Esrey 1996). Agricultural variables such as irrigating households worsens the diarrhoea related morbidity of households, holding income as constant. Meanwhile, in the literature, diarrhoea is both a cause and effect of malnutrition (Brown 2003); so the effect of diarrhoea on malnutrition is not as strong as previously highlighted (Mahmud & Mbuya, 2015).

The study further finds that malnutrition is significantly associated with the inadequacy of improved water and sanitation infrastructure facilities. Access to improved sanitation increases the height-for-age z-scores by 1.19 points at a 1% level of significance. With the presence of improved sanitation infrastructure, access to improved drinking water significantly increases height-for-age z-scores and weight-for-age z-scores. A similar result is also found in the study of Esrey (Esrey 1996). Agriculture plays a dual role in nutrition sensitive and nutrition specific objectives. For the nutrition specific objects, irrigating and livestock rearing households have more income and food that helps to reduce the malnutrition of children under-five. In contrast, for the nutrition sensitive objectives, agriculture has an adverse effect on household diarrhoea if adequate food and personal hygiene are not maintained. Therefore, agriculture plays a dual role and the net effect depends on the hygienic status of a specific household. Unimproved sanitation in the community, such as widespread open defecation and open pit hanging toilets, contaminates canals and irrigating water which adversely affects the nutritional status of children under-five, a conclusion also reflected in some studies (Steele and Odumeru 2004). This analysis finds that irrigating and livestock rearing households show an increase in the nutritional outcomes of children under-five when other household characteristics such as access to improved water and sanitation, expenditure on cleanliness and other household care variables are controlled for. Therefore, one finding is when proper hygiene investment is ensured in terms of money, time and behaviour, changing the agricultural variables works in terms of increasing the nutritional status of children under-five.

Regarding the nexus effect of agriculture, water, sanitation and hygiene on the nutritional status of children under-five, it can be said that improved water and sanitation infrastructure is the precondition for the reduction of child malnutrition (Mahmud and Mbuya 2015). Agriculture plays a positive role in reducing malnutrition if and only if the personal, food and environmental hygiene is maintained properly. So it is the hygiene which mostly matters for a reduction of malnutrition even after controlling for the other household characteristics such as household size, income, education and location. For maintaining proper hygiene, investment is required for personal, food and environmental cleanliness. Expenditure on cleanliness and hygiene is a long term investment which offers not only the nutritional benefit for children under-five but also reduces both other diseases and morbidity (Mahmud and Mbuya 2015).

The analysis finds that in rural Bangladesh, the role of improved water and sanitation infrastructure is weakly related to malnutrition in children under-five. The study only finds a reduction of percentage of stunting and underweight children due to access to improved water infrastructure but does not find any significant impact on it of access to improved sanitation. Improved sanitation access is found to increase the height-for-age z-scores a small amount, which does not guarantee a reduction of stunting. A similar result was found in the meta-analysis of the Cochrane review, where they found that WASH intervention only moderately increases weight and height but does not significantly have an impact on reducing malnutrition (Dangour et al., 2013). In the last few decades, Bangladesh has successfully managed to reduce the diarrhoea incidence, but the level of malnutrition there is above 40 percent, which constitutes an alarming situation. The extensive oral rehydration programme has reduced the diarrhoea prevalence and related morbidity to a greater extent which has not translated into a comparable effect on child nutritional outcomes. It is not diarrhoea, but the tropical/ environmental enteropathy, which works as a causal pathway from poor sanitation and hygiene to malnutrition (Humphrey 2009). In his paper, Humphrey hypothesized that children under-five living in poor sanitation and hygiene conditions receive chronic exposure to enormous faecal bacteria and undergo a subclinical disorder in their small intestine which is clinically known as tropical/environmental enteropathy. It is subclinical because it does not reveal any sign/symptoms, whereas diarrhoea is a clinical disorder which results in appetite and nutrient loss within a very short period of time. During the condition of environmental enteropathy, the small intestine of children under-five reduces the capacity to absorb the nutrients from the food they eat. As a result, although there is observance of diarrhoea, the nutritional status of children under-five is poor. One of the major causes which increases environmental enteropathy is the low level of hygiene practices (Mahmud and Mbuya 2015). In the Bangladesh National Baseline Hygiene Survey 2014, only 57 percent of female caregivers washed their hand with soap, while in the Bangladesh Integrated Household Survey 2015, it was observed that more than 40 percent of households did not have any arrangement for handwashing in their premises and even if they had an arrangement, no adequate water was present.

A multi-sectoral approach is needed to address the severe problem of malnutrition in children. As part of this, adequate food, environmental health, and child care are associated with the reduction of stunting in children (Newman 2013). Adequate environmental health means improved water and sanitation infrastructure, and handwashing and child care means antenatal care, immunization, exclusive breast-feeding, mother's BMI, iron-folic acid supplementations for the mother and access to health clinics. Bangladesh children who have all three dimensions such as adequate food, environmental health and care possess a 30% lower prevalence of stunting than those who possess none of these (Newman 2013). In Bangladesh all these three dimensions – food, environmental health and care - are equally necessary; only one of these cannot tackle the problem. Water and sanitation quality is a necessary condition but not sufficient. To maintain lower environmental enteropathy, proper hygiene should be maintained from human and animal waste, agricultural activities and industrial pollution. Therefore, time, money, knowledge and effort is necessary to invest in combating malnutrition in children.

2.6 Conclusion

The analysis has found that improved water and sanitation infrastructure has reduced diarrhoea related morbidity in children. Education, household dietary diversity score and water purification could reduce the diarrhoea incidence in children under-five. Irrigating households possesses some risk of diarrhoea incidence as it may worsen the situation if this is not then followed by adequate hygiene and water purification. Furthermore, household income does not have any impact on reducing diarrhoea incidence.

Access to improved sanitation and water infrastructure has a positive impact on child nutrition. Agriculture plays the dual role of providing nutrition sensitive and nutrition specific objectives. It plays a positive role in reducing malnutrition if and only if the personal, food and environmental hygiene is maintained properly. Therefore, it is the hygiene which mostly matters for reduction of malnutrition even after controlling for the other household characteristics such as household size, income, education and location. For maintaining proper hygiene, investment is required for personal, food and environmental cleanliness. Expenditure on cleanliness and hygiene is a long term investment which not only provides nutritional benefit to children under-five, but also reduces other diseases and morbidity.

Chapter Three

3 The impacts of piped water on water quality, sanitation, hygiene and health in rural households of north-western Bangladesh - a quasi-experimental analysis[2]

3.1 Introduction

The world is still suffering from a lack of proper sanitation and safe drinking water in the twenty-first century. Although a significant improvement has been made in terms of reducing open defecation, it is still practiced by a substantial portion of the population (946 million, 13% of the world's population) and could cause sanitation-related health problems. The multipurpose characteristics of water use, especially for irrigation and domestic purposes, leads to health issues which could be explained by the trade-offs between water quantity and quality.

Water quality is very crucial for domestic use, especially for drinking, and therefore water needs to be properly handled. Water quality at the source often differs from water quality at the point of use. Access to piped water by itself is insufficient for improving child health (e.g., decreasing diarrhoea incidence) and child development (Jyotsna Jalan and Ravallion 2003). Indeed, piped water interacts with a wide range of other determinants of child health such as hygienic water storage, water treatment, sanitation infrastructure, medical treatment and nutrition (Jalan and Ravallion, 2003). To maintain and develop human capital, constant investment in water and sanitation (WATSAN) infrastructure is required, along with investment in effecting behavioral and cultural changes. Household health expenditure is seen as a growth-friendly investment; cost-effective and efficient health expenditure can increase the quantity and productivity of labor through increasing life expectancy (European Commission 2013). While investing in WATSAN infrastructure and education do not benefit households immediately, it brings long-term returns in human capital formation, reduces the cost of treatment and provides positive external benefits to the society. Households can invest in their health in several ways, such as establishing proper sources of water, setting up sanitary latrines, educating themselves on proper hygiene practices, taking preventive actions, purchasing medicine and health services, and even buying health insurances. In fact, it is well established that safe hygiene practices are the single most cost-effective means of preventing infectious diseases, but the investment in hygiene is low both in health and water-sanitation sector (Curtis et al. 2011).

Access to water is not the only indicator of household well-being; water quality and quantity are important indicators too. Crucially, the three indicators are interlinked. For instance,

---

[2] This chapter is published as a ZEF Discussion Paper on Development Policy No. 217 and also under review for journal publication in *Water Resources and Rural Development.*

distance to a water source affects water quality (Devoto, Duflo, Dupas, Parienté, and Pons, 2012) and the amount of work involved in water collection affects a household's per capita water use. Kremer found that 58% of the surveyed households reported having insufficient water for their daily use (Kremer et al. 2011). Having insufficient water has negative consequences on hygiene behaviour, height-for-age and diarrhoea incidence in under-five children (van der Hoek et al. 2002). Further, it creates intra-household inequalities as the burden of water collection directly falls on women and girls, which reduces their economic activities and opportunities, including the education of children. Devoto *et al.* (2012) showed that an adequate amount of water from a piped water network allows for more leisure time and higher productivity by reducing the burden of water collection.

Water quality affects the sanitation status of a household. Unimproved sanitation and poor hygiene worsen water quality by allowing pathogens to contaminate water. Improved sanitation decreases diarrhoea morbidity and diarrhoea mortality, including the probability of hookworm infection. In comparison, better water quality plays a smaller role in reducing diarrhoea than sanitation and hygiene (Esrey et al. 1991a). The importance of water quality and sanitation in reducing health risk has been well-documented (Esrey et al. 1991a; Fewtrell et al. 2005a; Waddington et al. 2009). The health benefits of access to improved water are less observable than those of sanitation: they can only be realized if access to improved sanitation is ensured and if there is sufficient water available for domestic use. (Esrey 1996). A study conducted in 145 low- and middle-income countries showed that in 2012, about 502 thousand diarrhoea deaths were caused by inadequate drinking water, about 280 thousand by inadequate sanitation and about 297 by inadequate hand hygiene (Prüss-Ustün et al. 2014). Improved sanitation is associated with fewer diarrhoea cases and improved height and weight of children; height and weight of children were found to be higher in urban areas than in rural areas (Esrey 1996). Installing water filters and building high-quality piped water systems with sewer connections are better at reducing diarrhoea cases than other kinds of intervention (Wolf et al. 2014). A study showed that diarrhoea incidence and cholera incidence in Bangladeshi households could be reduced by simple water filtration (Colwell et al. 2003; Huo et al. 1996; Huq et al. 2010). Sanitation can be improved for people in rural Bangladeshi villages by giving subsidies for building latrines. Such intervention can also cause a beneficial spillover effect by encouraging neighboring villages which have yet to receive subsidies to also improve on their sanitation infrastructure and build latrines (Raymond Guiteras, Levinsohn, and Mobarak 2015; Kaiser 2015).

The nutrition status of under-five children is affected by the quality of water and food in a household. Food and kitchen utensils can easily be contaminated with pathogenic bacteria through washing and cooking. Food can be contaminated through preparing meals with unimproved water. Preparing food with unimproved water therefore poses a serious health risk and can cause adverse health effects, including malnutrition in children. Malnutrition impairs the immune system and makes children more vulnerable to diarrhoea (van der Hoek et al. 2002). Diarrhoea has a long-term negative impact on cognitive development in young children (Keusch et al. 2006). Infants with poor nutritional intake are at higher risk of diarrhoea and malnutrition than those receiving nutritional supplementation (Javaid et al. 1991). One way of breaking the vicious cycle of diarrhoea and malnutrition is to increase the use of safe water and improved sanitation. This reduces the transmission of pathogens, thereby lowering diarrhoea incidence and child mortality and improving nutritional status (Esrey 1996). Van der Hoek et al. (2002) found that larger water storage is associated with higher diarrhoea risk and child stunting prevalence.

There are a handful of studies that investigated the relationship between improved water and health gains (Esrey et al. 1991b; Fewtrell et al. 2005b; Hoque et al. 1996; Waddington et al. 2009; Wolf et al. 2014). The impact of piped water on health has been documented in several studies under different conditions (Devoto et al., 2012; Gamper-Rabindran, Khan, and Timmins, 2010; Jalan and Ravallion, 2003; Klasen, Lechtenfeld, Meier, and Rieckmann, 2012). Gamper-Rabindran et al. (2010) showed that access to piped water reduced child mortality in Brazil by 20% from 1970 to 2000.

A randomized controlled trial experiment in urban Morocco, which highlighted the effects of piped water in an urban setting, suggested that piped water improves neither water quality nor health, but rather helps save time and reduces intra-household conflict (Devoto et al. 2012). Another study conducted in an urban setting with quasi-experimental analysis (Klasen *et al.*, 2012) showed that piped water in urban Yemen worsened health outcomes if water is rationed, thus highlighting the inter-correlations between water quantity, water quality and human health. They suggested that piped water systems can only improve health outcomes when water supply is continuous. On the other hand, a study conducted in rural India showed that access to piped water only improved the health of well-educated and high-income households and not poorly educated households (Jalan and Ravallion, 2003). However, the study did not investigate water quality.

The objective of this paper is to estimate the impact of piped water use on water, sanitation, hygiene, and health outcomes in rural households living in the marginalized[3] area of north-western Bangladesh. The hypothesis is that the BMDA piped water service will make a difference in health outcomes between a treated household (i.e., those with access to BMDA piped water) and a control household (i.e., those without access to BMDA piped water).

This paper differs from the previously mentioned papers in terms of its setting and scope. This paper studied the health impact of using and handling piped water in a marginalized rural setting and investigated the microbiological quality of water and kitchen utensils, which is a unique aspect of this study. To study the health effects of piped water connection in a water-scarce area of Bangladesh, the following variables were investigated: the level of the fecal

[3] The term "Marginality" is an involuntary position and condition of an individual or group at the margin of the social, political, economic, ecological and biophysical system, that prevent them from access to resources, assets, services, restraining freedom of choice, preventing the development of capabilities, and eventually causing extreme poverty (Gatzweiler and Baumüller, 2014).

bacteria *E. coli* in drinking water and on kitchen utensils, water, sanitation and hygiene infrastructure and behaviour, and various health outcomes (such as diarrhoea incidence and child anthropometrics).

3.2 Sample and Data

3.2.1 Sample

In Bangladesh, safe drinking water is becoming more and more scarce because of salinity and arsenic contamination. In the 1990s, 97% of the population had access to safe water, but this figure dropped to 74% in 2006 because of widespread and severe arsenic contamination (GoB and UNDP, 2009), while the arsenic-adjusted figure was 86% in 2009 (GoB 2012). According to the Joint Monitoring Program 2015 report, 87% of the households in Bangladesh have access to improved drinking water, 61% have improved sanitation facility, and only 1% defecate openly (Unicef and WHO, 2015).

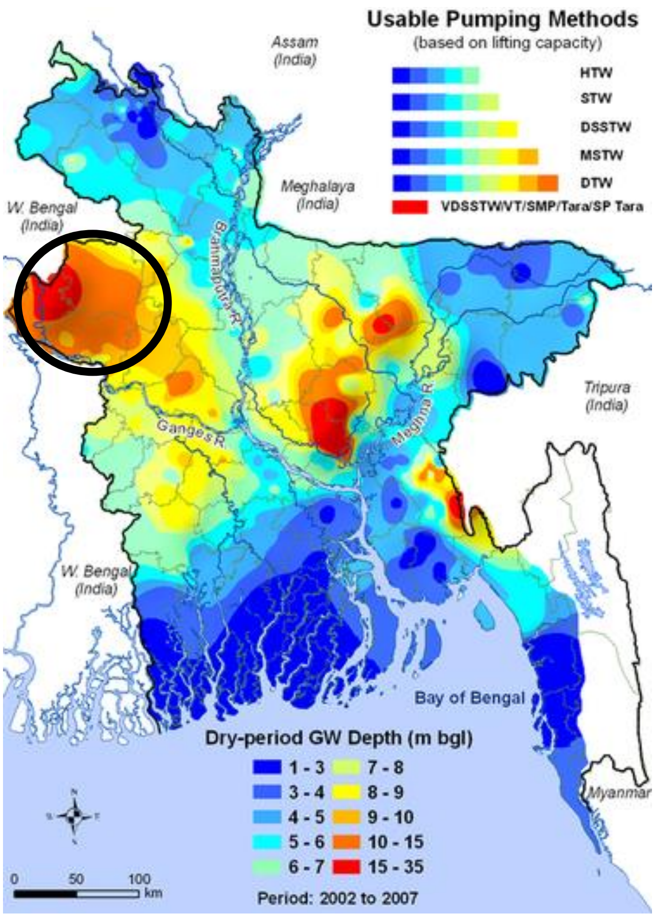


Figure 3.1: Map of Bangladesh based on usable pumping method.

Source: Shamsudduha, Taylor, Ahmed, and Zahid (2011).

Humans mostly depend on ground water for potable water. Groundwater is the world's largest ubiquitous source of high-quality fresh water (Shiklomanov and Rodda, 2003; Taylor, 2013). Groundwater depletion has recently been detected in arid and semi-arid areas because of intensive abstraction of water for irrigation purpose (Konikow, 2011; Rodell, Velicogna, and Famiglietti, 2009). The aquifer level in the north-western part of Bangladesh is below normal caused by very high rates of water extraction. In this part of the country, it is not easy to obtain groundwater by drilling boreholes or setting up tube wells (Figure 3.1). A significant amount of money is required to build a deep tube well for extracting groundwater. As shallow tube wells are not recommended for drawing groundwater, deep tube wells are necessary for accessing pure drinking water (Chen et al. 2007; Escamilla et al. 2011). People living in this area are marginalized in term of access to fresh groundwater. Therefore, the BMDA, a public body, has started an initiative to supply water for irrigation and household uses using pipelines. It has covered an extensive area in northern-western

Bangladesh based on an analysis of water needs in that area. As of 2014, 15,054 deep tube wells have been built, supplying irrigation water to 255,256 hectares of land used for cultivating *Boro* rice. Besides irrigation water, the authority also supplies drinking water to many parts of its working areas. By 2014, they had established 1,100 overhead water tanks, each containing 25,000 liter of water. The water flows from the overhead tanks to the households through a network of pipes. The BMDA charges a household a minimal amount of money (approx. Tk. 10) for every person using the water in a month.

The aims of the BMDA drinking water project are as follows:
1. Supply potable water to every household in rural areas throughout the year.
2. Ensure the around 500 thousand people in this area have access to arsenic-free water.
3. Eradicate diseases caused by 1.) Arsenic and 2.) Shortage of potable water.
4. Improve the health of the people living in the rural villages
5. Create a reliable drinking water supply in the rural villages.

3.2.2 Conceptual framework

Human health is affected by the transmission of pathogens from faeces and waste water to humans. Pathogens are transmitted through various agents such as improper sanitation and hygiene, and unsafe drinking water sources (Figure 3.2). The transmission of pathogens from faeces to human can takes place through hands, flies and ground or surface water. Not washing hands after defecation may allow pathogens to enter into human body through various routes, such as eating, drinking, preparing food, and feeding. Pathogens can be transmitted from ground and surface water to humans in various ways. Preparing food with untreated surface water, drinking surface water, and ingesting water while bathing in a pond or river can introduce pathogens into the human body, which may result in many water borne diseases. Ground and surface water can be contaminated by sewage, flood and chemical compounds. Piped water can be contaminated by sewage or flood water seeping into a pipeline. Chemical compounds such as arsenic, chlorine, iron, manganese and sodium can pollute water. These chemical compounds, along with the other industrial chemical wastes, can even pollute underground water sources, which is more dangerous than the surface water pollution in the long run. The transmission of pathogens can be stopped by interventions such as water treatment at source and the point-of-use (POU), and improving sanitation and hygiene (Waddington et al. 2009).

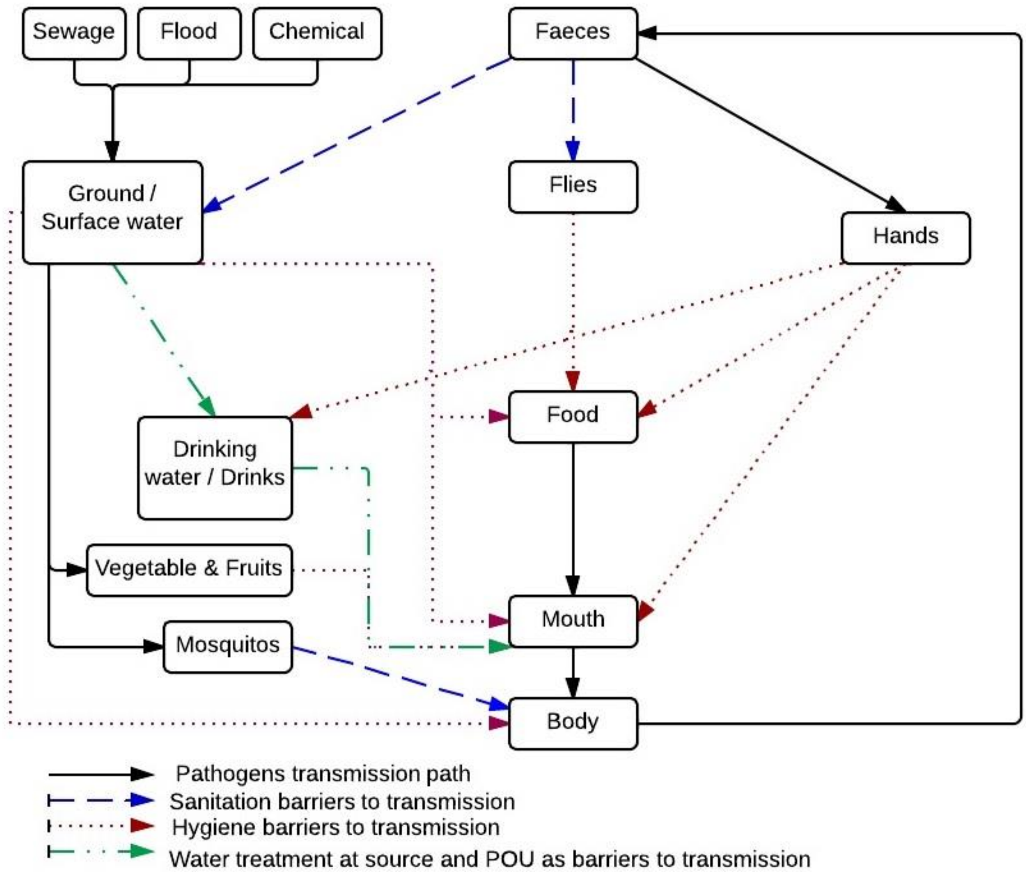


Figure 3.2: Water treatment, sanitation and hygiene barriers to transmission of pathogens. Source: Author's calibration; adopted from Prüss, Kay, Fewtrell, and Bartram, (2002), and Waddington et al. (2009).

In Figure 3.2, the arrows (both dotted and solid) show the possible routes of pathogen transmission; the dotted arrows indicate that the particular route of transmission can be interrupted by interventions. The colour of each dotted arrow indicates which method acts as an effective barrier to pathogen transmission for that particular transmission route. A blue dashed arrow denotes sanitation is an effective barrier to pathogen transmission, a red dashed arrow denotes hygiene, and a green dashed arrow denotes water treatment. The figure clearly shows that WATSAN interventions can stop pathogen transmission and therefore reduce the risk of waterborne diseases.

Agriculture plays an important role in maintaining water quality. The relationship between agriculture, water and sanitation can be analysed as shown in Figure 3.3, where potential interventions with external drivers indicate the outcome of interest. Agriculture can affect water quality, sanitation and hygiene, and vice versa. To alter the magnitudes of the relationship between these three variables, various kinds of interventions are required. The different kinds of interventions can be categorized as follows: (1) institutional intervention, such as capacity building and closing gender gap; (2) cultural intervention, such as providing education on hygienic behaviour; (3) and financial intervention, such as providing technological and financial resources. For the purpose of microeconometric analysis, if all external drivers remain unaltered, the kinds of interventions mentioned above could generate a positive impact on health outcomes.

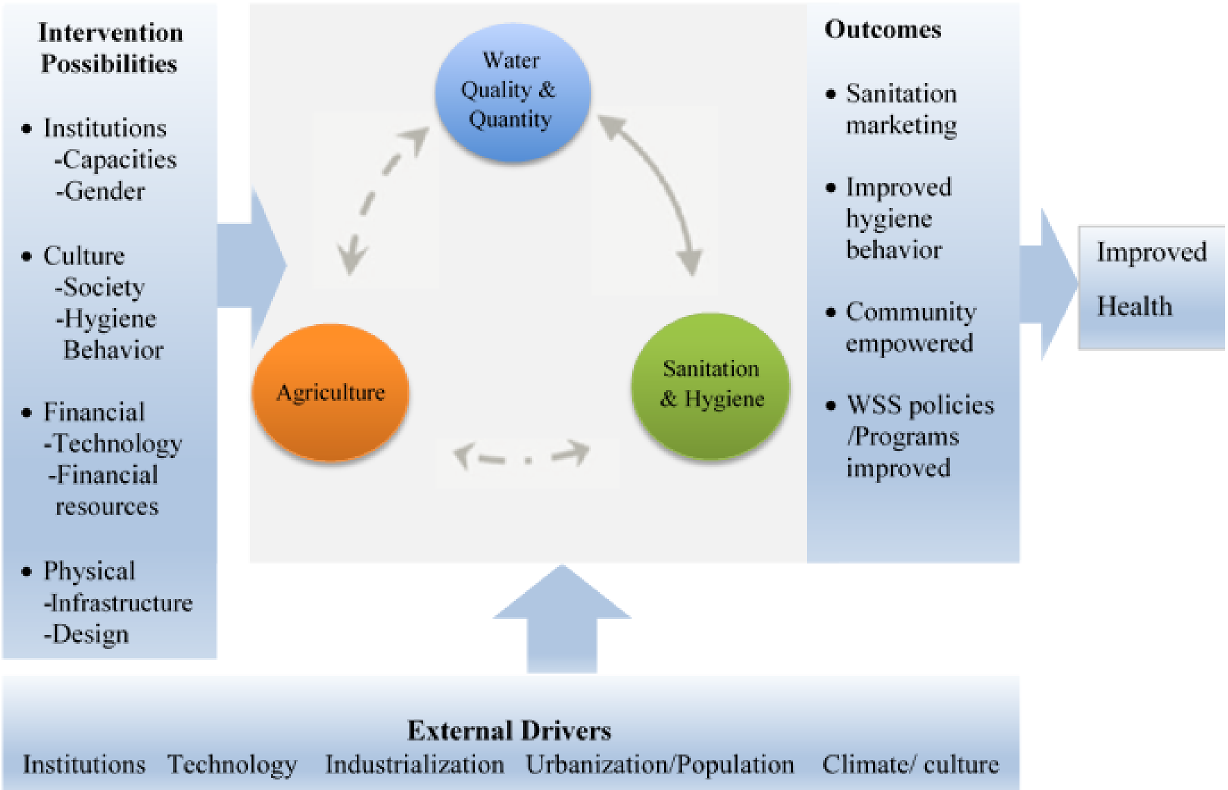


Figure 3.3: Conceptual framework of Agriculture-water-sanitation nexus on human health
Source: (Tsegai, Mcbain, and Tischbein, 2013)

3.2.3 Data

The selected study areas are located in the Rajshahi and Naogaon district (Figure 3.4), two dry areas located in north-western Bangladesh. The BMDA has built a piped-water network in these two areas. The survey data used in the analysis was obtained from a baseline survey conducted for a randomized controlled trial experiment concerning food hygiene education that took place in the following months.

3.2.3.1 Sample size selection

For this paper, 512 households were randomly chosen from two main clusters – those that villages that have received BMDA intervention and those that have not. The sample size satisfied the minimum sample size (498) calculated based on a Poisson statistical regression power analysis. The analysis considered an effect size (ES) of 0.95 (i.e., the minimum difference in the outcome between treated and non-treated subjects is on average 5%) and a multicollinearity across the covariates of 0.7 (which is quite extreme) and allowed for a probability of Type I error of 5% and a statistical power (1-Probability of Type II error) of 80%.

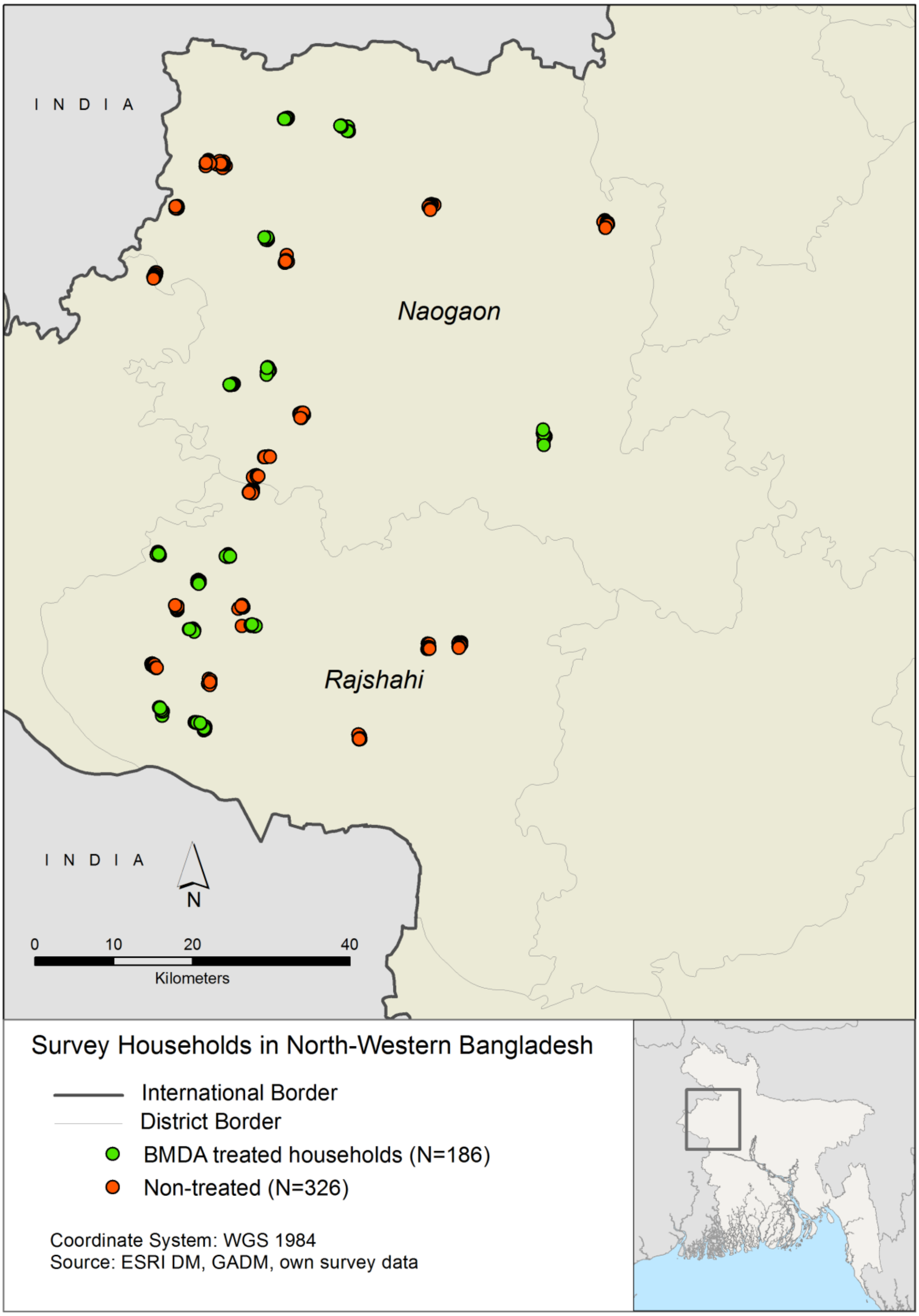


Figure 3.4: Map of study areas in Rajshahi and Naogaon district.

Source: Author's calibration based on primary data: baseline survey 2014.

3.2.3.2 Sampling procedure: cluster sampling

The cluster sampling technique was used in this study. Cluster sampling is useful because it does not require exhaustive lists of every single person in the population to be compiled. According to World Health Organization (WHO) guidelines, the population within a cluster should be as heterogeneous as possible and different clusters should be as homogenous as possible among themselves. The WHO also recommends that the number of clusters in the sampling frame should be at least five times larger than the number of randomly selected clusters.

A random sample was chosen from a list of clusters determined by a list of villages (or mouzas) in the districts studied. In this quasi-experiment, all clusters can be classified into two main clusters: 1) villages whose households are connected to the piped-water network (public intervention in 389 mouzas) and 2) villages without access to the piped-water network (in 359 mouzas). A useful rule of thumb is that there should be a minimum of 30 clusters. With our sample size of 512 households, we needed to survey 16 households per cluster (mouza) from a total of 32 mouzas; this means that 16 mouzas were to be randomly selected from the list of villages with BMDA intervention and another 16 from the list of villages without BMDA intervention. The random selection was done using Stata. We note that our data is well within the WHO recommendations on the minimum ratio between clusters in the sampling frame and the sample survey. In each of the 32 villages, a small *census survey* was conducted to identify eligible households. Only households that have at least one child younger than five years old were included in this study. Then 16 households were randomly selected from the eligible households in each village.

3.2.4 Identification

The survey was conducted among 512 households, 256 of which were living in areas with BMDA drinking water coverage and the other 256 in areas without the coverage. It was observed that many households living in areas with BMDA drinking water coverage did not actually receive BMDA piped-water services because of technical problems, such as faulty water pumps. Hence, only households that actually received piped-water services were identified as BMDA-treated. By adopting this definition, we considered the actual receipt of piped water when analyzing the impact of BMDA pipe-water services, rather than BMDA's intention to supply piped water to households. According to this definition, 186 households were considered BMDA-treated and 326 households were not considered BMDA-treated.

3.2.5 Data collection

Household survey:

Household survey (baseline) was conducted in November 2014 in the rural villages in Rajshahi and Naogaon district, located in north-western Bangladesh (Figure 3.4). Every household received a detailed 28-page questionnaire that asked for information about a household's assets, income, food and non-food expenditure, investment and financial activities, WATSAN-and hygiene-related practices, and agricultural activities. The households took part in this survey willingly and did not receive any financial incentives in return. Each questionnaire required approximately two hours to fill out. A total of ten field enumerators and a supervisor were involved in collecting the information from households.

The study was approved by the ZEF ethical committee of the University of Bonn to protect the rights of the survey respondents. All households received extensive information about the study and had to sign a consent form prior to participating in the survey. All households had the right to discontinue their participation at any time during the observation period. Each household was given an identification card for follow-up.

Anthropometric survey:
On the same day as the household survey, a field enumerator took anthropometric measurements of under-five children in the households. The height and weight of the under-five children were measured in this survey. The measurements taken were determined according to WHO guidelines for anthropometric measurements. The measurement took place on the same day as the survey because households might not be available on the following days, which might reduce the sample size of the anthropometric data. The field enumerator also recorded the GIS information of all households, including their latitude and longitude.

Microbiological testing of water and food utensil:
In the days following, a laboratory research assistant (LRA) visited the households and collected water and food utensil samples from the household. The LRA collected a glass of drinking water from the same jar the household use (the point of use). The water sample was collected in a sterilized bottle and kept in a cool box for transporting to the laboratory.

The LRA also tapped or pressed a "food stamp" on the households' drinking glass, spoon and main cutting instrument. The number of food stamp samples was recorded, and the media (food stamps) were kept in a cool box for transporting to the laboratory.

The LRAs are microbiology graduates and have been trained for this kind of assignment. Two LRAs worked simultaneously in different areas. Each LRA covered 16 households in a mouza and then returned to the lab on the same day. Before commencing their fieldwork, they were trained at the International Centre for Diarrheal Disease Research, Bangladesh (icddr,b) by a senior scientist.

***E. coli* testing procedure in the Laboratory:**
The bacterium *Escherichia coli O157 (E. coli)* is the most commonly recommended indicator of faecal contamination in water and food utensils. The WHO recommends there should be no *E. coli* in a 100 ml drinking water sample. In the survey, *E. coli* was measured by filtering 100 ml of drinking water through a 0.22 μm filter paper (cellulose nitrate membrane filter; 47 mm diameter; pore size of 0.2 microns; Sartorius, Germany) using a vacuum filtration unit. Then the filter paper was removed and placed onto a Compact Dry EC growth media plate (Nissui Pharma, Japan) to incubate it at 37-39°C for 24 hours. After incubation, the LRAs

counted and recorded the number of *E. coli* colony forming units (cfu), indicated by blue colonies, and the number of coliform colonies (red colonies) on each of the Compact Dry EC media (Figure 3.5).

Food stamp XM-G agars (HyServe, Germany) were used to test for *E. coli* on kitchen utensils (a glass, a spoon and a cutting knife). Food stamp sampling is a simple-to-use bacteriological testing method for the presence of bacteria in food. A food stamp (10cm^2 XMG agar) was pressed once on each of the three specimens in the household and then kept in the cool box for transporting to the laboratory. The food stamp was then incubated at 37-39°C for 24 hours. After incubation, the LRAs counted and recorded the number of *E. coli* colony forming units (cfu), indicated by blue colonies, and the number of coliform colonies (red colonies) on each of the XMG agar media (Figure 3.5).

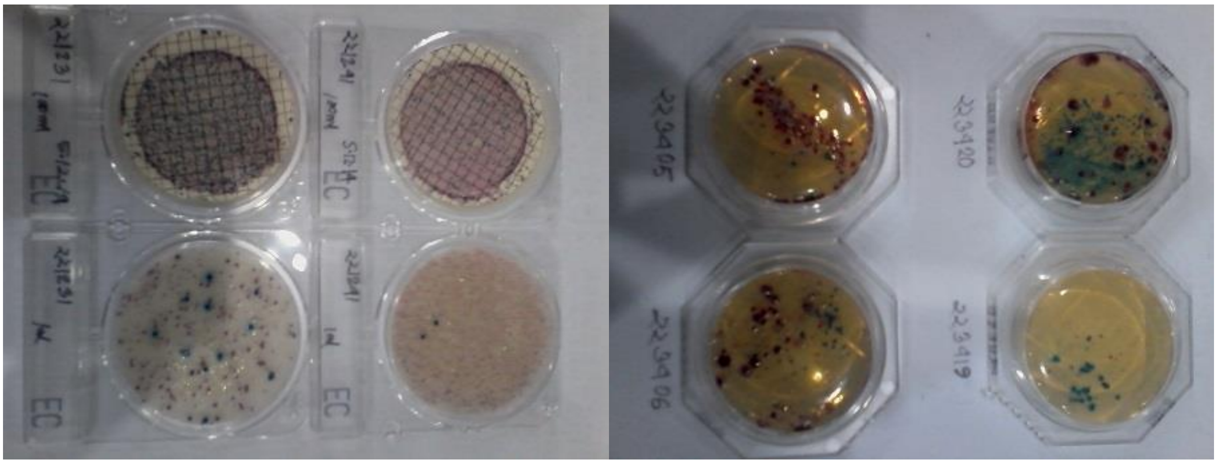


Figure 3.5: *E. coli* colony forming units (cfus) in 100 ml water (left) and *E. coli* cfu in food preparing utensils (right).
Source: Based on primary data: Microbiological survey 2014.

3.3 Descriptive statistics

3.3.1 Household characteristics

The average age of a household head was similar in both the treated and control groups (35 years old). On average, the household head of a treated household completed slightly more years of school than their counterpart in a control household; even then, they largely only received primary education (Table 3.3). The average household size was 4.72, whereby the number of male and female members are generally equal. About 98% of the household heads were married at the time of survey, and the treatment and control households did not show any significant difference in this regard. In total, 52% of the household heads were wage earners, which comprised 42% of the household heads in the treatment group and 57% in control group (Table 3.3). About 57% and 48% of the households were agricultural and non-agricultural households respectively. The percentage of non-agricultural households in the treatment group (58%) was higher than in the control group (42%); the difference was statistically significant at the 0.01 level. There was no significant difference between the treatment and control groups in terms of irrigation field ownership; 63% of the households had irrigation fields.

On average, a treated household had significantly more land than a control household (0.96 acres as compared to 0.54 acres). The same was also true for agricultural land. In our survey, 87% of the households owned livestock, and the average number of livestock was 15.3, whereby on average a treated household owned more livestock than a control household (Table 3.3). On average, a treated household had a higher household expenditure than a control household; the difference between their expenditure was statistically significant. Generally, food expenses constituted more than half of the total expenditure. Around 48% of the households had access to microfinance services, which on average lasted for more than 3.5 years. These marginalized households also reported saving almost 35% of their annual expenditure, which is a rather high figure.

3.3.2 Access to improved drinking water

The quality of household drinking water is classified into improved and unimproved. In this paper, an improved drinking-water source is defined as a piped-water network, private tube well, community tube well, rainwater, protected springs or protected ring well; an unimproved drinking-water source is defined river, pond, canal, or irrigation water from shallow or deep tube well (Table 3.1). Our sample survey found that 99.46% of the households in the treatment group (N=186) used improved water for drinking; in comparison, 93.87% of the households in the control group (N=326) did so. The Fisher's exact test yielded a p-value of 0.002, which means that the difference between these two groups is statistically significant at the 0.01 level, i.e. the two groups are different.

The households in the control group mostly obtained drinking water from community tube wells (67%) and their private tube wells (27%), while very few households in the treatment group (1.61% and 2.69% respectively) relied on these two sources for drinking water (Table 3.1). Most of the households in the treatment group got their drinking water from piped sources (95.17%), whereas none of the households in the control group did so. The Fisher's exact test yielded a p-value of zero, which means the mean value of the treatment group and the control group are different from each other.

Community tube wells are established by private households or, in some places, by government or non-government agencies. Households do not need to pay for the water they draw from a community tube well. Some households also collect drinking water from private deep tube wells which are meant for irrigation. Different households had to travel different distances to collect drinking water. Figure 3.6 shows the distribution of households by the distance (in meters) between their house and the nearest drinking water source. Control households were more likely to collect water from tube wells located far away from their home. While 82% of the treated households were required to travel less than 50 m to their drinking water source, only 57% of the control households could do that. On average, households in the control group were required to travel longer distances than those in the treatment group. The Fisher's exact test yielded a p-value of zero for the difference between the mean distance traveled by the treatment and that traveled by the control groups.

Table 3.1: Drinking water facilities in sample households

	Total		Treatment		Control	
	N	%	N	%	N	%
Piped water from outside of house	13	2.54	13	6.99	0	0
Piped water from inside of house	164	32.03	164	88.17	0	0
own tube well	93	18.16	5	2.69	88	26.99
community tube well	221	43.16	3	1.61	218	66.87
Deep tube well (for irrigation)	1	0.2	1	0.54	0	0
Private Deep tube well (not piped)	20	3.91	0	0	20	6.13
Total	512	100	186	100	326	100

Source: Baseline survey, 2014. Fisher's exact = 0.000

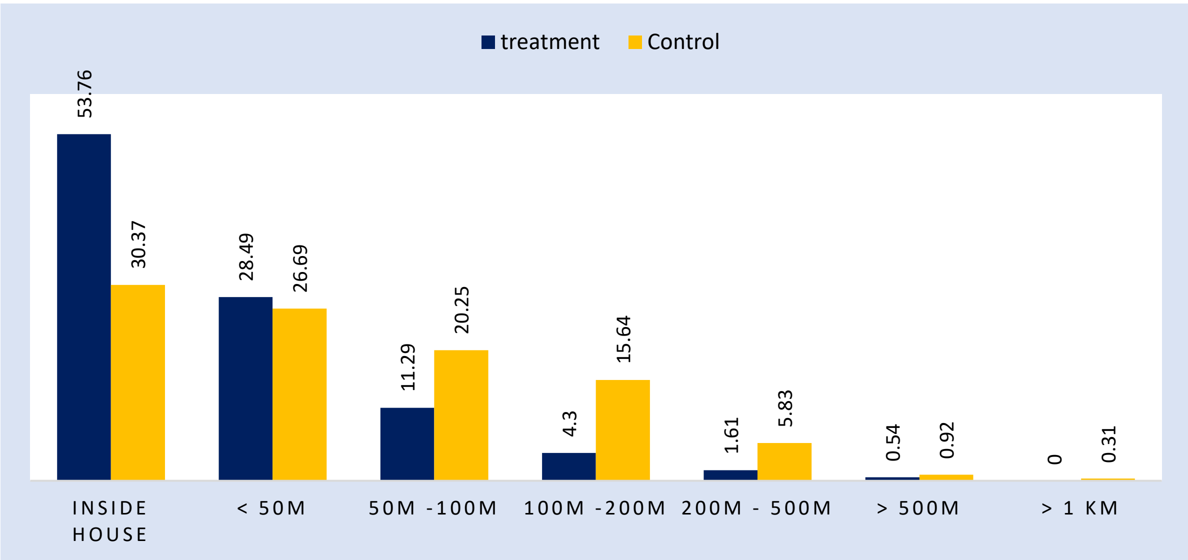


Figure 3.6: Percentage of households by traveling distance to collect drinking water. Fisher's exact= 0.000
Source: Primary data-Baseline survey, 2014.

3.3.3 Microbiological quality of water and food utensils

Figure 3.7 shows the percentage of households by their risk levels in terms of the *E. coli* cfu count found in their drinking water. Only 25% of the households in the treatment group had drinking water in which *E. coli* was not detected, whereas this figure was 20% for the control group. Although the distributions of cfu count in drinking water differs slightly between the control and treatment groups, the overall difference is not statistically significant; the Fischer exact test yielded a p-value of 0.126.

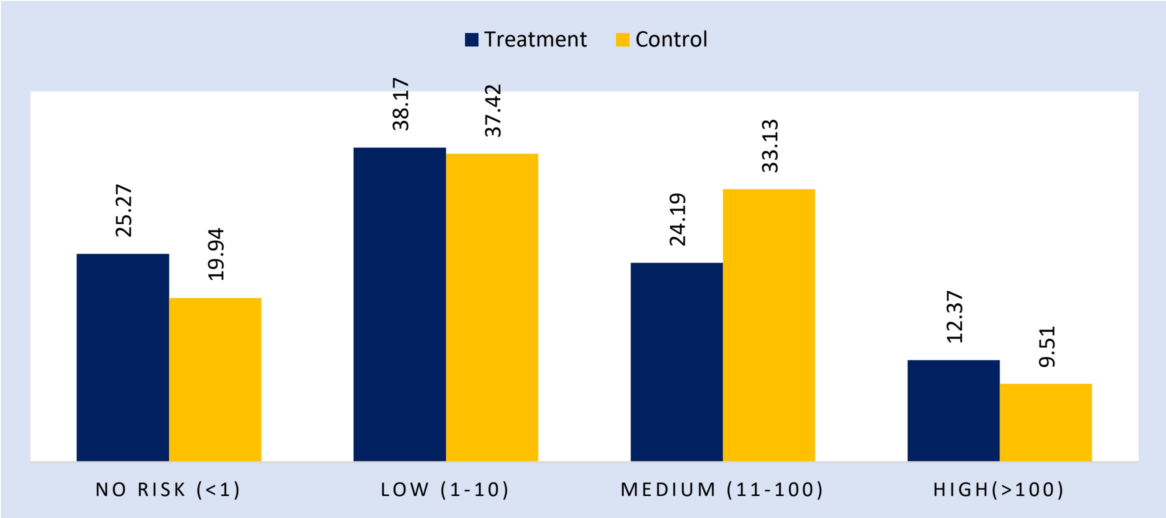


Figure 3.7: Percentage of households under different risk level for drinking water faecal contamination based on *E. coli* cfu counts.
Fisher's exact = 0.126.
Source: Primary data- microbiological survey, 2014.

The contamination of kitchen utensils is closely associated with the use of contaminated water. Nevertheless, kitchen utensils can also be contaminated through other routes, such as handling utensils with unwashed hands and processing raw meat or fish. To identify microbiological contamination on kitchen utensils, we tested three items (a water glass, a spoon and a cutting knife) for *E. coli* by using the food stamps method. It is recommended that no *E. coli* should be found on kitchen utensils.

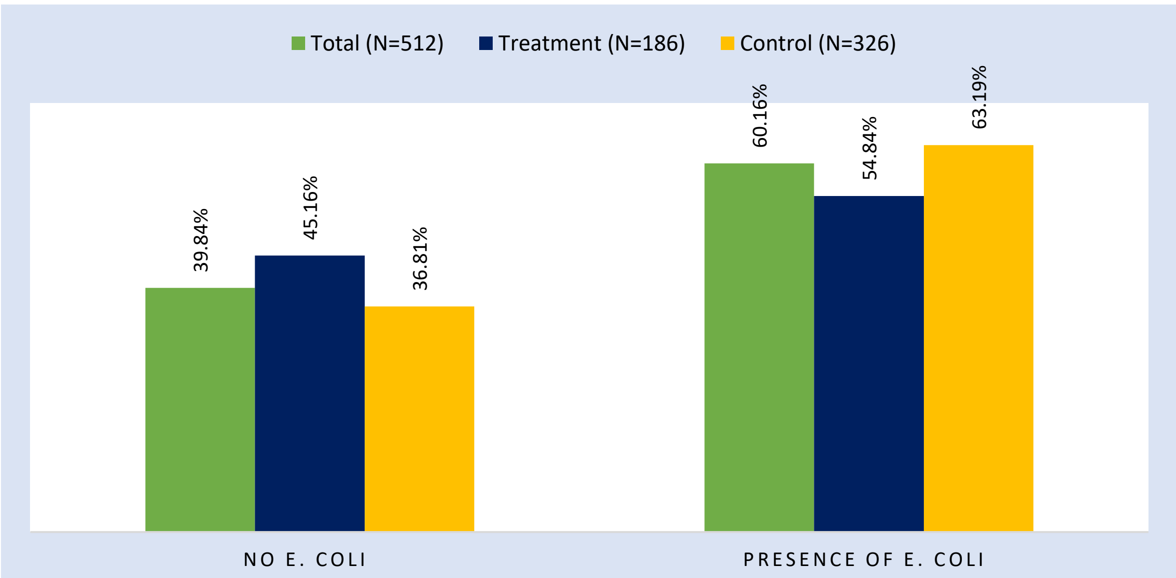


Figure 3.8: Presence of *E. coli* in the food preparing utensils.
Fisher's exact = 0.074
Source: Microbiological survey data, 2014.

The microbiological quality of kitchen utensils between treatment and control group are not statistically significant at the 0.1 level (Figure 3.9).

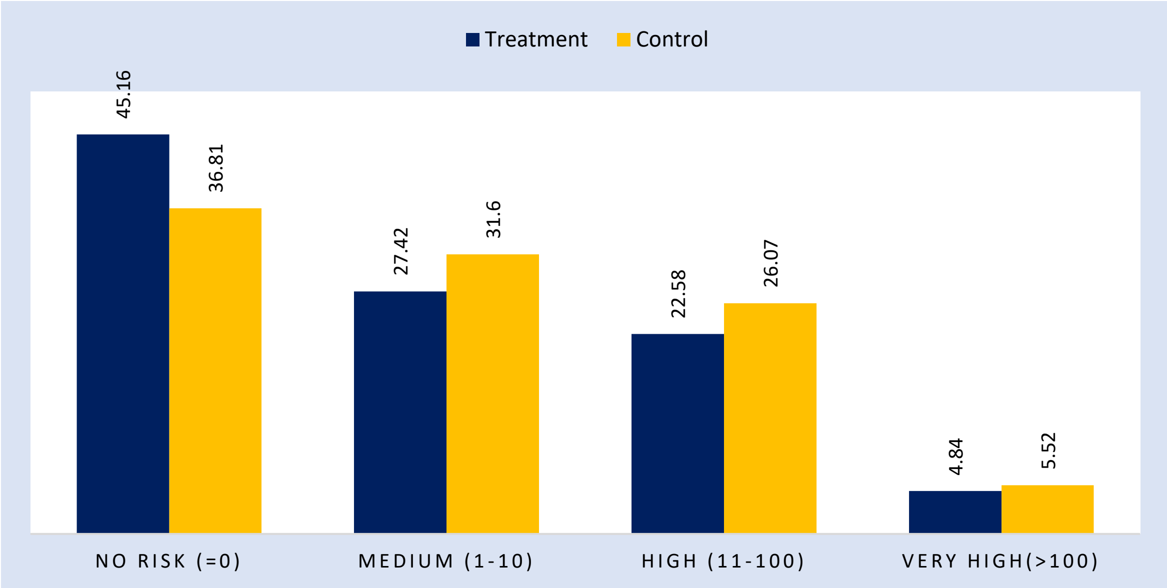


Figure 3.9: Percentage of households under different risk level for food preparing utensils fecal contamination based on *E. coli* cfu counts.
Fisher's exact = 0.338.
Source: Primary data- microbiological survey, 2014.

3.3.4 Sanitation facilities

The study areas had low sanitation coverage. Only 68% of the households had improved sanitation, which comprised 75% of the households in the treatment group and 63% in the control group (Table 3.3). Almost 17% of the households used hanging toilets, and 15% of the households still practiced open defecations. Only less than 1% of all households used community toilets. 21% of the households in the control group practiced open defecation, while only 4% of the treated households did so. The difference between the treatment and control groups was statistically significant at the 1% level (Table 3.2).

Table 3.2: Sanitation facility by treatment and control households

	Total		Treatment		Control	
	N	%	N	%	N	%
Open defecation	77	15.04	8	4.3	69	21.17
Hanging toilet (fixed place)	86	16.8	36	19.35	50	15.34
Pucca/ bricked toilet (unsealed)	159	31.05	59	31.72	100	30.67
Sanitary toilet without flush (water sealed)	186	36.33	80	43.01	106	32.52
Sanitary toilet with flash (water sealed)	2	0.39	1	0.54	1	0.31
Community latrine	2	0.39	2	1.08	0	0
Total	512	100	186	100	326	100

Source: Primary data- baseline survey, 2014. Fisher's exact = 0.000

3.3.5 Hygiene practices

Many of the households in the study areas had inadequate hygiene. Only 68% of the households reported regularly washing their hands with soap after using the toilet. Very few (only 3%) households reported actually washing their hands with soap before feeding their children (Table 3.3). The difference between the treatment group and the control group in terms of handwashing practices was statistically significant. Around 76% of the treated households reported washing their hand with soap after using the toilet; in comparison, 64% of the control households did so. Similarly, 5% of the treated households said that they washed their hands with soap before feeding their child, while 2% of the control households reported doing so. The difference between the two groups is statistically significant.

On average, the households in the treatment group used more soap than those in the control group. The per capita soap consumption in the study areas was merely half a bar of soap (approx. 50 g) per month. Besides, households rarely cleaned their water container with soap. Only 26% households did so regularly, which consisted of 32% of the treated households and 22% of the control households. The difference between the two groups is statistically significant.

3.3.6 Child diarrhoea and medical expenditure

Child diarrhoea could result from unimproved water, unimproved sanitation and poor hygiene practices and may have long-term consequences on child's development. Diarrhoea cases in under-five children living in the study areas were recorded for a month, and it was observed that child diarrhoea was not highly prevalent in the areas. Only 13% of the households reported diarrhoea cases in their under-five children, which comprised 11% of the treated households and 14% of the control households (Table 3.3). There was no significant differences between the treated and control households in terms of diarrhoea incidence. The treated households generally invested more money in adult and child health than the control households. On average, a treated household spent BDT 578 monthly on treating illness in under-five children, whereas the control household spent BDT 519 for this purpose. A treated household spent an average of BDT 4703 every year on adult healthcare (older than five years old), while this figure was BDT 3994 for the control households. In terms of the amount of money spent on healthcare, the difference between the two groups was not statistically significant.

3.3.7 Water collection burden

It is mostly women who took up the duty of collecting water for the entire household. Women were tasked with collecting drinking water in almost 97% of the households. Although they did not have to spend much time on collecting water (only 12.77 minutes on average), the activity is still a burden on them. Notably, the women in a treated household spent around half as much time as those in a control household on collecting drinking water.

Table 3.3: Summery statistics

Variable	Total (N=512)	Treatment (N=186)	Control (N=326)	P-value (treatment =control)
Household Characteristics				
Female headed households (dummy)	1%	0.5%	1.2%	0.45
Age of household head (years)	35.26	35.24	35.27	0.98
Completed years of schooling of household head	4.64	5.73	4.01	0.00
Maximum completed schooling in the household	7.77	8.49	7.36	0.00
Household size	4.72	4.92	4.61	0.05
Total number of male in the household	2.36	2.44	2.31	0.24
Total number of female in the household	2.36	2.48	2.30	0.06
female/male ratio	1.27	1.27	1.27	1.00
Household head currently married (dummy)	98%	98%	98%	0.81
Household occupation: wage earning (dummy)	52%	42%	57%	0.00
Household occupation: agriculture (dummy)	57%	59%	56%	0.47
Household occupation: non-agriculture (dummy)	48%	58%	42%	0.00
Total land (in acre)	0.69	0.96	0.54	0.01
Total agricultural land (in acre)	0.55	0.77	0.42	0.01
Total free land (in acre)	0.005	0.004	0.006	0.38
Number of Livestock	15.30	19.31	13.02	0.13
Number of cows	1.21	1.24	1.20	0.78
Number of goat	0.92	0.92	0.91	0.93
Number of poultry	9.09	9.67	8.75	0.41
Number of shared livestock	0.18	0.16	0.20	0.52
Food expenditure (BDT)	59692.67	65786.71	56215.71	0.00
Non-food expenditure (BDT)	39915.68	49469.15	34464.92	0.00
Total expenditure (BDT)	110835.40	121502.20	95411.55	0.00
Per capita expenditure (BDT)	23543.75	24828.40	20554.05	0.00
Participants of Microfinance programme (dummy)	48%	46%	49%	0.54
Duration of membership (years)	3.91	4.52	3.58	0.10
Household savings (BDT)	36729.38	43737.03	32731.15	0.17
Irrigating households (dummy)	63%	61%	63%	0.62
Sanitation				
Access to improved sanitation (dummy)	68%	75%	63%	0.01
Annual cost for maintaining a toilet (BDT)	258.20	334.25	214.82	0.32
Water				
Access to improved drinking water (dummy)	96%	99%	94%	0.00
Annual cost for water (BDT)	231.61	631.61	3.39	0.00
Time spend to collect drinking water in a day (minute)	12.77	8.09	15.46	0.00
Draw water with a mug from jar (dummy)	35%	37%	34%	0.44
Size of the water container (liter)	17.78	23.47	14.54	0.00
Minutes to collect drinking water	4.6	3.9	5.1	0.0
100ml drinking water *E.coli* count (cfu)	44.52	50.79	40.93	0.43
100ml drinking water *Coliform* count (cfu)	400.61	421.55	388.68	0.40
E.coli count in the food utensils (cfu)	36.47	25.48	42.77	0.22
Coliform count in the food utensils (cfu)	78.12	65.44	85.38	0.28
Presence of *E. coli* in the 100 ml water (dummy)	78%	75%	80%	0.16
Presence of *Coliform* in the 100 ml water (dummy)	97%	99%	97%	0.11
Presence of *E. coli* in food preparing utensils (dummy)	60%	55%	63%	0.06
Presence of *Coliform* in food preparing utensils (dummy)	94%	94%	93%	0.71
Disease				
Child diarrhoea in last month (percentage) (dummy)	13%	11%	14%	0.24
Annual disease cost for adult (BDT)	4251.14	4702.53	3993.59	0.46
Monthly disease cost for children (BDT)	540.5	577.98	519.13	0.63
Hygiene				
Hand wash with soap after coming from toilet (dummy)	68%	76%	64%	0.01
Hand wash with soap before feeding child (dummy)	3%	5%	2%	0.05
Clean water container with soap (dummy)	26%	32%	22%	0.02
Total soap consumed per month (number, 1 soap =100gr.)	2.31	2.67	2.11	0.00
Per capita soap consumption per month (number)	0.51	0.56	0.48	0.00

Source: Primary data- baseline survey, 2014.

3.3.8 Child anthropometrics

Children in the treatment and control groups had similar height-for-age z-score and weight-for-age z-score. But children in the treatment households were better off than those in the control households in terms of their weight-for-height z-score and BMI z-score, as evident in the scores that are statistically significant from zero.

Table 3.4: Child anthropometrics by treatment and control households

	Mean (N=569)	Treatment (N=207)	Control (N=362)	P-value
Height-for-age z-score	-1.57	-1.59	-1.56	0.85
Weight-for-age z-score	-1.50	-1.40	-1.56	0.10
Weight-for-height z-score	-0.88	-0.72	-0.97	0.01
BMI z-score	-0.74	-0.59	-0.83	0.02
Stunted	36%	34%	37%	0.48
Severely stunted	10%	10%	10%	0.89
Underweight	32%	27%	36%	0.03
Severely underweight	7%	7%	7%	0.76
Wasted	13%	11%	14%	0.40
Severely wasted	2%	2%	2%	0.87

Source: Primary data- baseline survey, 2014.

In the study areas, 36% of the children exhibited stunted growth and 10% were severely stunted (Table 3.4). Furthermore, 32% of the children were underweight; the treatment group had a lower percentage of underweight children (27%) than the control group (36%). The difference between these two groups was statistically significant in terms of the prevalence of underweight children. The percentage of severely underweight rate was similar in both groups (around 7%). Among the households surveyed, 13% of the children were found to be wasted.

3.4 Theory and Methods

3.4.1 Theory and Assumptions

This paper is developed based on the "Theory of Change" which explains the process of change by outlining the causal linkages (short-, medium- and long-term outcomes) of an intervention in a societal setting. Logical relationships are used to generate outcome pathways. Theory of Change has been discussed much in literature, including Anderson and Harris (2005), James (2011), and Stern et al. (2012). The steps to build a Theory of Change include (1) defining interventions, objectives and outcomes; (2) laying out the main steps in a causal chain, (3) Identifying the underlying assumptions, (4) adding a temporal dimension, (5) identifying the key evaluation questions, and (6) validating and revising.

This analysis is based on a Theory of Change that assumes that piped water improves health and productivity (Figure 3.10). This causal link works through investment in the water, sanitation and hygiene infrastructures which, in the short term, results in lower child diarrhoea incidence, reduction in time used for water collection, and clean kitchen utensils. The long-term outcomes are improved physical development in under-five children (i.e., lower prevalence of stunting, underweight and wasting) and higher productivity (fewer sick days). In any Theory of Change, there are always some assumptions to simplify the model.

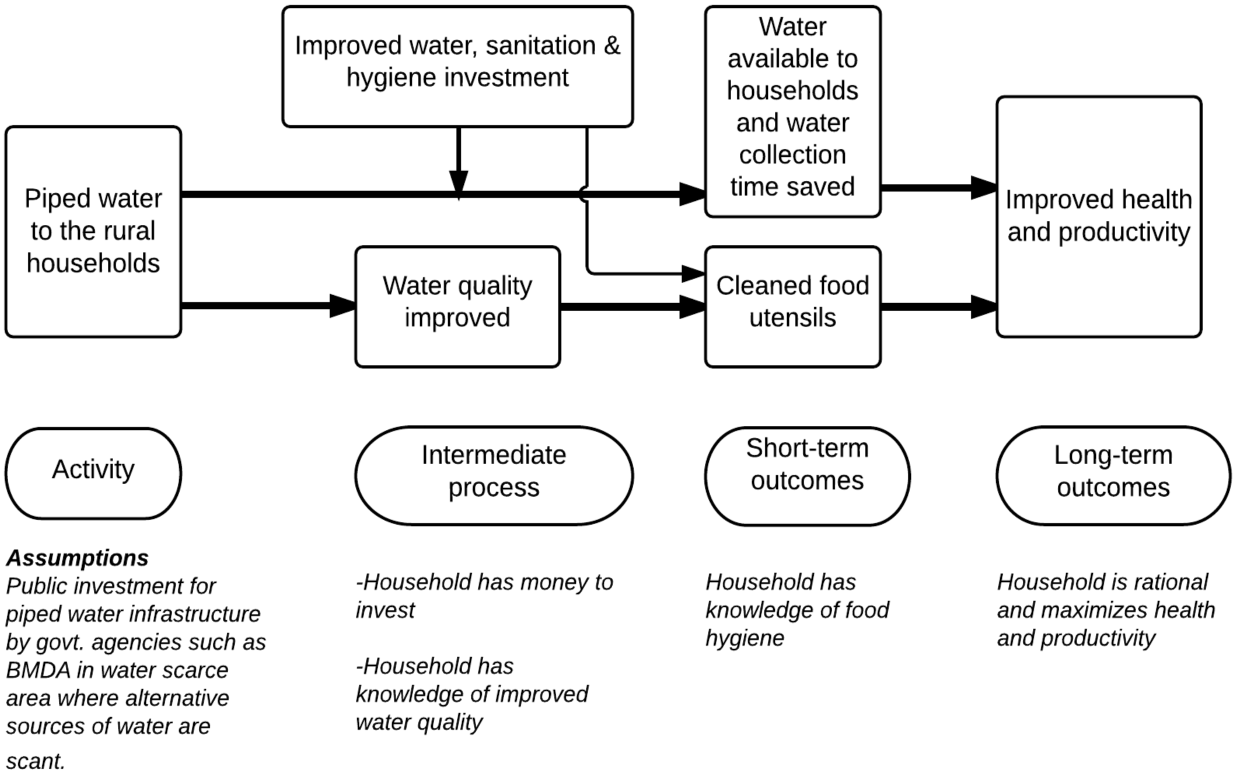


Figure 3.10: Theory of Change- impact pathways.

Source: Authors' calibration

3.4.2 Propensity Score Matching (PSM)

Propensity score matching (PSM) was used to estimate the causal effects of piped water on child health in a cross-sectional sample without random placement. In this study, the placement of the treatment (piped water) was not random. The BMDA established its piped-water network based on community needs and geographical location. So the households' access to piped water is endogenous and estimating ordinary least square (OLS) will generate biased results. Although both OLS and PSM require conditional independence assumptions, PSM, unlike OLS, does not need a parametric model and therefore allows mean impacts to be estimated without the arbitrary assumptions of functional forms and error distributions (Jalan and Ravallion, 2003). The instrumental variable estimator (IVE) could also have been used, but it also requires the conditional independence assumption, which cannot be tested. The

IVE requires an exclusion restriction, which is not satisfied by using a single cross-sectional data set but rather requires longitudinal data (Jalan and Ravallion, 2003). PSM confines its attention to matched sub-samples by dropping unmatched comparison units from the analysis and therefore differs from regression methods, which requires the use of the full sample. Impact estimation using the full sample can lead to more biased results and is less robust for specifying the regression function (Rubin and Thomas, 2000).

The PSM technique is increasingly used as a tool for program evaluation (Caliendo and Kopeinig, 2008; Heinrich, Maffioli, and Vazquez, 2010). This technique matches individuals in the treatment group with "identical" individuals in the control group based on observable characteristics. Then, to determine treatment effects, participating households are matched with non-participating households with similar "propensity scores" using some weights. A propensity score is the conditional probability of being assigned to a specific treatment given a set of observed covariates. In this paper, a probit regression model was used to estimate propensity scores.
The treatment here is

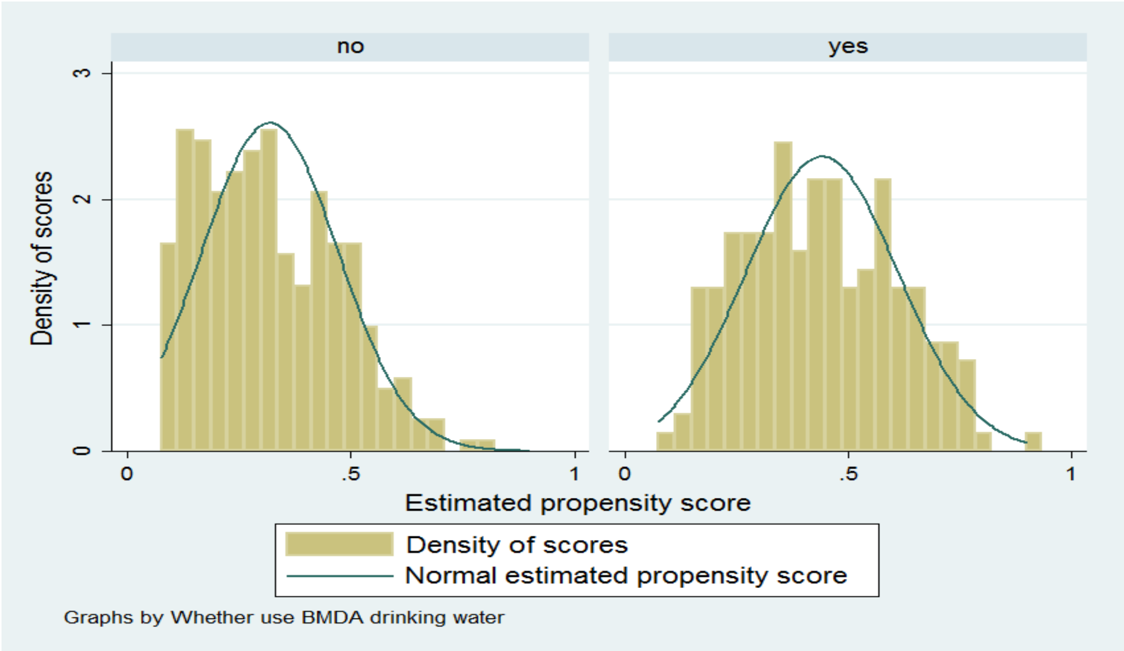
$$y_i = bmdause = \begin{cases} 1 & if\ households\ uses\ piped\ water\ from\ BMDA \\ 0 & if\ household\ doesn't\ use\ piped\ water\ from\ BMDA \end{cases}$$

Here, the outcome of using piped water is denoted by y_1 and the outcome of not using of piped water $(bmdause=0)$ by y_0. The impact can be observed in the average treatment effect on the treated (ATT), which is defined as

$$ATT = E(y_1 - y_0 \mid \text{bmdause} = 1) = E(y_1 \mid \text{bmdause} = 1) - E(y_0 \mid \text{bmdause} = 0) \text{ ...... (1)}$$

The first term of Eq. (1) is observable, whereas the second term is non-observable because it is impossible to consider an individual to be a recipient and non-recipient simultaneously. A comparison group with similar observable characteristics can be created using PSM to eliminate this problem when estimating the ATT.
The Stata command "pscore" (Becker and Ichino, 2002) was used to estimate the propensity score. Table 3.3 shows the households characteristics and other covariates that were considered. The first step was to estimate the propensity score so that it satisfied the balancing property: this program generates five blocks of observations, ensuring that the mean propensity score of the treatment group and the control group are the same in each blocks. The balancing property was satisfied in the program, and this guarantees that the treatment group and the control group had balanced (similar) covariates within the five blocks. Stata identified the region of common support from the estimated propensity scores of the two groups, ensuring that any combinations of observed characteristics among the treatment households can also be found among the control households (Caliendo and Kopeinig, 2008). The region of common support was determined by the program to be

[0.11256162, 0.89771079], which was the common area of the estimated propensity scores of treatment and control group. Within the region of common support, the estimated propensity score of the treatment group ranged from a minimum of 0.1125616 to a maximum of 0.8977108, and the propensity scores of the control group ranged from 0.1145692 to 0.7893264 (Figure 3.11).



Control group *Treatment group*

Figure 3.11: Estimated propensity score for treatment and control groups
Source: Author's calculation.

After estimating the propensity scores, three types of matching were used to evaluate the impact of piped water on different outcomes. The types of matching used were nearest-neighbor matching, stratification matching and kernel matching. The different types of matching have different advantages. Further, the regression-based nearest-neighbor matching was also implemented to check the robustness of the results. The Stata command "nnmatch" (Abadie, Drukker, Herr, and Imbens, 2004) was used for the analysis. In nearest-neighbor matching, a household in the control group was chosen as a matching partner for a household in the treatment group based on their closest propensity score. Matching "with replacement" was used here to reduce the biasness and increase the average quality of the matching estimator (Smith and Todd, 2005). Stratification matching works by partitioning the common support of the propensity scores into a set of strata and calculating their impact in each strata (P. Rosenbaum and Rubin, 1983). Kernel matching, on the other hand, is a non-parametric matching estimator that uses the weighted average of all households in the control group to construct the counterfactual outcome. The advantage here is the use of more variance as a result of using more information (Caliendo and Kopeinig 2008).

PSM eliminates only biasness in the treatment effect resulting from observable heterogeneity. One may argue that unobserved heterogeneity (hidden bias) could also impact the treatment effect, and thus matching estimators are not robust enough against this hidden bias (Caliendo and Kopeinig, 2008). Since the magnitude of selection bias is impossible to estimate, the sensitivity analysis proposed in “Rosenbaum Bounds” (Rosenbaum 2002) had to be implemented. The method shows how strongly unobserved variables might affect the selection process and undermine the implication of a matching analysis. If an outcome of interest is found to be non-sensitive, the results produced from matching estimates would suffice for impact evaluation. For continuous outcome variables, the Stata command “rbounds” (DiPrete and Gangl, 2004) was used, and for the binary outcome variables, the Stata command “mhbounds” (Becker and Caliendo, 2007) was used, which is based on the bounds by Mantel and Haenszel (1959).

3.5 Impact estimates

The impact of piped water access on the rural households was analyzed in terms of water-sanitation quality, hygiene practices and child health. The results are based on two types of analyzing units: a household-level analysis (Table 3.5) and an individual-level analysis (Table 3.6). The PSM for these two categories was first done using different matching techniques (nearest-neighbor, stratification and kernel matching) and subsequently using a regression technique based on the nearest-neighbor method.

The impact of the treatment is shown for each outcome of importance in the three categories (water-sanitation facilities, hygiene behaviour and health outcomes) in the ATT and coefficient columns in Table 3.5 and Table 3.6. As mentioned earlier, the impact was estimated using three different matching algorithms and subsequently a regression-based technique as a robustness check. For most of the results discussed below, the estimates were rather robust across the estimation techniques, as evident in the number of statistically significant impacts.

3.5.1 Impact on water quality, water access and cooking utensils

In this category of variables, there are two direct determinants of health: the microbiological quality (*E. coli* or general coliforms) of (1) drinking water and (2) kitchen utensils. The results obtained using all three estimation techniques showed that using piped water did not have any statistically significant impact on these two indicators.

Water quality was not improved due to piped water use. The *E. coli* counts in 100 ml of drinking water found in the treated households were not significantly lower than those found in the control households. The results produced by the three types of matching techniques were almost consistent. The p-value of the difference between the drinking water *E. coli* counts was not significant.

Table 3.5: Impact of access to BMDA piped water on different outcome variables based on Propensity Score Matching

Outcome variables	Nearest-Neighbour Matching[b] (Treatment=186; Control=116)		Stratification Matching (Treatment =183; Control =328)		Kernel Matching[b] (Treatment =186; Control =325)		Regression based nearest-neighboring matching (N=512)	
	ATT	SE	ATT	SE	ATT	SE	Coefficient	SE
Water-Sanitation facilities								
Access to improved sanitation	0.065	0.06	0.027	0.04	0.03	0.04	-0.00	0.06
Access to improved drinking-water	0.027	0.03	0.05***	0.02	0.048***	0.01	0.06**	0.02
Time to collect drinking water (min/day)	-5.89***	2.02	-6.73***	1.56	-6.931***	1.76	-9.35***	2.21
100ml drinking water E. *coli* count (cfu)	1.94	33.35	2.18	17.6	-0.251	18.14	-25.12	23.26
100ml drinking water Coliform count (cfu)	98.21	47.37	30.73	41.83	24.53	43.92	-23.64	52.03
E. *coli* count in the food utensils (cfu)	-43.55	22.09	-12.5	13.11	-14.27	13.31	2.61	17.35
Coliform count in the food utensils (cfu)	-32.175	25.1	-17.44	17.97	-20.18	16.43	-19.3	25.44
Distance of drinking water source (meter)	-0.645**	0.16	-0.56***	0.12	-0.57***	0.11	-0.45***	0.14
Drinking water container capacity (litre)	7.82*	3.73	8.7**	3.91	8.36**	3.52	8.55*	4.25
Water cost (BDT)	630.6***	40.42	615.03***	41.71	628.12***	43.11	632.60***	50.36
Hygiene situation								
Hand wash with soap after toilet (%)	0.097	0.06	0.049	0.04	0.053	0.04	0.06	0.05
Hand wash with soap before feeding child	0.038	0.03	0.035	0.02	0.035*	0.02	0.03	0.02
Clean water container with soap	0.075	0.06	0.056	0.05	0.058	0.04	-0.03	0.06
Total soap consumption per month	0.21	0.14	0.224	0.12	0.253*	0.11	0.24	0.15
Health outcomes								
Child diarrhoea in last one month (age<59months)	-0.011	0.03	-0.006	0.03	-0.024	0.03	-0.00	0.04
Cost for illness for adults (Thousand BDT)	-0.109	1.35	-0.786	0.79	-0.104	1.22	0.00	1.18
Cost for illness for children (Thousand BDT)	0.041	0.12	0.035	0.14	0.072	0.12	0.06	0.18

Source: Authors' calculation based on primary data. [b] represent Bootstrapping 50 times. Matching variables are: *Household savings, per capita expenditure, number of livestock, number of cow, number of goat, number of poultry, total land, wage earning households, agricultural household, non-agricultural household, age of household head, household size, electricity, distance from road, distance from small market, distance from big market, distance from health center, distance from town.* note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.6: Impact of access to piped water on child growth based on Propensity Score Matching

Child health outcome	Nearest-Neighbour Matching[b] (Treatment=207; Control=139)		Stratification Matching[b] (Treatment=207; Control=356)		Kernel Matching[b] (Treatment=207; Control=356)		Regression based nearest-neighboring matching (N=569)	
	ATT	SE	ATT	SE	ATT	SE	Coefficient	SE
Height-for-age z-score	-0.010	0.164	-0.077	0.102	-0.076	0.100	-0.04	0.15
Weight-for-age z-score	0.138	0.117	0.083	0.103	0.102	0.100	0.12	0.13
Weight-for-height z-score	0.184	0.170	0.173	0.113	0.195	0.109	0.21	0.13
Stunted (dummy)	0.006	0.068	0.015	0.039	0.003	0.043	0.01	0.06
Severely Stunted (dummy)	0.010	0.034	0.013	0.025	0.007	0.028	0.03	0.04
Underweight (dummy)	-0.053	0.050	-0.065	0.050	-0.071*	0.037	-0.07	0.05
Severely underweight (dummy)	0.010	0.030	0.003	0.029	0.001	0.021	0.01	0.03
Wasted (dummy)	-0.012	0.037	-0.018	0.030	-0.022	0.030	-0.07	0.04
Severely wasted (dummy)	0.014	0.014	0.007	0.010	0.004	0.012	0.01	0.01

Source: Authors' calculation based on primary data. [b] represent Bootstrapping 50 times. Matching variables are: *Household savings, per capita expenditure, number of livestock, number of cow, number of goat, number of poultry, total land, wage earning households, agricultural household, non-agricultural household, age of household head, household size, electricity, distance from road, distance from small market, distance from big market, distance from health center, distance from town.* note: *** p<0.01, ** p<0.05, * p<0.1

The same was also true for the coliform counts in drinking water. This means that there was no significant difference between the microbiological quality of drinking water samples obtained from households with piped water and those without piped water. The microbiological quality of kitchen utensils was not significantly improved by using piped water (Table 3.5). The results obtained using the regression-based matching technique were also consistent in terms of all water- and food-quality variables; the regression-based matching technique yielded insignificant p-values. The only statistically significant variable was the access to improved water. The matching-based methods as well as regression-based method yielded statistically significant difference in access to improved water. Access to piped water increased percentage of households with access to improved water by 5% (at the 0.01 significance level) in both the stratification matching and kernel matching methods. In the regression-based model, the increase in access to improved water was estimated to be 6 percent at the 0.05 significance level.

An important and direct benefit of using piped water is time saving. The three PSM techniques yielded similar estimated time savings. With access to piped water, a treated household could save approximately 6 minutes (nearest-neighbor matching), 6.7 minutes (stratification matching) or 7 minutes (kernel matching) daily when fetching water (Table 3.5); the results were all statistically significant. Using the regression-based technique, a household was estimated to save 9 minutes a day because of access to piped water. Although the time saving was not substantial, access to piped water also had other implications on the treated households, such as shorter distances to water collection point and hygiene issues. The treated households needed to travel shorter distances than the control households to their nearest drinking water source. A treated household had to travel approximately 0.6 m less than a control household to collect water, depending on the matching technique used for estimation; the results were statistically significant. The regression-based technique estimated that a household had to travel 0.5 m less than a control household to collect water.

Access to piped water also significantly increased water storage capacity. Households in the treatment group generally used more containers for storing water than those in the control group. It was found that access to piped water increased a household’s water storage capacity by between 7.8 and 8.7 liters, depending on the matching technique used for evaluation; the results were all statistically significant. The treated households’ tendency to store more water could be a result of water rationing in the areas with access to piped-water network. Similar results were obtained using the regression-based model; a treated household’s water storage is about 8.6 liters larger than that of a control household (Table 3.5). In the low and middle income countries, non-continuous water supply contributes to more water storage and possibly more bacterial growth in the storage (Brown et al. 2013). In this case improved water storage intervention may retain the water quality (Günther and Schipper 2013). Households with access to piped water also paid more for water than those without access to piped water. Using the three matching techniques, it was estimated that a treated household paid between BDT 615 and BDT 630 more for their water consumption (Table 3.5). The regression-based model showed a similar result (BDT 633); the result is statistically significant at the 0.01 level (Table 3.5). Sanitation was also an important aspect. It was observed that access to piped water did not significantly increase the access to improved sanitation among the treatment group. It was expected that piped water would positively influence access to improved sanitation, especially in terms of access to flush toilets or other improved toilets.

3.5.2 Impact on hygiene practices

Water and hygiene are very much related because improved water is essential to proper hygiene practices. Therefore, the study also looked at how access to piped water changes hygiene behaviour. It was found that access to piped water did not significantly increased the likelihood of a household practicing proper handwashing (i.e., with soap) after using toilet and before child feeding. The different matching techniques gave different estimates of the improvement in handwashing practices before child feeding where only kernel matching estimated a 3.5% improvement at 10% significance level (Table 3.5). This result is not consistent with the other estimated results and we can't say that the handwashing with soap before feeding child has been improved due to piped water use.

In terms of other hygiene indicators, such as cleaning water container with soap and monthly soap consumption, the treatment group and the control group did not show any statistically significant difference in all types of analyses. The only exception was the difference between the monthly soap consumption of a treated household and that of a control household as estimated using the kernel matching method.

3.5.3 Impact on health

In this study, impact on health was measured in terms of child diarrhoea incidence, the cost of treating children and the cost of treating adults. Unlike the study by Klasen et al. (2012), none of the analyses found significant difference between the treatment group and the control group in terms of child diarrhoea incidence; that is, the t-statistics and the p-value were not statistically significant (Table 3.5). The same was true for the cost of treating children and adults. Access to piped water did not significantly reduce the amount of money spent on treating illnesses in children and adults.

3.5.4 Impact on child growth

Child growth is a measure of the nutritional status of under-five children. Improving child growth is an important goal of providing piped water to rural households. Access to piped water did not have any significant impact on any of the child growth indicators measured (Table 3.6). The difference in height-for-age z-score, weight-for-age z-score and weight-for-height z-score between the treatment group and the control group were not statistically significant in our analysis. Even following the WHO z-score classification system, it was found that no statistically significant difference was observed between the treatment group and control group in the categories of child growth indicators (such as stunting, severe stunting, severely underweight, wasting, severe wasting).

3.5.5 Sensitivity analysis

A sensitivity analysis is performed to check how strongly unobserved variables affect the selection process either causing an under- or overestimation of the matching results. In our sensitivity analysis, the p-value was not exactly the same as the matching results and as the different matching pairs because of outliers. The sensitivity analysis was conducted using Rosenbaum bounds. The results for continuous and binary variables are reported separately. For the continuous outcome variables, only the significant variables from matching results are shown in Table A. 7.6. The analysis was based on the assumptions that (1) there was no unobserved confounder due to selection bias and (2) all relevant characteristics were matched so that the treatment group and the control group both had the same basis for analysis. When gamma equals one and the p-value is significant, it implies that there is no hidden bias due to unobserved confounder. For the variable water collection time, the upper and lower bounds remained equal. But if the gamma is increased to two (i.e., if the odds of a household being in the piped water programme are doubled because of different values of unobserved factors), despite being identical in the matched covariates, the inference in the upper bound remains significant but the lower bound fails to hold it significance level. So if the gamma is doubled, some unobserved factors may have affected the impact.

The result obtained by calculating with different gamma values shows the level of sensitivity of the produced results, but it does not imply that unobserved heterogeneity exists and there is no effect of treatment on the outcome variables (Becker and Caliendo, 2007). The result only show the confidence interval of the treatment effect would include zero if the odds ratio of the treatment assignment differs between the treatment and control groups by the gamma value. One should be cautious while interpreting the result of the matching analysis and the sensitivity analysis. For example, water collection time shows if gamma is equal to one then the result is significant but if the gamma is doubled then it losses its significance level. The Hodges-Lehman Point estimate supports the result of significance level which shows both the upper and lower bounds changes its sign if gamma is doubled, which means that the result is sensitive when the odds are doubled. The sensitivity analysis of the variables “distance of drinking water source” and “drinking water container capacity” followed the same trend as the analysis of the variable “time to collect drinking water”. On the other hand, the sensitivity analysis of the variable “water cost” indicated that the matching results were not sensitive to unobserved factors or that the variable was not affected by hidden bias. For the individual-level analysis of child anthropometrics (Table A. 7.8), the results of its sensitivity analysis have to be interpreted in a similar way. It is notable that the lower bounds of the two variables “weight-for-age z-scores” and “weight-for-height z-score” couldn’t hold significance level when gamma value was increased to two.

For the sensitivity analysis of the binary variables, Mantel-Haenszel statistics is shown with its significance levels in Table A. 7.7 and Table A. 7.9. The variable “access to improved drinking water” was explicitly sensitive when the gamma value was doubled but underestimated. This shows that there might some unobserved heterogeneity or hidden bias for this variable. The impact on the variable “handwashing with soap before feeding” became insignificant when gamma was one; as gamma increased to 1.2, the impact became insignificant when gamma is 1.7 and at 2 it is still significant but underestimated. This variable was non-sensitive in the beginning but became sensitive at higher gamma (Table A. 7.7). For the variable “percentage of underweight children” (Table A. 7.9), the result was significant at all values of gamma. The result of sensitivity does not necessarily mean that there is no treatment impact on this variable, but rather it shows that the result becomes sensitive at different values of gamma. So one should be cautious when interpreting the results of the sensitivity analysis and its relation to matching results.

3.6 Discussion of results and policy implications

Groundwater is the only source of potable water in Bangladesh. In north-western Bangladesh, groundwater is becoming scarcer as it is depleting at a high rate (Figure 3.1). Many households use piped water supplied by the BMDA, which charges the households a nominal fee per month for the service. Other sources of public piped water obtained from deep tube wells are community tube well and private tube wells. Many households that use piped water from the BMDA complained that the BMDA rations water. Households get discontinuous water supply and hence store water for later use. The water supplied by the BMDA is generally clean and originates from deep tube wells. However, piped-water rationing may encourage households to practice unhygienic water handling and storage. The data in this study did not capture the frequency and amount of water rationing.

The study results suggest that supplying piped water to the marginalized communities as a form of public intervention could improve access to improved water and reduce the time a household spent collecting water, but it could not guarantee water quality at the point of use. Similar results were also found by Devoto et al. (2012). The level of *E. coli* in drinking water was not significantly improved by having access to piped water. Similarly, the microbiological quality of kitchen utensils also did not improve with access to piped water; there was no significant difference the level of *E. coli* on kitchen utensils between the treatment group and the control group. Therefore, access to piped water by itself cannot ensure good microbiological quality in water and on kitchen utensil. Piped water needs to be treated before it is consumed or used for washing kitchen utensils. For example, boiling or filtering piped water can reduce the level of *E. coli* in water. The knowledge of proper hygiene practices needs to be improved in the rural households to ensure that their drinking water and kitchen utensils are safe for use. This study also found that the treated households tended to store more water than the control households. Because improper water storage may offer a conducive environment for bacterial growth, proper handling of water storage containers and regularly cleaning the container with soap may help reduce the risk of water contamination. However, this is not the main focus of the paper.

The risk of child diarrhoea and other waterborne diseases could be reduced by ensuring that water and food are safe for consumption. But the study showed that under-five children in a household with access to piped water generally didn't have better weight-for-age and weight-for-height z-scores than their counterpart in a household without access to piped water. This finding contradicts the study by Briscoe et al. (1986). The percentage of underweight children in the treated group was also lower than that in the control group. Under-five children in the treated group were also less likely to be underweight than their counterpart in the control group. However, this result is only significant at 10% level in Kernel matching, other matchings do not show any significant results which implies the lack of consistency. However, access to piped water did not offer any advantage in terms of increasing access to improved sanitation, improving the microbiological quality of water and kitchen utensils, improving handwashing practices after defecation, lowering child diarrhoea incidence, decrease the cost of treating illness and, more importantly, reducing the prevalence of stunting and wasting in under-five children. This paper also investigated other possible gains from having access to piped water, such as the quantity of water use, the amount of leisure time, the number of working day lost, and school absenteeism. However, no statistically significant difference was found in any of these variables. Also, the data for these variables are not available for all observations, which restricted the analysis to only some of the outcome variables.

3.7 Conclusion

Access to piped water generated a positive impact on access to improved water and significantly reduced the amount of time a household spent collecting drinking water. However, access to piped water by itself could not ensure adequate drinking water quality at the point of use because the treatment households tended to store piped water in reaction to discontinuous water supply. Using the level of *E. coli* and coliforms as measures of microbiological quality, the study found that access to piped water did not have any significant impact on the microbiological quality of drinking water and of kitchen utensils. Therefore, proper household hygiene practices and good drinking water supply management are vital for maintaining drinking water quality at the point of use. This raises the question of how much piped water does a household need to be able to stop using water from unsafe sources and therefore improve their food and water hygiene. Unfortunately, the data collected for study is inadequate for addressing this particular issue.

Hygiene practices among household members did not get improved in the treatment group. Washing hands before feeding child and after defecation are not significantly different in the treated and control group. Monthly soap consumption among the treated households remained low and was not significantly improved compared to the control households. This hints that the root cause of contaminated household drinking water may be improper hygiene practices. Further, dirty water storage containers may have also contributed to unsafe point-of-use drinking water. A water storage container may be improperly cleaned because of its design. For example, a container may have an open mouth, allowing water to easily contaminated, or be too narrow to be properly cleaned. However, the study data does not allow us to explore this issue further. The results also showed that a treated household tended to have a larger water storage capacity than a control household, which makes proper cleaning of water containers even more important. Although a piped-water connection does not ensure good water quality, households still have to pay for the piped water. As a result, a treated household spent significantly more on water services than a non-treated household.

Access to piped water did not bring about any significant immediate impact on health. Diarrhoea incidence in under-five children was not significantly reduced by having access to piped water. Also, the cost of treating illnesses in adults and children was not significantly lower in the treatment group. The short-term health impact of piped water may also manifest itself in fewer sick days and fewer days of school absence. However, no significant difference was found in these two variables between the treatment and control groups. This could have been caused by the following reasons: First, the data on the number of days under-five children were absent from school because of water- and sanitation-related diseases were limited as children start school at the age of five or six. Second, the data on the number of sick days taken by adults due to waterborne diseases were limited because of its low prevalence. This paper also found no significant changes in the number of working hours and the amount of leisure time between the treatment and control groups. The time saved by not having to travel to a distant water source was not reflected in an increase in leisure time. Hence, this paper adheres strictly to analyzing daily time spent by a household on collecting water.

We also observed the long-term health impact of piped water in child anthropometrics. It was found that under-five children in the treatment group had similar anthropometric measures, for example- weight-for-age, weight-for-height and height-for-age z-scores than their counterpart in the control group. These observations indicated that access to piped water couldn’t improve the long-time development of under-five children, which is the expected outcome of a water-sanitation intervention. Similarly, the two groups did not show any significant difference in terms of the prevalence of stunting, underweight and wasting among under-five children. However, both type of measurements show the similar results.

Overall, the BMDA piped water project has been a success because the state supplies water to some marginalized households in rural areas, where water availability is low. Access to piped water generated much benefit, such as improving access to improved water, decreasing the amount of time spent on collecting water, decreasing the distance to a drinking water source. Despite not having a significant impact on health outcomes, the piped water network has brought about significant water infrastructure, and therefore we recommend that the government should expand the piped water network to other marginalized communities.

Chapter Four

4 Behavioural change investment through food hygiene education: a Randomized Controlled Trial (RCT) experiment in rural Bangladesh

4.1 Introduction

The latest estimates published by UNICEF and the WHO indicate that almost 91% of the world's population have access to improved drinking water and 67% to improved sanitation (United Nations 2015). Despite the progress in terms of access to improved water and sanitation, diarrhoea causes 8.9% of total child deaths annually in the world (WHO 2016). Even diarrhoea related morbidity for children under-five is a chronic root cause of low productivity in the later stage (Keusch et al. 2006). Contaminated water, either at POU or Point of Source (POS) is one of the main causes of diarrhoea (Nath, Bloomfield, and Jones 2006; Prüss et al. 2002b; Prüss-Üstün et al. 2008; Zwane and Kremer 2007). A large number of studies have suggested that water quality at POU is often much lower than at POS because of (re)contamination taking place, possibly during water collection transport or storage, for instance due to improper handling (Günther and Schipper 2013; Wright et al. 2004). Hence, the provision of improved water access does not necessarily produce positive health impacts (Devoto et al. 2012; Hasan and Gerber 2016; Klasen et al. 2012) or a limited impact (Waddington et al. 2009; Wright et al. 2004; Zwane and Kremer 2007).

The quality of water and food in a household can affect the nutrition status of children under-five. Food and kitchen utensils can easily be contaminated with pathogenic bacteria through washing and cooking. Food can be contaminated through preparing meals with contaminated water and dirty hands. Preparing food with unimproved or contaminated water therefore poses a serious health risk and can cause adverse health effects, including malnutrition in children. Malnutrition impairs the immune system and makes children more vulnerable to diarrhoea (van der Hoek et al. 2002). Diarrhoea has a long-term negative impact on cognitive development in young children (Keusch et al. 2006). Infants with poor nutritional intake are at higher risk of diarrhoea and malnutrition than those receiving nutritional supplementation (Javaid et al. 1991). One way of breaking the vicious cycle of diarrhoea and malnutrition is to increase the use of safe water and adequate hygiene practices. This reduces the transmission of pathogens, thereby lowering diarrhoea incidence and child mortality and improving nutritional status (Esrey 1996).

Despite the gradual decline in the undernutrition of children under-five since the 1990s, the prevalence rate remains high in Bangladesh. In 2013, 38.7 percent of children under-five were stunted, 18 percent were wasted and 35 percent were underweight (Mahmud and Mbuya 2015). According to the WHO classification of child nutrition, the current status of underweight and wasting remains in the 'very high' category.

Interestingly, the linkages between undernutrition and poverty are not obvious. Undernutrition is not only observed in the poorest segment of the income level but also in the highest level; almost 25 percent of children under-five are underweight and stunted, and 15 percent are wasted in the highest income category (Mahmud and Mbuya 2015). The underlying determinants for undernutrition remain in the domain of inadequate food security, child and maternal care and unhealthy environments, and these three factors play complementary roles (Figure 4.1). Empirical evidence shows that jointly these three determinants contribute only 13 percent of under-five stunting but separately each contributes almost 33 percent (Mahmud and Mbuya 2015). However, in the determinant 'environmental health', it is not clearly known how much is contributed by general hygiene and how much is contributed by food hygiene. Indeed, evidence of the contribution of food hygiene education in reducing child undernutrition is scant in the literature.

General hygiene plays an important role in receiving the benefits from improved water and food. Many households in rural Bangladesh have inadequate sanitation facilities and hand washing practices, especially after defecation and before eating food. 68% of the households in north-western Bangladesh reported that they wash their hands with soap after using the toilet but only 3% wash their hands before eating food (Hasan and Gerber 2016). The low rate of handwashing before eating food may result in the entry of the faecal pathogen into the human intestine and cause diarrhoea, especially in children under-five. Food hygiene behaviour of households, especially for children under-five, is very important because they are vulnerable to different health shocks. Food hygiene includes maintaining proper hygiene throughout the food preparation, processing, serving and storing. Household economics regarding food hygiene involves time, cost, knowledge and behavioural change. Interventions that target changing behaviour on food hygiene may contribute to change in health outcomes such as diarrhoea and investment in healthcare as well as water and sanitation quality. It is clear from the literature that conventional universal hygiene education messages are unrealistic, irrelevant and incomplete in the context of the local people and hence individuals do not follow the hygiene messages (van Wikj and Murre 2003). Besides the enabling factors (skill, time and means), an individual takes decisions over what guidelines to follow based on the community practices, own belief and values, existing own and community resources, attitude and external influences (Hubley 1993). So it is important to know at which level the intervention is targeted. Community level intervention may create more space for the individuals to react and also produce more spill over inside the community, which ultimately increases the social welfare. The greater effectiveness of communal behaviour to hygiene comes when the community members themselves jointly address a problem and undertake actions to permanently improve the conditions (van Wikj and Murre 2003).

The low demand for health prevention measures may be observed in the consumers because of their low perception of the possible benefit, which sometime comes many months or years after the intervention. In most cases they underestimate the health prevention measures and are less likely to follow them. When consumers underestimate the health benefits of certain behaviours, the natural response is to provide them with information of the prevention measures (Kremer and Glennerster 2011). Among the other channels, one possible effective channel through which health education affects behaviour is information. It is a common situation in which people have imperfect information and interventions are expected to work assuming that they are the rational processors of information. It is observed that households of both those who pay for the piped water and those who do not pay possess the same health outcomes and hygiene practices and fail to gain from their paid infrastructure. Payment for improved water couldn't change their perception of the health benefit over the non-payers as both of them treat their drinking water in the same way (Hasan and Gerber 2016). Both groups, irrespective of their water infrastructure, maintain the same level of inadequate hygiene which impeded them from achieving health gains. This argument is consistent with the findings of Luoto et al. (2011) who showed that effects are more likely to be driven by salience. People in the study area had knowledge of arsenic contamination of drinking water but no knowledge of faecal contamination such as pathogen bacteria (*E. coli*). They also had no prior knowledge of food utensil contamination with *E. coli* bacteria and its perniciousness. So rather than being a Bayesian decision maker (individual having prior information of a certain event) and rationally processing information, people may respond to intervention based on the salience of the contamination. Even though the information is publicly available, the assembling of information requires time and effort which is mostly expressed in the cognitive effort or attention. To take an informally demanding decision, a person requires a full model of information acquisition which considers both search and attention constraints (Pope 2006). But a limited attention model that considers the information may not be full but instead focus their attention on an incomplete choice set of available information for the individual adaptive decision. The individual may employ an informal benefit-cost analysis to impose attention optimally and most often decisions are made based on information of salience which goes beyond the dimensions of economic benefit-cost analysis (for example spatial, temporal and cultural dimensions). So in this setting, when the individual knows the level of contamination in their storage container, they can respond to the intervention of individual and communal level information. This experiment is based on the limited attention model and is expected to have a higher impact on their behaviour and other health outcomes.

It is well established that safe hygiene is the single most cost-effective means of preventing infectious disease but that investment in hygiene is low both in the health and water-sanitation sector (Curtis et al. 2011). A study in Vietnam reported that risk of diarrhoea was significantly higher for the children of those mothers who prepared food for cooking somewhere other than the table than for those who prepare on the table, based on a longitudinal study (Takanashi et al. 2009). Another study in Indonesia highlighted the role of food hygiene maintenance in lowering diarrhoea incidence in low-socioeconomic people, based on a cross sectional study (Agustina et al. 2013). However this study did not establish the causal link between food hygiene and diarrhoea and is not free from endogeneity issues. Both evidence and the observational studies show that improved hand-washing and safe stool disposal benefit health outcomes like diarrhoea. Although there is a growing understanding of the drivers of hygiene behaviour, some important gaps exist in the literature. It is noted that almost no trial of the effectiveness of intervention to improve food hygiene in developing countries are available (Curtis et al. 2011; DFID 2013). Hence, the scope for conducting an RCT of FHE is promising to establish how food-hygiene practice matters in the daily routine can achieve major gains for household health outcomes. Even with the randomization, little is known from the community level actions. To achieve a large scale behavioural change in the society, especially regarding hygiene, a community approach is recommended as individuals react based on their local knowledge, belief and community resources (van Wikj and Murre 2003). Our research makes contributions by identifying how food hygiene education affects water quality, hygiene practices, health outcomes and their interlinkages in rural households. To our knowledge, we are the first to analyse the stand-alone impact of FHE, providing the households with microbiological test results of water and kitchen utensils, training and information (in the form of a poster and explanations) in a marginalized rural setting. Our RCT experiment of food hygiene education eliminates the possible endogeneity and biasness of the intervention to investigate impacts on water quality, hygiene practices and health outcomes.

Conceptual framework

To address the determinants of child undernutrition, it is necessary to examine the different levels of factors affecting it. To make sustainable improvements in nutrition, it is also necessary to understand the multifaceted determinants of undernutrition and then take actions accordingly.

The multifaceted determinants of undernutrition are classified into three main phases: immediate, underlying or basic. Figure 4.1 depicts the conceptual framework of child undernutrition which is adopted from UNICEF and subsequent work in this area. The *immediate* causes of undernutrition include inadequate dietary intake and diseases which form a kind of vicious cycle in which one causes the other. The underlying causes of undernutrition comprise three main determinants: food insecurity, inadequate care for the children and mothers as well, and poor health and environmental conditions. All three determinants are caused by some basic determinants which include political and economic structures, sociocultural environment, and potential resources such as the environment, technology, people etc.

The present work of FHE intervention works in the areas of care and environmental conditions, which are marked by the black coloured rectangular box (Figure 4.1). The environmental and health condition is comprised of safe water and sanitation, healthcare availability and the environmental safety. Resources for care involve knowledge and belief of caregivers, his/her physical and mental status and control over the resources. The prime objective of this intervention is to educate the primary caregivers about the importance of safe water and sanitation, maintaining food hygiene and also keeping the environment clean and safe. So it covers both the care and also the environmental aspect of health. Food hygiene education aims to provide hygiene messages to address this particular aspect in the conceptual framework.

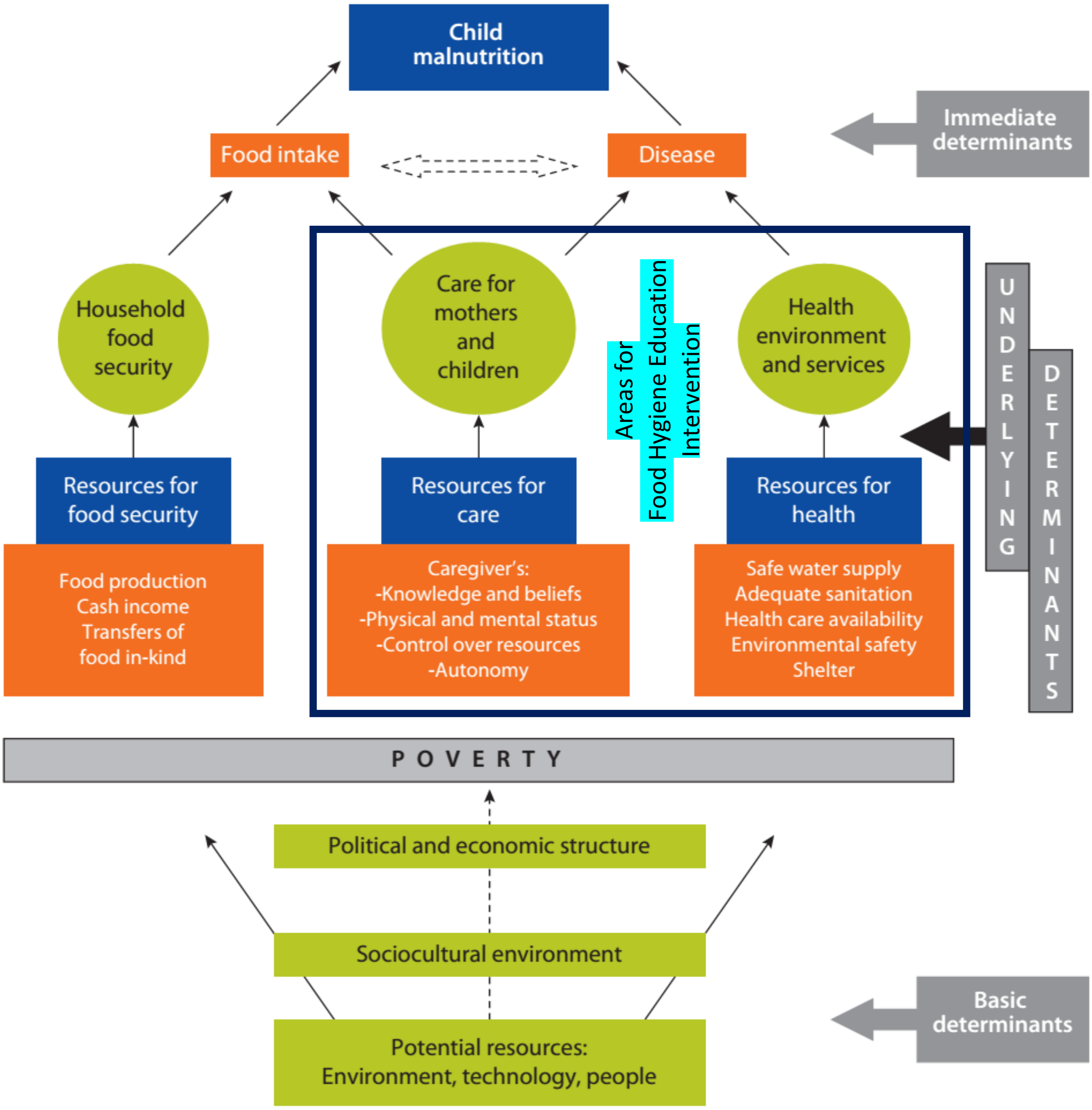


Figure 4.1: Conceptual framework for Food Hygiene Education (FHE) experiment.
Source: Adapted from (Mahmud and Mbuya 2015) and (Engle et al. 1999; UNICEF 1990)

Safe water and sanitation, along with other environmental services, determines the health outcome of children. Improved water and sanitation is the major area of focus here because human health is affected by the transmission of pathogens from faeces and waste water to humans. Pathogens are transmitted through various agents such as improper sanitation and hygiene, and unsafe drinking water sources (Figure 3.2). The transmission of pathogens from faeces to human can takes place through hands, flies and ground or surface water. Not washing hands after defecation may allow pathogens to enter into the human body through various routes, such as eating, drinking, preparing food and feeding. Pathogens can be transmitted from ground and surface water to humans in various ways. Preparing food with untreated surface water, drinking surface water and ingesting water while bathing in a pond or river can introduce pathogens into the human body, which may result in many water borne diseases. Ground and surface water can be contaminated by sewage, flood and chemical compounds. Piped water can be contaminated by sewage or flood water seeping into a pipeline. Chemical compounds such as arsenic, chlorine, iron, manganese and sodium can pollute water. These chemical compounds, along with the other industrial chemical wastes, can even pollute underground water sources, which is more dangerous than the surface water pollution in the long run. The transmission of pathogens can be stopped by interventions such as water treatment at source and POU, and improving sanitation and hygiene (Waddington et al. 2009). In Figure 3.2, the arrows (both dotted and solid) show the possible routes of pathogen transmission; the dotted arrows indicate that the particular route of transmission can be interrupted by interventions. The colour of each dotted arrow indicates which method acts as an effective barrier to pathogen transmission for that particular transmission route. A blue dashed arrow denotes that sanitation is an effective barrier to pathogen transmission; a red dashed arrow denotes hygiene and a green dashed arrow denotes water treatment. The figure clearly shows that hygiene interventions such as FHE can stop pathogen transmission (red dotted lines) and therefore reduce the risk of waterborne diseases.

4.2 Research Design

To evaluate how food hygiene education information impacts on hygiene behaviour and health outcomes, the study selected the area of the north-western part of Bangladesh where the availability of drinking water was inadequate and hygiene practices were quite low. Two districts of this area (Rajshahi and Naogaon) were chosen based on the availability and feasibility of the microbiological laboratory facility in the mentioned area. The University of Rajshahi facilitated the laboratory work by providing their laboratory space and instruments. All microbiological samples were transported from the sample villages of this adjacent two districts on a daily basis.

4.2.1 Intervention

The FHE intervention was given to rural households of north-western Bangladesh. Households in the sample were selected with the inclusion criteria of having at least one child of under-five years of age as the primary objective was to assess the health impact of the intervention on this group of children. To set a barrier to pathogen transmission from faecal to human body, treatment was designed consisting of the following elements: (1) microbiological test results of contamination from *E. coli* bacteria in drinking water and on food preparing utensils, (2) training to maintain food hygiene at the household level, and (3) a poster of hygiene messages to be hung in the dining area (Figure A. 7.4, Appendix). In the treatment villages households received all the above-mentioned treatment altogether for free of cost. The intervention was given to the first treatment group at end of January 2015 to the beginning of February 2015 and to the control group in March 2015. Before the intervention, households in this region did not receive any kind of similar intervention or any kind of WASH intervention from government or NGOs. The baseline data which was collected in October 2014 confirmed the absence of possible cross intervention in the study area.

The intervention was implemented by hiring an experienced trainer who worked for local NGOs for several years and had adequate knowledge of conducting Focus Group Discussion (FGD) in the rural villages. The trainer, appointed for short term employment, conducted one-hour training session per day in the sample village where the village contained only 16 sample households. He contacted all the targeted households in the sample village before sitting for a session and also invited the household head and the wife of the household head or the primary caregiver to the child for participating in the training session. The training sessions were organized mostly in the afternoon because primary caregivers have relatively free time in this part of the day. The participating households did not receive any financial incentives or any in-kind benefit to participate in the training session as well as participating in the whole study.

The trainer organized the sitting arrangement on a mat in a specific house-yard which is known to most people in the village or generally where NGO activities takes place. After introducing the agenda, he announced the *E. coli* testing results of drinking water and food preparing utensils to the participants and also described the result to them. Besides, he provided the brief description of the hygiene poster “8 ways for keeping food safe and clean” to the participants in this one hour session. Furthermore, he went to each participating household to hang the poster in their dining area by himself to eliminate the possible misuse of the poster by the children or other household members. Then he also signed in the household ID card provided for this study purpose.

4.2.2 Sampling frame

The study area is the two district of north-western Bangladesh namely Rajshahi and Naogaon (Figure 4.2). This area is called Barindra belt where drinking water is scarce because of the low aquifer level caused by high rate of water extraction. Therefore, obtaining ground water in this area is not easy and needs substantial investment for establishing deep tube-well because shallow tube-well doesn’t necessarily guarantee the ground water access (Chen et al. 2007; Escamilla et al. 2011). Inhabitant in this part of Bangladesh are marginalized in terms of ground water access and therefore, the BMDA, a government organization, established a wide area underground pipe line network connecting the deep tube-wells and supplying water for irrigation and drinking purpose in order to meet the needs of this area. Because of the water scarcity, the hygiene status in this area was not adequate.

4.2.3 Sample size selection

The randomized experiment had to confine in a small sample size because of the time and stringent budget. For this experiment, a total of 512 households was randomly chosen from two main clusters – villages those that received BMDA piped water for drinking and those that did not. Following Poisson statistical regression power analysis, the sample size satisfied the minimum sample size (498) calculation. The power analysis considered an effect size (ES) of 0.95 (i.e., the minimum difference in the outcome between treated and non-treated households is on average 5%) and a multicollinearity across the covariates of 0.7 (which is quite extreme) and allowed for a probability of Type I error of 5% and a statistical power (1-Probability of Type II error) of 80%.

4.2.4 Sampling procedure: cluster sampling

The experiment followed cluster sampling technique because it did not require exhaustive lists of every single person in the population to be compiled. The sampling guideline of the WHO suggests that the population within a cluster should be as heterogeneous as possible and different clusters should be as homogenous as possible among themselves. For selecting the number of clusters, the WHO also recommends that the number of clusters in the sampling frame should be at least five times higher than the number of randomly selected clusters.

Sample was randomly chosen from a list of clusters which was composed of the list of villages (or mouzas) in the districts studied. BMDA provided the lists of villages where they had intervened previously and another list of villages where they were going to intervene in near future. In this experiment, the study classified two main clusters: 1) villages with connection of the piped-water network (public intervention in 389 mouzas) and 2) villages without access to the piped-water network (in 359 mouzas). The villages in these two clusters were similar in terms of socio-economic activity and water scarcity.

In order to gain sufficient power of the analysis, the useful rule of thumb is that there should be a minimum of 30 clusters (List, Sadoff, and Wagner 2011). Hence, in order to get a sample size of 512 households, it is required to survey 16 households per cluster (mouza) from a total of 32 mouzas; this means that 16 mouzas are to be randomly selected from the list of villages with BMDA drinking water intervention and another 16 from the list of villages without BMDA intervention. The random selection was done using the Stata, a statistical software. It is noted that the sample selection satisfies the WHO recommendations on the minimum ratio between clusters in the sampling frame. A small *census survey* was conducted in each of the 32 villages to identify eligible households. A household having at least one child younger than five years old was included only in this study. Then 16 households were randomly selected from the eligible households in each village.

4.2.5 Experimental design

The FHE treatment was randomly assigned to the village level where all the sample households received the treatment. The rationale for doing randomization is that it solves the problem of selection bias because treatment remains uncorrelated with the observable and unobservables characteristics. Randomized evaluation provides an unbiased treatment impact estimates which satisfy the internal validity of the intervention. As the study area is stratified by mainly two regions in terms of drinking water intervention areas such having BMDA-piped water areas and non-piped water areas, the study randomized the treatment in each of the strata separately.

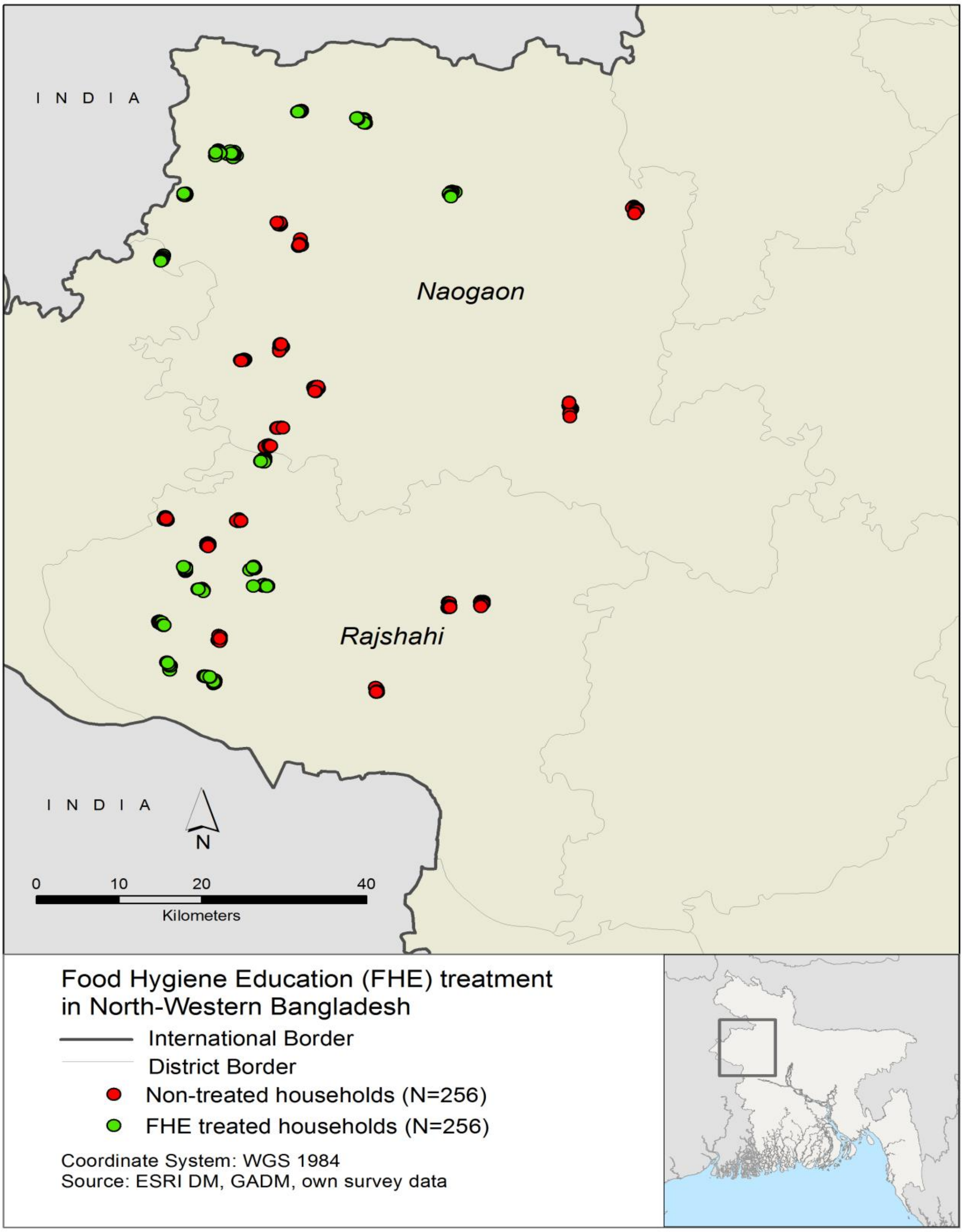


Figure 4.2: Map of the study areas in Rajshahi and Naogaon district.
Source: Authors' calibration based on primary data.

The stratified randomization provides the benefit of having similar treated and control groups with respect to key variables, protection against Type I and Type II errors, and improves power and hence reduced required sample size. The study followed a randomized-phased in experiment where 16 villages (8 from BMDA and 8 from non-BMDA area) were covered in the first phase keeping the rest 16 villages as control counterpart. Consecutively in the second phase the rest of the 16 villages was covered. So in the first phase, 256 households received treatment and 256 remained as control counterpart.

4.2.6 Compliance, attrition and identification

The study assumed treatment homogeneity and 100 percent compliance of the participating households. The households were communicated and explained the household consent form for participating in the experimental survey including the water and kitchen utensil microbiological test. With the consent and signature of the participating households (16 in each village) in the consent form, the study ensured full compliance with the treatment. The study further assumed the homogenous treatment effect because the treatment types and treatment delivery module were same to all participating households. In the field experiment, all 16 households in a village received *E. coli* test results of drinking water and food preparing utensils, and a hygiene poster. However, not all the households took part in the training session even after getting invitation to join. The partial compliance in the training participation may cause a selection bias problem in the treatment effect which needs to be checked before producing the impact estimates. It is known from the field survey that those households who didn't participate in the training session were involved in the household core work and couldn't actually make time to join. It is less likely to be a case that these households are different from the participating households' covariates, however, a comparison of household covariates is needed to make a conclusion.

The study encountered no attrition because no households or villages were dropped out of either from the treatment or control group over the intervention implementation period. All households were found present in the village in order to receive the intervention. Sometimes, child anthropometric measurements were not possible in the same day in a villages because few children went out for visiting their relatives. But the measurement of those children was collected when they were available after few days. Complete migration of any household was not reported in the survey.

As there was no household dropped out form the intervention and the intervention was intended to treat (ITT) all the 512 household, it was reasonable to have 256 households as treated in the first phase and all treated in the second phase. For policy making perspective, the study produces the short term impact estimates from the households having only one month of treatment exposure (1024 observations). Furthermore, the study also estimates the medium term impact estimates from the households having two months of treatment exposure versus one month of treatment exposer (1024 observations). Because of the treatment design and the policy making issues, it is reasonable to estimate average treatment effect (ATE) of the treatment. As the treatment was provided with a package of three components and the study didn't randomized within the treatment components, it is advisable to concentrate only the overall treatment effect rather than having treatment effect from each component. From this setting, treatment effect of any particular component of the treatment is not possible which the limitation of this study is.

4.2.7 Spill overs issue

Spillover effect is such that untreated households get treated by the intervention. The study expects a spillover effect inside the village but not from village to village. Hence the village is the unit of randomization in this study. The treatment was randomized in such a way that no adjacent village remained as control. So the distance between the treatment village and control village was reasonable enough to determine no spill over. Moreover, information provided in the treatment such as test results of water and food preparing utensils were household specific and varied household to household, and the training participation and poster were only provided to the specific participating households. So it would even generate moderate spillover effect within the village. Hence the village level randomization nullifies the possible spillover effect of the treatment outcome and satisfy the non-violation of stable unit treatment value assumption (SUTVA).

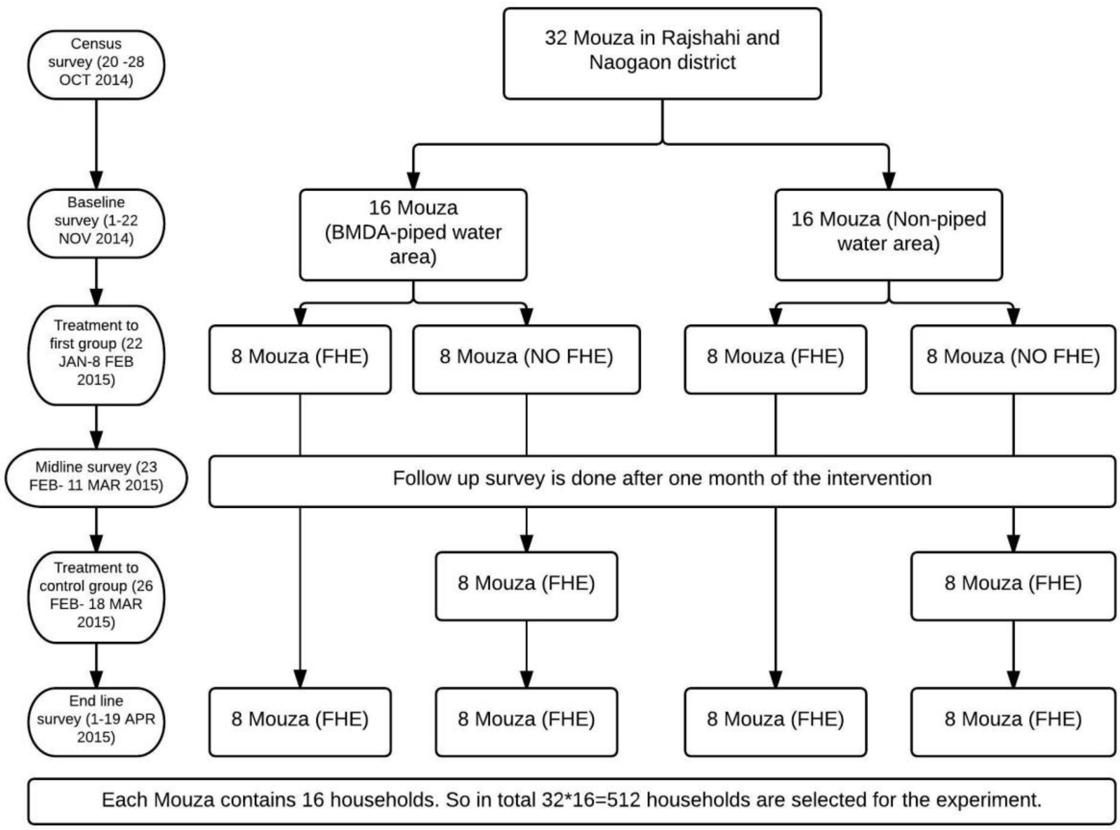


Figure 4.3: Tree diagram of the Food Hygiene Education (FHE) intervention.

Source: Author's calibration

4.3 Tree diagram of randomization

The study is a randomized phased-in evaluation where one group of clusters receives treatment in the first phase and the remaining group in the second phase. In this study, a total of 32 mouzas (mouza is equivalent to village) are considered where 16 mouzas are from BMDA piped areas and another 16 are from non-piped areas. In each strata, 8 mouzas are given the treatment of the FHE keeping 8 mouzas as control (Figure 4.3). In the second phase these controls were also given treatment. So in the endline survey all the villages were treated but the first group has 2 months of treatment exposure and the latter group has only one month of treatment exposure.

4.4 Data and methods

Primary data from the households was collected in three phases- Baseline (1-22 NOV, 2014), Midline (23 February- 11 March 2015), and Endline (1-19 April, 2015). The intervention was provided in the first phase (22 January-8 February, 2015) and in the second phase (26 February to 18 March, 2015). Each village received one month time in between treatment and follow up survey. In each survey households' questionnaire and microbiological test of drinking water and food preparing utensils were conducted. Child anthropometric measures were only collected in the baseline and in the endline.

4.4.1 Data collection

4.4.1.1 Household survey

Household survey was conducted from November 2014 to April 2015. In the baseline survey, every household received a detailed 28-page questionnaire that asked for information about a household's assets, income, food and non-food expenditure, investment and financial activities, WATSAN- and hygiene-related practices, and agricultural activities. The households took part in this survey willingly and did not receive any financial incentives in return. Each questionnaire required approximately two hours to fill in. A total of ten field enumerators and a supervisor was involved in collecting the information from households.

The study was approved by the ZEF ethical committee of the University of Bonn to protect the rights of the survey respondents. All households received extensive information about the study and had to sign a consent form prior to participating in the survey. All households had the right to discontinue their participation at any time during the observation period. Each household was given an identification card for the follow-up surveys.

4.4.1.2 Anthropometric survey

On the same day of the household survey, a field enumerator took anthropometric measurements (height and weight) of children under-five in the households. The collection of anthropometric measurements followed the guidelines of the WHO. The measurement took place on the same day as the household survey because households might not be available on the following days, which might reduce the sample size of the anthropometric data. The field enumerator also recorded the GIS information of all households, including their latitude and longitude.

4.4.1.3 Microbiological testing of water and food utensil

In the days following, a laboratory research assistant (LRA) visited the households and collected water and food utensil samples from the household. The LRA collected a glass of drinking water from the same jar the household use (the point of use). The water sample was collected in a sterilized bottle and kept in a cool box for transporting to the laboratory. The LRA also tapped or pressed a "food stamp" on the households' drinking glass, spoon and main cutting instrument. The number of food stamp samples was recorded, and the media (food stamps) were kept in a cool box for transporting to the laboratory.

The LRAs are microbiology graduates and have been trained for this kind of assignment. Two LRAs worked simultaneously in different areas. Each LRA covered 16 households in a mouza and then returned to the lab on the same day. Before commencing their fieldwork, they were trained at the International Centre for Diarrheal Disease Research, Bangladesh (icddr,b) by a senior scientist.

4.4.1.4 E. coli testing procedure in the Laboratory

The bacterium *Escherichia coli O157 (E. coli)* is the most commonly recommended indicator of faecal contamination in water and food utensils. The WHO recommends there should be no *E. coli* in a 100 ml drinking water sample. In the survey, *E. coli* was measured by filtering 100 ml of drinking water through a 0.22 µm filter paper (cellulose nitrate membrane filter; 47 mm diameter; pore size of 0.2 microns; Sartorius, Germany) using a vacuum filtration unit. Then the filter paper was removed and placed onto a Compact Dry EC growth media plate (Nissui Pharma, Japan) to incubate it at 37-39°C for 24 hours. After incubation, the LRAs counted and recorded the number of *E. coli* colony forming units (cfu), indicated by blue colonies, and the number of coliform colonies (red colonies) on each of the Compact Dry EC media (Figure 3.5).

Food stamp XM-G agars (HyServe, Germany) were used to test for *E. coli* on kitchen utensils (specifically a glass, a spoon and a cutting knife). Food stamp is a simple-to-use bacteriological testing method for the presence of bacteria in food utensils. A food stamp (10cm^2 XMG agar) was pressed once on each of the three specimens in the household and then kept in the cool box for transporting to the laboratory. The food stamp was then incubated at 37-39°C for 24 hours. After incubation, the LRAs counted and recorded the number of *E. coli* colony forming units (cfu), indicated by blue colonies, and the number of coliform colonies (red colonies) on each of the XMG agar media (Figure 3.5).

4.4.2 Verifying randomization: Internal and external validity

Randomization of the treatment ensures the internal validity. For the external validity, it can be said that this experiment is also applicable to any rural village in Bangladesh. So the experiment also satisfy the external validity.

4.4.3 Data quality assurance

The collected data had been checked thoroughly by the Field Supervisors and also by the data entry operators to find out possible anomaly. Households' questionnaires had been manually checked and then data was captured in automatic matching by scanning each page. In each step, all the issues of capturing and digitizing had been monitored by the Field Supervisors. The microbiological testing results and the procedures had been supervised and scrutinized by the senior scientist from icddr,b regularly. Any kind of reporting of the data had been verified with both graphical image and also inputted data sheet. Data quality was maintained in each level of the experiment and also in the survey process.

4.4.4 Descriptive statistics

It is observed from Table 4.1 that most of the household characteristics are similar for the treatment group and the control group in the baseline survey. It is recommended that before the intervention, treatment and control covariates should be similar. The p-value in this table shows that considering all the households, the average value of all characteristics are not significantly different between treatment and control households, except for *household size, number of cows and poultry, per capita expenditure, savings* and *distance from the small market*. In most of these cases, control households are better off than the treatment households. Control households have more *per capita expenditure* and *savings* than the treatment households. As these few covariates are not exactly similar between the treatment and control group, they are used as control variables in the regression equation to check for the robustness of the produced results.

In the experiment, the average age of the head of the household is 35, having only seven years of schooling on average and maintaining a family of four to five people. Half are wage earners and involved in agriculture (Table 4.1). It is found that the microbiological quality of drinking water and kitchen utensils improves in the follow up surveys (Table A. 7.10, appendix). *E. coli* counts in drinking water and food preparing utensils have been reduced from baseline to endline. In addition, access to improved water for household works and also monthly cost for water have increased from baseline to endline. Intervention also stimulates the access to improved sanitation, which increased from 68% in the baseline to 87% in the endline. Handwashing with soap increased from 68% to 97% for toilet visitors and from 3% to 29% for feeding children, which is a major gain (Table A. 7.10, appendix). It is also noted that the soap consumption and handwashing score has increased, and the household food hygiene index also has doubled in the endline. However, there is no change in the socio-environmental status in the baseline to endline.

Table 4.1: Baseline characteristics of treatment and control households before the intervention

Household characteristics	Control (N=256)	Treatment (N=256)	P-value [Treatment – Control]
Age of household head (years)[a]	35.0	35.5	0.61
Completed years of schooling of household head[a]	4.7	4.6	0.72
Maximum completed schooling in the household	7.8	7.7	0.75
Household size[a]	4.6	4.9	0.02
Percentage of female headed household	1%	1%	0.65
Household head currently married (dummy)	98%	98%	0.52
Household occupation: wage earning (dummy)[a]	49%	54%	0.29
Household occupation: agriculture (dummy)[a]	61%	54%	0.11
Household occupation: non-agriculture (dummy)	45%	50%	0.25
Total land (in acre)[a]	81.3	57.1	0.10
Number of shared livestock	0.20	0.17	0.63
Number of cows	1.0	1.4	0.04
Number of goat	1.0	0.9	0.52
Number of poultry	10.3	7.8	0.02
Number of Livestock	14.8	15.8	0.82
Food expenditure (BDT)	59230	60155	0.73
Non-food expenditure (BDT)	41741	38090	0.36
Total expenditure (BDT)	106532	103247	0.61
Per capita expenditure (BDT)[a]	23328	20886	0.04
Household savings (BDT)	47070	26389	0.01
Participants of Microfinance programme (dummy)	45%	51%	0.22
Household have access to electricity (percentage)[a]	61%	56%	0.28
Distance from road (kilometre)[a]	0.5	0.4	0.23
Distance from small market (kilometre)[a]	0.9	1.9	0.00
Distance from big market (kilometre)[a]	5.3	5.1	0.60
Distance from health centre (kilometre)[a]	3.4	3.5	0.55
Distance from nearest town (kilometre)[a]	8.0	10.9	0.00

Source: Authors calculation from baseline survey 2014. [a] Denotes the variables (household characteristics) are used as control variables in the regressions.

An improvement has been observed in the anthropometric measures of children under-five. Although there is no visible change in the z-scores of the overall sample from baseline to endline (Table A. 7.11 and Figure 4.4), a change is observed in the percentage categories of nutritional status which are done according to the JMP classification (Figure 4.5).

The percentage of stunted and severely stunted children has been improved from the baseline to the endline (Figure 4.5). The percentage of stunted children has been reduced by almost 2% and severely stunted by 1% from baseline to endline. But from this descriptive analysis, it is not possible to say for which factors these changes are made. This requires an econometric analysis, which follows in the later part of this paper. A big change is observed in the percentage of underweight children; it has been reduced from 33% in the baseline to 28% in the endline (Figure 4.5).

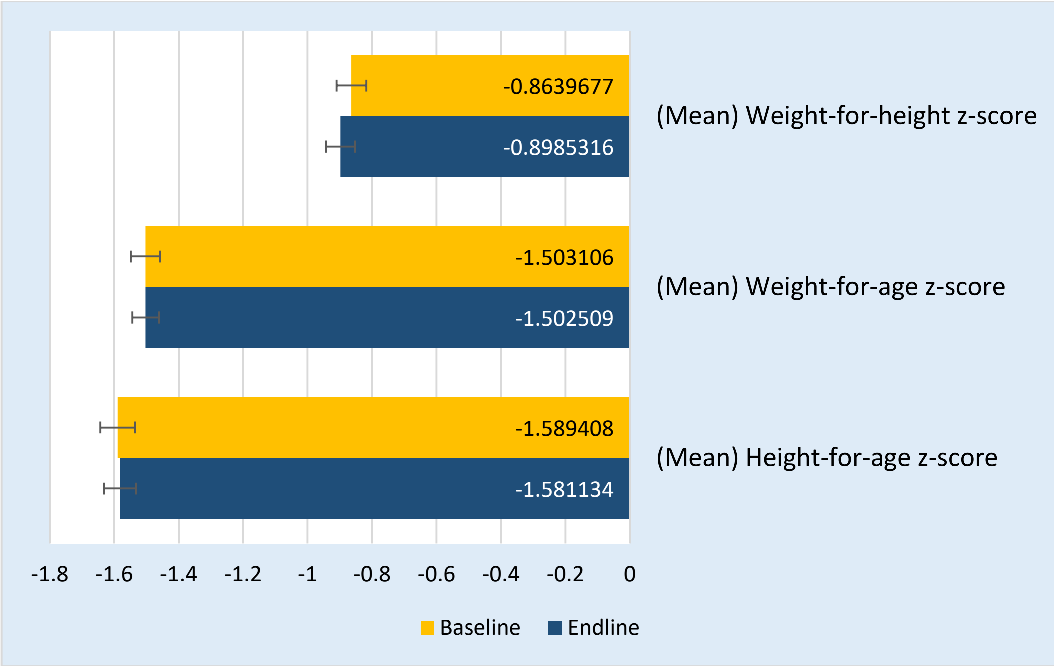


Figure 4.4: Status of child anthropometrics (z-scores) in both baseline and endline.
Source: Primary survey data.

The percentage of severely underweight children has dropped by only 1% from baseline to endline. But there is no improvement found in the percentage of wasted and severely wasted children. Furthermore, there is no significance difference in anthropometric in boys and girls. It is observed from Figure 4.5 that the number of children in the endline is 538, which is less than the baseline number of 557. The reason behind this reduction is that 19 children are found to be more than 5 years of age in the endline. To make the anthropometric analysis consistent with the WHO guidelines, the marginal aged children are dropped from the results, which is found to have no systematic pattern to affect the regression results.

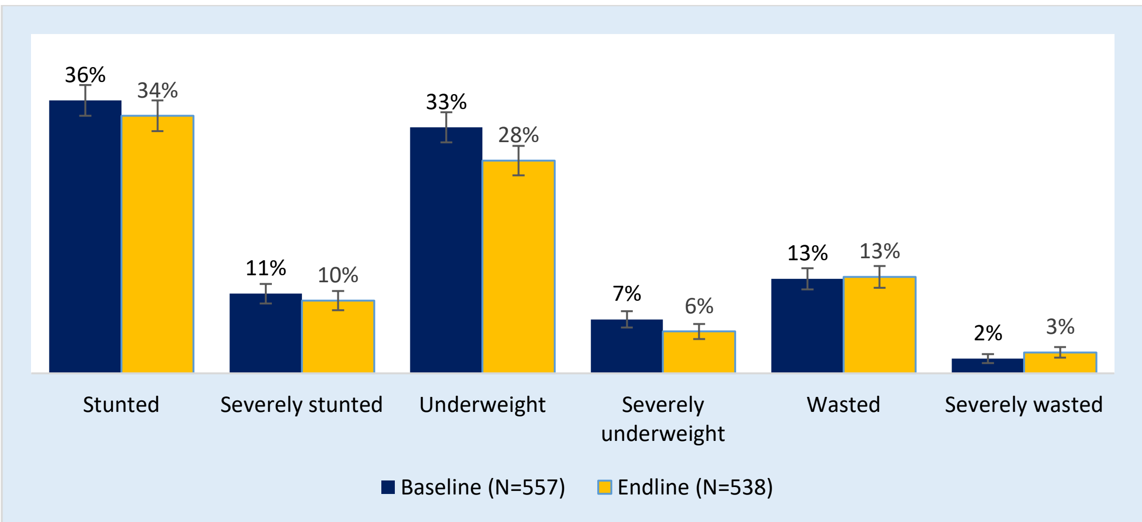


Figure 4.5: Child nutritional status in baseline and endline.
Source: Primary survey data.

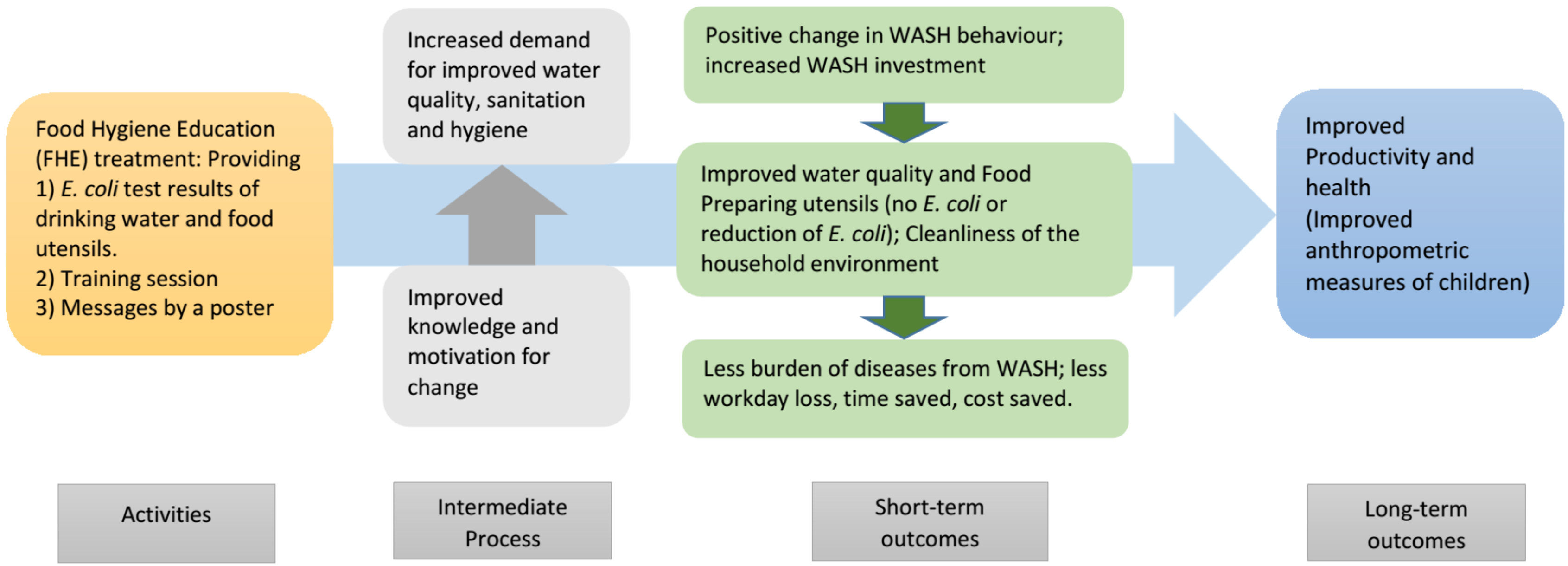
Figure 4.4 and Figure 4.5 do not show any difference between the treatment and control households. It is observed from Table A. 7.11 that there is no significant difference between the treatment and control households in terms of mean values of the height-for-age z-score, weight-for-age z-score and weight-for-height z-score both in the baseline and in the endline. The stunting and underweight mean difference for treatment and control households are not found to be significant in any round. Only a significant mean difference is found in the percentage of wasted children in the baseline but not in the endline.

4.4.5 Methods

Child nutrition is an important element of health production which contributes towards formulating human capital. As health involves both production and consumption aspects, individuals' health behaviour decisions about themselves and also their children depend on allocation of time for work and leisure, money, cultural beliefs, communal actions and the expectation of lifetime utility (Becker 1976; Grossman 1972a, 1972b; van Wikj and Murre 2003).

This paper is developed by outlining the causal linkages (short and long-term outcomes) of an intervention in a societal setting (Figure 4.6). The time frame of the experiment does not allow for the long-term outcomes to be captured, it concentrates only on short and medium term analysis. Logical relationships are used to generate outcome pathways assuming that the intervention of FHE improves health and productivity. This causal link works through an increased demand for improved water, sanitation and hygiene practices by better knowledge and motivation for change, resulting in a reduction of *E. coli* in water and food utensils, increased practices of food hygiene and a reduced burden of disease. The long-term outcomes are improved physical development in children under-five (i.e. lower prevalence of stunting, underweight and wasting) and higher productivity (better physical and mental performance).

The intervention postulates a set of assumptions. These assumptions are the constraints of the experiment, and if relaxed may change the outcome of the experiment. The intervention is expected to work within the set of assumptions through the immediate process which produces short term, medium term and long term outcomes. But in this experimental time frame, the long term outcomes could not be observed. Long term means that all the variables in the experiment are subject to change, nothing is fixed. But in the short term outcomes, at least one variable is fixed. So rather than waiting for the long term outcomes, the study attempts to identify the medium term outcomes (which is one month additional exposure to the treatment over the one month exposure).



Assumptions

-Households' imperfect information about faecal-oral transmission
-No recent hygiene education program in the village
-Household has at least one child.
-Access to water and sanitation.
-Access to food

-Households rationally process provided information
-Income of households doesn't change
-Price doesn't change for water, sanitation.
-Household cares for good health.

-household has money and time to invest.
-Primary care-giver has physical strength and capacity
-food intake pattern doesn't change
-No change in environmental setting

-Household is rational and maximizes health and productivity
-household maintains sustainable practices of food hygiene education

Figure 4.6: Impact Pathways for the Food Hygiene Education (FHE) intervention.

Source: Authors' calibration.

4.4.5.1 Econometric Methods

Difference-in-difference (D-i-D) estimation is applied to identify the impact of the FHE treatment. The analysis employs the data from the baseline, midline and endline to establish the short and medium term impact. For the short term impact (one month exposure to treatment), the study has analysed the midline survey, with one group of households as the control considering the baseline characteristics. In the medium term, the endline survey is analysed including the baseline characteristics. Medium term analysis has the benefit of two months of after treatment exposure over the one month exposure, so it mainly shows the marginal benefit of having one more month of after treatment exposure although both of the groups already have the treatment.

The D-i-D regression equation can be written as follows-

$$Y_{it} = a + DD.T_i t + \beta T_i + \delta t_i + \varepsilon_{it} \qquad (1)$$

In equation (1), Y_{it} represents the outcome variables. The study identifies several outcomes variables including continuous, dummies, count and indices which require different regression models to follow. β provides the coefficient of the treatment T for individual i. Similarly, δ gives the coefficient of time t for individual i. DD is the coefficient of the interaction term of $T_i t$ which gives the impact estimates of the treatment. ε_{it} is the error term of the regression. Difference-in-difference (D-i-D) estimation allows for covariates to control for the treatment impacts and in the analysis, household covariates are used. In the analysis, a panel data regression model, panel data Probit model and panel data Poisson model are used to get the impact estimates.

In the outcome variables, the following indexes are used: socio-environmental status, households' handwashing scores and household food hygiene index. All these scores and indexes are the simple summation of some binary variables within the possibility of maximum and the minimum. As there are eight hygiene messages in the poster of intervention and some messages also includes multiple pieces of information, it is reasonable to construct an index so that it can measure how a household may respond to the intervention. Similarly, when a household is told to wash their hands, it is very difficult to assess how each household member washes their hands during the many critical times, so a simple measure is required to construct the overall handwashing score of the household members. Similarly, for the socio-environmental status, it is extremely difficult to distinguish which aspect of cleanliness is to be considered and which is not. Therefore, the study gives equal weight to each category and construct and score, which ranges from 1=good to 3=bad.

4.4.5.2 Cost-Benefit Analysis

Cost-Benefit analysis (CBA) is an important part of programme evaluation as it is very much linked to policy issues. Policy makers want to see the possible benefits of a project and hence they allocate budgets for a new project. In this chapter, the RCT experiment of the FHE is evaluated based on the benefit-cost ratio, which means how much benefit may be generated for a dollar or euro invested in a programme. CBA is calculated based on the estimated cost of the project for the experiment and also with the help of other existing literature in this field. It also uses several assumptions to make the analysis simple and straightforward. The benefits of investing in water and sanitation are enormous. For USD 1 invested in the sanitation and hygiene, the programme returns USD 5-28 (Sijbesma and Christoffers 2009). Even a single component of the water, sanitation and hygiene intervention would generate a considerably high benefit. Several researchers have argued that hygiene intervention standalone could reduce the diarrhoea incidence by 10% even in the absence of water and sanitation infrastructure (Cairncross and Valdmanis 2006; Larsen 2003).

4.5 Regression Results

According to Table 4.2, the study follows some short and medium term outcomes for the intervention of food hygiene education. Short term means after one month of intervention (where training, poster of hygiene messages and *E. coli* result of drinking water and food utensils were described once, and the poster was hung in their dining area). Medium term means two months (two months from the training day and the poster being hung in the household) versus one month exposure of the control group (control group treated later on). The intervention works through an intermediate process which comprises the willingness to change the behaviour and increased knowledge, etc. and these factors result in the short term outcomes such as improved water and food utensils quality, more hygiene practices, improved cleanliness and a reduced burden of disease. In the medium term outcome, it shows the improved nutritional outcomes. It is necessary to allow sufficient time to observe the nutritional outcomes of children under-five. The study observance time (one and two months after the intervention) might be the earliest time to observe these outcomes. But the other short term outcomes such as behavioural changes are more effective in the short term, especially immediately after one month. It is therefore interesting to observe the impact of the behavioural changes in two consecutive months. As the data collection faces time and budget constraints, the analysis is set to the short (evaluation of treated households one month after the receipt of treatment) and medium term (two months after the treatment receipt versus one month after the treatment receipt). Caution should be used when interpreting the medium term results because they show the impact of two months' exposure to the treatment over one month of exposure, and show the marginal benefit of having one more month of exposure when both of the groups are treated. The robust standard errors of the regressions are computed at the village level, which is the unit of randomization used here.

4.5.1 Impact on water quality and kitchen utensils

The findings show that FHE treatment had a positive impact on the microbiological quality of drinking water and kitchen utensils. *E. coli* colonies were reduced by 48 cfus in the short term (1% level of significance) and 25 cfus in the medium term (10% level of significance) in their drinking water after the treatment (Table 4.2).

Table 4.2: Impact of FHE on microbiological quality of drinking water and food utensils

	E.coli in drinking water (number of colonies)			E. coli in food preparing utensils (count of colonies)					
	Short term		Medium term	Short term			Medium term		
	Coefficient		Coefficient	Coefficient		Elasticities	Coefficient	Marginal effect	Elasticity
Treatment (FHE)	26.173*	19.610	20.464	-0.224*	-0.437	-0.219	-0.355	-3.256	-0.178
	(15.016)	(13.480)	(12.656)	(0.118)	(13.812)	(6.906)	(6.815)	(62.621)	(3.411)
Time	15.839	15.887	-12.550	-0.500*	-0.500*	-0.25*	-1.623***	-14.879	-0.814***
	(14.579)	(14.632)	(10.158)	(0.290)	(0.290)	(0.145)	(0.296)	(30.47)	(0.148)
Treatment* Time (Impact)	-47.703***	-47.764***	-24.923*	-1.317***	-1.317***	-0.33***	-0.161	-1.479	-0.041
	(17.996)	(18.071)	(13.706)	(0.420)	(0.421)	(0.105)	(0.416)	(4.354)	(0.104)
BMDA operated area	8.954	12.700	4.286	0.127***	0.152	0.076	0.149	1.368	0.075
	(10.797)	(11.155)	(10.284)	(0.016)	(7.960)	(3.988)	(6.715)	(63.454)	(3.361)
HH characteristics	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Constants	26.941***	10.106	3.643	2.769***	3.571		3.578		
	(9.974)	(25.138)	(22.708)	(0.110)	(46.862)		(25.807)		
Observation	1018	1018	1019	1018	1018	1018	1019	1019	1019

Source: Authors calculation based on primary data. The number in the parentheses shows the robust standard error clustered in the village level. Household characteristics are shown in Table 1. note: *** p<0.01, ** p<0.05, * p<0.1

Table 4.3: Impact of Food Hygiene Education (FHE) on handwashing practices

	Handwashing with soap after defecation					Handwashing with soap before feeding children				
	Short term			Medium term		Short term			Medium term	
	Coefficient		Marginal effect	Co-efficient	Marginal effect	Coefficient		Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	-0.234	-0.230	-0.05	-0.185	-0.033	0.233	0.203	0.026	0.222	0.042
	(0.201)	(0.157)	(0.034)	(0.147)	(0.026)	(0.273)	(0.275)	(0.035)	(0.250)	(0.047)
Time	0.441**	0.436**	0.094**	1.421***	0.254***	0.856***	0.847***	0.108***	1.470***	0.275***
	(0.205)	(0.205)	(0.042)	(0.280)	(0.040)	(0.244)	(0.243)	(0.030)	(0.237)	(0.038)
Treatment* Time (Impact)	1.221***	1.259***	0.271***	0.533	0.095	0.567*	0.561*	0.071*	-0.039	-0.007
	(0.240)	(0.229)	(0.050)	(0.335)	(0.063)	(0.303)	(0.300)	(0.038)	(0.271)	(0.051)
BMDA operated area	0.209	0.108	0.023	0.068	0.012	0.159	0.005	0.001	0.033	0.006
	(0.185)	(0.152)	(0.033)	(0.134)	(0.024)	(0.148)	(0.146)	(0.019)	(0.117)	(0.022)
Household characteristics	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Constants	0.614***	-0.196		-0.651**		-2.501***	-3.061***		-2.464***	
	(0.186)	(0.321)		(0.317)		(0.326)	(0.531)		(0.417)	
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table 4.4: Impact of FHE on child diarrhoea in last one month

	Short term			Medium term		Elasticity	
	Coefficient		Marginal effect	Coefficient	Marginal effect	Short term	Medium term
Treatment (FHE)	0.963***	1.005**	0.112***	0.978***	0.107***	0.503**	0.489***
	(0.345)	(0.397)	(0.043)	(0.309)	(0.033)	(0.199)	(0.154)
Time	0.990***	0.990***	0.11***	0.802***	0.088***	0.495***	0.401***
	(0.377)	(0.377)	(0.040)	(0.310)	(0.032)	(0.189)	(0.155)
Treatment* Time (Impact)	-1.051**	-1.051**	-0.117**	-0.773*	-0.084*	-0.263**	-0.193*
	(0.509)	(0.509)	(0.056)	(0.402)	(0.044)	(0.127)	(0.101)
BMDA operated area	-0.179***	-0.169*	-0.019*	-0.020	-0.002	-0.085*	-0.01
	(0.050)	(0.094)	(0.010)	(0.241)	(0.026)	(0.047)	(0.121)
Household characteristics	No	Yes	Yes	Yes	Yes	Yes	Yes
Constants	-2.896***	-2.515***		-3.149***			
	(0.306)	(0.746)		(0.941)			
Observation	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table 4.5: Impact of FHE on anthropometric z-scores for one additional month of exposure.

	Height-for-age z-score		Weight-for-age z-score		Weight-for-height z-score	
Treatment (FHE)	0.106	0.113	-0.025	-0.036	-0.122	-0.140
	(0.138)	(0.139)	(0.118)	(0.107)	(0.097)	(0.099)
Time	0.047	0.047	-0.052	-0.052	-0.135*	-0.137*
	(0.071)	(0.071)	(0.040)	(0.040)	(0.082)	(0.082)
Treatment* Time (Impact)	-0.075	-0.073	0.092*	0.095*	0.189*	0.191*
	(0.095)	(0.096)	(0.054)	(0.054)	(0.104)	(0.105)
BMDA operated area	-0.029	-0.080	0.049	0.040	0.091	0.114
	(0.127)	(0.103)	(0.106)	(0.085)	(0.080)	(0.076)
Household characteristics	No	Yes	No	Yes	No	Yes
Constants	-1.629***	-1.761***	-1.515***	-1.685***	-0.847***	-1.000***
	(0.123)	(0.253)	(0.108)	(0.222)	(0.090)	(0.221)
Observation	1095	1095	1095	1095	1095	1095

Source: Authors calculation based on primary data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment. As there is no absolute control in the endline (all are treated in the endline) and there is not available data of anthropometrics in the midline, it is not possible to measure the impact of only FHE on nutritional outcomes. As both of the groups are treated, one group has two month of exposure and another has one month of exposure. note: *** p<0.01, ** p<0.05, * p<0.1

The *E. coli* level in the food preparing utensils has also decreased because of the intervention. In the short term, considering the covariates, its coefficient is reduced by 1.3 colonies for the treated households compared to the control households, at a 1% level of significance. The treatment elasticity in the food preparing utensils, which measures the percentage change in the count of *E. coli* colonies for a percentage change in the programme participation, is inelastic and the findings show that *E. coli* was reduced by 33% in the food utensils in the midline at a 1% level of significance (Table 4.2). No significant difference in the medium term for reducing *E. coli* was found, which means that all the households responded to the treatment immediately and have continued doing so (no increase of decrease detected). The household with two months of exposure have no incremental benefit over the one month of exposure group. The result from the medium term implies that even if there is no significant relative difference between the two groups after they both had the intervention, the impact of the treatment might have a difference in their respective absolute terms.

It is also important to note the percentage of households that could reduce the *E. coli* level to zero both in drinking water and food preparing utensils. In the short term, the marginal effect of treatment for reducing *E. coli* to zero in drinking water is 21% (1% level of significance) and in the medium term is 17% at a 5% level of significance (Table A. 7.12, Appendix). This proves that 21% of households stopped contaminating water after the treatment and continue to maintain this 17% more than those who have only one month of exposure. Households' improvement in the drinking water is observed in terms of water treatment practices too. Households' willingness to treat water has increased by 5% after the intervention in the short term which is significant at a 5% level (Table A. 7.13, Appendix). The study didn't find any significant impact for making *E. coli* level zero in the kitchen utensils after the intervention (Table A. 7.12, Appendix). These results on water quality and water treatment imply that households have changed their behaviour after the treatment, which indicates a positive sign towards health investment.

4.5.2 Impact on hygiene practices

Households' handwashing increased after the intervention. In the short term, 27% of the households increased their handwashing after defecation by using soap, which is statistically significant at a 1% level after controlling for the households' covariates (Table 4.3). In the medium term, the difference between the two month group and one month group is not statistically significant, which means that both of the groups have increased their handwashing after defecation. So a marginal benefit for an additional one month has not been established here. It can therefore be said that handwashing treatment is effective immediately after the intervention. Similarly, households' regular practice of handwashing with soap before feeding children has increased by 7% (10% level of significance) after the intervention compared to the households without the intervention (Table 4.3).

Treated households reported that their quantity of soap purchased (1 soap=100 gram soap bar) after the intervention increased compared to the control counterpart. In the short term, after the intervention the quantity of soap purchased increased by 0.7 unit (10% level of significance) which means almost one soap compared to the control counterpart (Table A. 7.14, Appendix). But the incremental impact of an additional one month is not found to be significant in the medium term analysis. Households' practice of water handling remains unchanged as it resembles the cultural factors of that area. Most of the households in the study area used to fill their glass with drinking water using a cup or long handled big spoon from a water jar. After the intervention, their practice of drawing water from a jar with a mug has not changed statistically, even in the short term (Table A. 7.14, Appendix).

The frequency of cleaning a water jar with soap or soap materials has increased in the treatment households compared to their controlled counterparts. After controlling for the households covariates, the finding show that 15% of the households have increased their frequency of cleaning the water jar with soap after the intervention, and this is significant at a 5% level (Table A. 7.15, Appendix). In the medium term, there is no significant difference between the two month exposure group and the one month exposure group. There is no statistically significant difference found in the cleaning of the toilet with soap materials after the intervention, both in the short and medium term (Table A. 7.15, Appendix). This result has big implications for WATSAN investment in the households and it seems that households didn't increase their purchasing of additional soap/ soap materials for cleaning the toilet because of the intervention. Besides, cleaning or maintaining the toilet in a hygienic way is also a matter of cultural practice and changing the behaviour of cultural practice requires time to adjust, and so within a short time these changes might not be apparent. It seems that they only care about drinking water with a greater emphasis as they perceive the severity of the diarrheal diseases.

Changes of hygiene indexes:

The study examined several indexes such as handwashing scores, WATSAN indexes, Food Hygiene Index, Socio-environmental cleanliness index, etc. All these scores and indexes are the simple summation of binary variables. Household handwashing score is the average of handwashing at different critical times of a day. The score ranges from 0 (lowest) to 9 (highest). It implies that households with a handwashing score of 9 wash their hands at all critical or recommended times. In the short term, the findings show that the handwashing score for treatment households increased by 0.47 (5% level of significance) than the control households after controlling for households' covariates (Table A. 7.17, Appendix). This result implies that treated households maintained better handwashing after the treatment than their control counterparts. There is no significant difference in the medium term as both groups have the same level of handwashing scores after receiving the intervention.

The household WATSAN hygiene index has also improved after the intervention. The WATSAN hygiene index is the simple average of cleanliness of the water, sanitation, food, personal and surroundings of the house. It ranges from 1(worst) to 3(best). This index is based on the interviewer observation of the households' cleanliness. It is observed that after the intervention in the short term, households' WATSAN hygiene index has increased by 0.14 points, which is statistically significant at a 1% level (Table A. 7.18, Appendix). This implies that treatment households are better off than the control households after the intervention. There is no statistical difference in the medium term as both groups have improved the index after receiving the treatment.

Households' food hygiene index is the average of different food hygiene related information that households practice after the intervention. It ranges from 0 (worst) to 14 (best). In the impact estimates, the findings show that in the short term, households who received treatment could increase the food hygiene index by 1.47 points compared to their control counterparts even after controlling for the household covariates (Table A. 7.18, Appendix). This improvement in the index implies that treated households are better off than the control counterparts after the intervention. In the medium term, the difference between the two months exposure group and the one month exposure group is not significant. The socio-environmental cleanliness index is an average of different cleanliness related information which is observed by the interviewer. It ranges from 1 (good) to 3 (bad). In the impact estimates, this variable is not significant both in the short and medium term analysis.

4.5.3 Impact on health

Impact on health investment

Health investment involves the expenditure for curing and preventing diseases. Household medical expenditure for the treatment of diseases for children and adults in the previous month and households' purchase of new WATSAN related equipment are observed to establish the households' investment behaviour after the intervention. Although one month is a very short period of time to realize the scope and take necessary actions, especially regarding some financial decisions after the treatment exposure, it is nevertheless rational to see the ex-post expenditure for curing the diseases. It is observed from Table A. 7.16 (Appendix) that household medical expenditure for WATSAN related diseases in the previous one month was reduced after the intervention, but this change is not statistically significant in the short and medium term. Medical expenditure for children and households for WATSAN related investment was not found to be significant after the intervention (Table A. 7.16, Appendix). The household monthly cost of water (water payment for piped water, purchasing of drinking water in work, water purification cost, etc.) has increased by BDT 5, which is not statistically significant (Table A. 7.17, Appendix). It can therefore be concluded that there is no impact of the intervention on the monthly cost of water both in the short and medium term. Sanitation maintenance costs are also not significant both in the short and medium term.

Impact on household morbidity:

Household morbidity is defined here as the count of diarrhoea episodes in the previous one month for both children and other household members. In each survey data collection, households were asked to recall how many diarrhoea episodes each child had in the previous month and the same was asked of other household members. In the short term impact estimates, the findings show that the marginal effect of treatment for reducing child diarrhoea is 12% (5% level of significance) even if controlling for the household covariates (Table 4.4). For the medium term, child diarrhoea is reduced by 8.4% at a 10% level of significance which means that the two month exposure group is still having less episodes of diarrhoea than the one month exposure group (Table 4.4). The elasticity of reducing diarrhoea is negative and it shows that by participating in the programme, the household could reduce the number of diarrhoea episodes by 26% (5% level of significance) in the short term and 19% (10% level of significance) in the medium term.

The diarrhoea of other household members including the children could also be another option to measure the household morbidity. It shows that in the short term, the marginal effect of the intervention on the diarrhoea of any household member is reduced by 9.3%, which is significant at a 10% level. The medium term estimate shows the reduction of diarrhoea by 9.1% at a 5% level (Table A. 7.19, Appendix). The elasticity shows that there is a 14% (10% level of significance) decrease in the household diarrhoea after the intervention in the short term estimates and a 17% reduction in the medium term estimates (Table A. 7.19, Appendix).

Impact on child nutrition:

Child nutritional status has also improved after the intervention. Child nutritional status includes both continuous variables (height-for-age z-score, weight-for-age z-score, and weight-for-height z-score) and dummy variables according to the WHO standard (stunted, severely stunted, underweight, severely underweight, wasted and severely wasted). Stunted, underweight and wasted has the cut off value of z-scores by -2SD (standard deviation) and the severely option is set at -3SD of z-scores. It is noted that the impact on child nutrition only compared the two months exposure group and the one month exposure group. The study measured the height and weight measurement of children under-five in the baseline and endline only. In the baseline, no household received treatment and in the endline both types of household received the treatment but one group has two months of exposure and the other group has only one month of exposure to the treatment. So it is reasonable to establish the impact of intervention on the two month exposure group compared to the one month exposure group.

Child weight-for-age z-scores have increased after the intervention by 0.10 (10% level of significance) for the children who had two months of treatment exposure compared to the children who had one month of treatment exposure, even after controlling for the household characteristics (Table 4.5). BMDA operated are not significant in this analysis. Similarly, the weight-for-height z-scores have increased by 0.19 (10% level of significance) for the two month exposure group compared to the one month exposure group after controlling for the household covariates. There is no significant difference found for the height-for-age z-score of the child anthropometrics (Table 4.5). The robust standard error in the parentheses are clustered in the village level as the randomization was done at village level.

Apart from wasting of under-five children, the other measures of nutrition such as stunted, underweight and their severity are not statistically significant for the two month exposure group compared to the one month exposure group. It is extremely difficult to conclude that these results are not the impact of the intervention because there are no absolute control children in the follow ups. All that can be observed is the marginal benefit of two month exposure over one month exposure. It is possible that both groups have shown improvement but their difference is too low to become significant. It is observed from Table A. 7.20 (Appendix) that the two month exposure group could reduce the percentage of stunted and underweight children after the intervention compared to the one month exposure group, but this difference is not statistically significant.

Wasting of children under-five has been reduced by 5% for the two month exposure group compared to the one month exposure group, which is significant at a 5% level after controlling for the household covariates (Table A. 7.21, Appendix). This is clearly a result of the impact of the intervention, as other household covariates are not significant here except for some distance factors (Table A. 7.23). To see the details of other household characteristics explaining the outcome variables, such as diarrhoea and nutritional outcomes, refer to Table A. 7.22 and Table A. 7.23.

4.6 Cost-Benefit Analysis result

This section analyses the cost and benefit of the FHE intervention for rural households in Bangladesh. It estimates the cost of the project to implement the experiment and also estimates the benefit it achieves for the programme. The analysis of the cost-benefit ratio involves several assumptions:

- Average exchange rate 1 Euro=83 BDT (April 2015)

- Expected sustainability of the provided knowledge is 2 years

- Household participation cost in the programme is zero

- Households receive the programme equally

- The number of participating households in the village is 16 but considering the spill-over effect and assuming each household will influence 4 adjacent households then the total beneficiaries of the programme in a village becomes 64 households (=16*4) and the total number of children is 2273 (=512 household*1.11 average under-five (U5) children*4 adjacent households)

- The estimated average shadow price for participating in the training programme is EUR 1.28 for a household for two hours (including the travel time) which is estimated considering the agricultural wage labour in that area.

- Discount rates at 3, 5 and 10 percent.

4.6.1 Cost analysis

The FHE experiment is composed of three elements: (1) microbiological test results of drinking water and food preparing utensils; (2) one hour training of the household members for maintaining food safety; and (3) a hygiene messages poster for each household.

A microbiological test of drinking water and food utensils was performed to find out the number of *E. coli* colonies. For each household, water and food utensil testing were performed three times to compare with the control households. The three times total cost for testing the drinking water and food utensil in the laboratory amounts to EUR 5300 (Table A. 7.25). This cost is relatively lower than the market rate for testing due to economies of scale. The sample testing is EUR 3.45 for both water and food utensil testing in this project. But if someone wants to test the drinking water in the laboratory, it costs at least EUR 5 in the local university or in the medical college, excluding the transaction cost. The public health department of the government does not offer such facilities to the people for testing E. *coli* in water. The second component of the intervention is the hygiene messages poster, for which the estimated cost for all 512 posters is approximately EUR 600 (Table A. 7.25). Two experienced trainers were involved to provide the training and the information of microbiological test results and they were paid almost EUR 1000 in total for this project. In addition, two microbiologists collected the samples from the households and tested those samples in the laboratory, preparing the result for the households. They were paid almost EUR 500 each and for three months the total value was EUR 3000 (=2 person* EUR 500* 3 months). Assuming the full participation by all 512 households in this training programme by spending at least two hours (including the travel time cost) during the working time, the total shadow price for their forgone wage is EUR 650 (EUR 1.28*512) (Table A. 7.25). The total cost for implementing the experiment is EUR 10,550, which is expected to create outcomes for at least 2 years. In the Indonesian study, it was found that in the Lombok region the handwashing programme was practiced among 79% of the respondents after 2 years of the intervention (Wilson and Chandler 1993).

4.6.2 Benefit analysis

Hygiene is the most cost effective intervention among all the water and sanitation related interventions. Hygiene promotion can avert under-five mortality for 4% of the cost of the water and sanitation facilities for a similar impact, and this ratio is even lower in the presence of a private connection of water and sanitation infrastructure (Larsen 2003). Therefore, hygiene promotion is the most cost-effective intervention.

Providing FHE to rural households generates a broad range of economic and social benefits. Rather than focusing on the indirect benefit generated from the experiment, the direct benefits such as improved hygiene leading to reduction of diarrhoea and positive nutritional outcomes are discussed here. Other positive externalities such as the spill-over effect from the programme and environmental value of more cleanliness and reduced illness are not calculated here. This analysis only measures the direct economic and social value of the FHE programme. Other direct benefits such as money saved due to fewer incidences of diarrhoea and also care time saved due to fewer diseases are not included here. Such an approach could make the calculation more conservative.

The direct benefit that follows the hygiene education is the reduction of water and sanitation related diseases, especially diarrhoea. The communities in the study areas were not adequately maintaining hygiene especially food hygiene and as a result the nutrients from food intake are not properly absorbed in the children's intestines because of various infections. Children were found to be malnourished even if they were not affected by the frequent diarrhoea. Although the level of diarrhoea is almost 13%, the level of malnutrition in this area is about 36%. The level of malnutrition is not always caused by diarrhoea but by other factors, such as parasitic worm infections and environmental enteropathy. Improvement in WASH can lead to improvement in the environmental enteropathy which helps to increase the nutritional absorption to the human body, especially for children (Humphrey 2009). Therefore, WASH intervention has both an impact on the reduction of diarrhoea and an improvement in the nutritional outcome of children, along with better environmental enteropathy.

The value of nutritional gain is enormous for children due to the hygiene intervention. The Copenhagen consensus challenge paper in 2012 on hunger and malnutrition stated that USD 1 invested in Bangladesh for nutritional intervention can return a benefit of USD 30 (Hoddinott, Rosegrant, and Torero 2012). The study from Hoddinott, Alderman, Behrman, Haddad, & Horton (2013) found that for each dollar invested in nutritional intervention, USD 23 was generated in return and the income raised by an average of 11.3%. They found that a Bangladeshi child born today who receives the nutritional intervention as a package, and works from 21 to 50 years of age after growing up, generates a benefit of USD 2,311 in today's amount (at a discount rate of 5%) and a **quarter** (=0.25) of this benefit is attributable to better water, sanitation and hygiene related interventions (Hoddinott et al. 2013). Hence, according to their calculations, WASH intervention could generate USD 577.7 (=USD2311*0.25) in today's amount for a reduction in malnutrition for a single child. As a result, the total nutritional value for conducting the FHE programme can also be beneficial in the long run. The study evaluates the impacts of the intervention on child growth after two months of the programme implementation and the findings show that the percentage of wasting for children under-five is reduced by 5%. It is noted that the other nutritional outcomes such as percentage of stunting and underweight were not found to be significantly reduced in this short period of time as biological changes requires time. This analysis further assumes that the intervention would bring positive changes in the stunting and underweight as well because the nutritional outcome in term of z-scores were found to be significant for those variables in the study. Hence, the value of nutritional outcome that was produced from the FHE intervention can be evaluated in the following way:

Expected benefit from the reduction of wasting = (568 children less than 5 years) (5% reduction in wasting in two months due to FHE intervention) (0.5*24 months) (USD 577.7) = EUR 196,897

The findings show that in 512 households, there are 568 children under-five and 774 under-ten years of age. This study not only benefits the nutritional outcomes of children under-five, but also children under-ten. However, for the CBA calculation, the children under-five are only considered. The analysis further assumes that the reduction of wasting after the two month period would be the same for all other months in the two year span. The findings indicate that the intervention will have a strong impact in the first two years and relatively less of an impact after two years (Wilson and Chandler 1993). Because of the simplicity of the calculation, the analysis is strict to only two years' expected benefits. So the two years (24 months) is divided by half as the impact was calculated in a two month interval. According to Hoddinott et al. (2013), EUR 2311 is multiplied by 0.25, as a quarter is attributable to WASH intervention. The calculation here means that a 5% reduction of wasting from the 568 children would generate EUR 196897 for a two year period.

Another direct benefit from this intervention is the reduction of diarrhoea, which also has economic value to the society. The study area, lacking adequate hygiene practices and knowledge on water and food utensil quality, would enhance the societal objective in this regard. This key societal objective can be measured by the Value of Statistical Life (VSL) of an individual. The VSL for a Bangladeshi person is not readily found in the literature except in the study of Mahmud (2006) and Miller (2000). They calculated that the mean VSL is USD 1,000,000 for a Bangladeshi in 2000 (Miller 2000), which is shown in Table 4.6.

To identify the value of aggregate gain from a reduction of diarrhoea in the intervention, it is required to estimate the value of Disability-Adjusted Life Years (DALY). DALY comprises two other options: Years Lost due to Disability (YLD) for people living with disability and Years of Life Lost (YLL) due to premature death. Using discounting and age weights, the WHO calculated the DALYs for infancy death at 33, and death at 5-20 years of age at about 36 DALYs (Mathers, Ezzati, and Lopez 2007; WHO 2017). The value per DALY can be determined by dividing the VSL by the number of DALYs assigned for a premature death, which is equivalent to USD 27,778 (Table 4.6).

Table 4.6: Calculation of value per DALY for Bangladesh

Country	GNI per capita, PPP adjusted, World Bank, 2015	Value of Statistical Life (VSL)	DALY equivalent for a premature death, on average	Value per DALY
USA	$57,540	$8,914,553	36	$247,626
Bangladesh	$3,560	$1,000,000	36	$27,778

Source: For Column 3, USA (Viscusi and Aldy 2003) and Bangladesh (Mahmud 2006; Miller 2000); column 4 (WHO 2017).

To identify the number of DALYs averted for this intervention, it is necessary to calculate the YLD and YLL averted separately. In Bangladesh, the average number of diarrhoea cases per child per year is 4.25 (Pathela et al. 2006), and each case of diarrhoea persists for 3.3 days (IFPRI 2016). The average disability weight for diarrhoea is 10 percent (Cameron et al. 2011; Prüss et al. 2002a). The number of beneficiary households is 512 in total, in which there are 568 children under-five or 774 children under-ten. So, when calculating the benefit, only 568 children under-five are used. The morbidity based DALY averted is calculated as 0.024 because of the FHE intervention (Table 4.7).

YLD= (568 beneficiaries) (4.25 diarrhoea cases per year per child) (3.3 days per diarrhoea case) (1/365) (10% disability weight) (11% reduction of diarrhoea) =0.024; and

The value averted each year= 0.024*27,778= USD 667 ≈ EURO 620 (Assuming 1 USD=EURO 0.93

The WHO reports that the under-five mortality rate per 1,000 live births in 2013 was 41.1 and among this, 6 are as a result of diarrhoea (WHO 2014). Assuming FHE intervention would reduce death caused by diarrhoea at the same rate as the incidence reduction (11%), there are 0.375 mortality based DALYs averted each year.

YLL= (568 beneficiaries) (6/1000 lives lost) (11% reduction) = 0.375; and

The value of YLL averted each year= 0.375*27,778=USD 10,413 ≈ EURO 9,684

During the first year, the benefit from averted DALYs is almost (EURO620 +EURO9684) =EURO 10,305. As it is assumed that the FHE intervention is expected to provide benefit for at least two years from the beginning of the intervention, so in the second year the expected benefit would be EURO 10,005 at a 3% discount rate which is also applied in Sijbesma & Christoffers (2009) and in the following year, the value would be EURO 9,713. So the total discounted value for the first two years is EURO 20,310 and for the first three years is EURO 30,023 (Table A. 7.24). For the sake of simplicity, we assume only the first two years. A different discount rate is also applied, such as 5% and 10%, to see the different values of CBAs.

Table 4.7: Summary of value per DALY calculation

YLD (Morbidity)		YLL (Mortality)	
Average Annual diarrhoea case per child	4.25	Proportion of lives lost to diarrhoea each year per 1000 child	0.006
Average persistence days for diarrhoea	3.3	Reduction to diarrhoea due to intervention (Table 4.4)	11%
Disability weight for diarrhoea	10%		
DALY averted each year	0.024	DALY averted each year	0.375
Value of YLD averted each year	€620	Value of YLL averted each year	€9,684

Source: Author’s calculation

4.6.3 CBA analysis

Table A. 7.25 summarizes the cost and benefit separately and also shows the CBA ratio at the discount rate of 3%. The CBA ratio shows the return of an investment in the hygiene practices. The estimated CBA ratio for the FHE intervention in the rural households in Bangladesh is 20.59 at a 3% discount rate (Table 4.8). The CBA also conducted some simulations considering the other discount rates such as 5% and 10%, in 3 different scenarios. Table 4.8 shows the CBA scenario for three groups of children such as U5 (under-five) and U10 (under-ten) children of the participant households and U5 children considering the spill over effect to an adjacent 4 households. In the first scenario, the CBA ratio for U5 children of the participant households is close to 20.5 at any discount rate of 3%, 5% or 10% (Table 4.8). Similarly, if the number of the beneficiary children is increased, such as also considering the children who are between 5 and 10 years old, a CBA ratio of 28 is shown in the third column of Table 4.8. It is very logical that FHE in the household will not only benefit the U5 children but also all the U10 children in the participating households. The CBA ratio has increased from 20.5 to 28 because of the increase in the beneficiary pool. If the pool is further increased, such as incorporating the U5 children from the adjacent 4 households (given that the experiment was intended to create some spill-over effect in the village level), the CBA ratio is increased to 82. This increase in the ratio is because of the increased number of children benefiting from the same cost. However, there is not much difference among the different discount ratios. Therefore, following the conservative approach of only using U5 children from the participating households, it can be said that the CBA ratio is 20.5. This means that for EUR 1 invested in the hygiene intervention, such as water quality information, training and hygiene message posters, a value would be generated of a minimum EUR 20 to the household. A similar result is also found in the study of Sijbesma and Christoffers (2009) where they found that USD 1 invested in the sanitation and hygiene programme returns USD 5-28.

Table 4.8: CBA ratio in different discount rates and age groups

Discount rate until two years	Under five (U5) children in the treated households (N=568)	Under 10 (U10) children in the treated households (N=778)	Assuming spillover effect at least to 4 households around a treated household for U5 children (N=568*4=2273)
3%	20.59	28.05	82.38
5%	20.57	28.03	82.31
10%	20.53	27.97	82.15

Source: Author’s calculation

4.7 Discussion

The FHE intervention has produced some short and medium term outcomes in terms of quality of drinking water and food utensils, hygiene practices, WATSAN investment and child nutritional outcomes. A RCT experiment has established the causality of the intervention on the above outcomes. The intervention is not intended to cause a change in the water and sanitation infrastructure as it mostly focuses on the hygiene aspects of individuals.

There is a high impact on handwashing and other hygiene related practices in the short run. Households used more soaps and also washed their hands after visiting the toilet and before feeding the children. They also cleaned their water jar with soap after the intervention. The FHE experiment did not increase the WATSAN investment, monthly cost of water and the sanitation maintenance cost of households, which supports the findings of Grossman (1972a) who concluded that education improves health by increasing the allocation of efficiency (increased practice of healthy behaviour) or productive efficiency (having greater health from the same set of inputs). The FHE improves the hygiene practices which is expressed in the WATSAN index, handwashing scores, food hygiene index and socio-environmental index. It can therefore be said that FHE enhances the allocative efficiency as well as the productive efficiency of the human health, especially for the children under-five.

The insignificance in the medium term outcomes doesn't necessarily mean that there is no impact, rather it suggests no benefit of further improvement if it continues to one additional month. This might be because the saturation or the return already touches the maximum where the marginal rate of return (slope) is zero. This finding of non-significance in the medium term also supports the argument of Luoto et al. (2011) who found that people respond to water treatment technologies more immediately after the information received, meaning recent messages are more salient. In the limited attention model, people only respond to the salience of the outcomes and the data has proved this.

In terms of the nutritional outcome, the impact should be studied carefully because it only shows the impact of one additional month of exposure to the treatment. This is because the study didn't include any absolute control households in the endline survey. As the anthropometric measurements of children (height and weight) were taken in the baseline and endline, it is not possible to measure the impact in the short term as well as the medium term. As both groups (treatment and control) had exposure to treatment, it can only be distinguished between the lengths of exposure. So Table 4.5, Table A. 7.20 and Table A. 7.21 represent the coefficient and the marginal benefit of having one more month of exposure to treatment. Weight-for-age z-scores and the weight-for-height z-scores have improved because of the two months exposure to the treatment compared to the one month. The large gain is found in the weight-for-height z-scores where two month exposure households could increase the z-score over the one month exposure group after controlling for the household characteristics. One of the major gains of the intervention is the reduction in the percentage of children with wasting by 5%. This means that although there is no absolute control group, the length of programme exposure of two months generates this impact compared to the one month exposure counterpart. This result implies that it requires time to gain some benefits in terms of the nutritional health outcome. This might be the lag effect of more hygiene in the first month. The reduction of diarrhoea in children under-five was 12% in the short term and 8% in the medium term which is the major gain of this intervention and contributed to the reduction of the percentage of wasted children. The intervention also helped to reduce the diarrhoea incidence of all household members by 9% in both the short and medium term analysis.

From the primary result of the intervention, it is evident that most of the indicators of the water, sanitation and hygiene have been improved from baseline to endline. This intervention is a small doable action that the government and non-government organizations can follow. The E*. coli* testing of water and food preparing utensils can be also done on a selective basis to identify the presence of bacteria. A poster of hygiene messages can make a huge difference to rural people. The cartoon scratching of the poster draws the attention of the children and also allows the women of the households to explain it and make a story of their own. Therefore, there is enormous scope for replication of this poster which can be used both in rural and urban areas where hygiene is a serious issue. Public health institutes of the government and NGOs can use the poster to implement their hygiene agendas.

One of the major limitations of this experiment is that it is not possible to identify the individual impact of each component of the FHE intervention. It only shows the impact of a package. Therefore, it might be interesting to know about the impact of training participation or else only the impact of water quality information, but because of the design of the experiment, this cannot be done. However, another limitation of the experiment was the time span constraint for measuring the possible change in child nutrition. The study has only considered one month of exposure but it is very difficult to find any reasonable impact within this short time. It requires several months even to get the gain in nutrition, which is already proved in the data. It should be considered that the lag effect of intervention-benefit may come a few months later. As this experiment is a randomized phased-in evaluation, there was no absolute control group of households, so the benefit of absolute impact of FHE on nutritional outcome cannot be measured, which is also a limitation of the survey. The impact of substituting this type of programme for electronic media such as Television and Radio is also not known, which thus needs further research. However, such a type of programme could be launched at a low cost for the betterment of the society. This intervention clearly has an impact on hygiene behaviour, water and food utensil quality, and reduces diarrhoea and wasting of children. FHE seems to be extremely relevant for this rural community in the long run, as in the short run we have already proved some gains.

The study finds that access to improved water and sanitation infrastructure is the precondition for a reduction in child malnutrition but these are not sufficient factors, a finding also observed in Mahmud and Mbuya (2015). WASH interventions only moderately help to increase the height and weight of children but do not significantly reduce the level of malnutrition (Dangour et al., 2013). Bangladesh has successfully combated the severity of diarrhoea in past decades but hasn't been able to reduce the level of malnutrition in children under-five. Studies found that it is not the diarrhoea but the environmental enteropathy which works as a causal pathway from poor sanitation and hygiene to malnutrition (Humphrey 2009). Keeping livestock and poultry inside the household's living room can increase the environmental enteropathy and increases the level of infections in children, which results in child stunting (George et al., 2015; D. Headey et al., 2016; Headey & Hirvonen, 2016). So it is the matter of personal and environmental hygiene which mainly impacts on child malnutrition besides water and sanitation infrastructure and household income and education. In this study it was found that household per capita expenditure is associated with the reduction of stunting and underweight in children under-five. FHE treatment in this study could only reduce the percentage of wasted children by almost 5% in a two month observation period, but the long term impact is not known. However, this impact magnitude for reducing malnutrition is not a big change maker. There needs to be investment in three areas: water-sanitation infrastructure, environmental cleanliness including the removal of animal faeces, and proper personal and food hygiene. Food hygiene intervention can explain a certain amount of malnutrition. Household income and education as a whole need to be addressed first in order to tackle these three goals. Therefore, it is necessary to invest in time, money, knowledge and effort for combating malnutrition in children.

The CBA analysis of the FHE programme shows a ratio of 20.5, which means that for USD 1 invested, the hygiene programme will return USD 20.5. Considering the discount rate of 3%, 5% and 10%, the CBA ratio still falls in the range of 20.5. The value of the ratio increases if the number of children is increased, such as U10 and the U5 children including the adjacent households. For children U10, the CBA ratio is 28 and for U5 with the adjacent households, it is 82. This result therefore shows that the investment return in the hygiene intervention is enormous and it is a minimum of 20 times the investment amount. A similar result is also found in the study of Sijbesma and Christoffers (2009).

4.8 Conclusion

FHE intervention for the rural households is intended to change the behavioural aspect of their hygiene practices which may lead to an improvement in the nutritional status of children under-five. The RCT experiment has produced short and medium term outcomes which are important from a nutritional point of view. FHE has improved the handwashing practices of the household especially after visiting the toilet and before feeding children. The intervention has improved the quality of drinking water and the food preparing utensils without significant investment in this sector. The E. *coli* level in the drinking water and the food preparing utensils is reduced by simple cleaning of utensils with soaps. Households have also started to treat their drinking water before use by filtering or boiling. These positive changes in the hygiene behaviour have brought a significant change in the nutritional outcome of children under-five. Diarrhoea among children as well as for the whole household has been reduced significantly due to intervention in the short and medium term. The major gains in the nutritional outcomes such as stunting, underweight and wasting require sufficient time to visualize; albeit, the wasting situation has improved after the intervention and is immediately visible after two months. Child nutritional outcomes such as weight-for-age z-score and weight-for-height z-score have increased after two months of exposure to the intervention. The FHE experiment has produced some immediate results and is expected to produce more fruitful results in the long term analysis. However, this study has a time limitation to capture all the future results. Further research is therefore necessary to evaluate the long term outcome of the FHE intervention on the rural households. The CBA of the FHE experiment on rural households shows a return of 20 times the invested amount in the hygiene intervention and more benefits gained in the long run, allowing for the spill over of the programme in the programme villages. It is therefore proved that the FHE programme is beneficial to the rural households and may also be beneficial to urban settings.

Chapter Five

5 Overall conclusions and policy implications

The water, sanitation and hygiene related burden of disease is one of the most important aspects of human capital formulation. WASH and nutrition are closely related; inadequate water, sanitation and hygiene impair the nutritional benefits to humans, especially to children. Over the last decade, Bangladesh has achieved remarkable success in terms of access to improved water, sanitation, and the reduction of diarrhoea, but it has still not managed to solve the problem of malnutrition. More than 40 percent of children under-five are malnourished in Bangladesh. The issue of better coverage of WASH and diarrhoea reduction versus the level of malnutrition is a complex dilemma to investigate. As WASH is a system issue, it needs to be investigated with many other complementary factors to establish the possible synergy effects with malnutrition. The economics of WASH and nutrition involves time, money, effort, care, knowledge, location, culture and institution; all of which should be assessed alongside the system issues of WASH and nutrition.

This study strives to find a solution by identifying the possible linkage of WASH and nutrition. The general objective of this research is to identify how the AG-WATSAN nexus matters for the health outcomes in the marginalized rural areas of Bangladesh and how household and community investment can benefit the economic and health outcomes of these people. In this dissertation, three closely related issues are discussed in the context of a marginalized rural setting: (1) linkages of the AG-WATSAN nexus in terms of their synergies and trade-offs in determining household health; (2) the impact of publicly provided piped water supply on food and water quality, sanitation, hygiene and the health of rural households in north-western Bangladesh; and (3) how a behavioural change experiment 'FHE' impacts on food and water quality, sanitation, hygiene and the health of those households. These three interrelated issues are analysed based on a national representative sample survey and an experimental sample survey, for which an RCT experiment of FHE was conducted.

WASH and nutrition are interlinked through the environmental conditions by direct and indirect pathways. There exists synergies and trade-offs among the three domains of water, sanitation, and hygiene; the effect of a specific domain is very much dependent on the other domains in causing malnutrition. To address the nexus of WASH and nutrition, there are three direct channels to be addressed. The first channel is through diarrhoea, the leading global cause for under-five mortality and morbidity. Diarrhoea which runs several episodes ruins appetite, the immune system, the absorption of nutrients, and the physical and cognitive development of children under-five. The second link for addressing WASH and malnutrition is different types of infections. Inadequate sanitation facilities such as open defecation or the unimproved sanitation infrastructure increase the risk of infestation of soils by eggs and larvae of helminth (which is a parasitic worm) which are transmitted into the human body through eating contaminated water and food or walking barefoot on contaminated soil.

Besides humans, agricultural activities such as livestock and poultry also possess the same risk because improper management of cow dung contaminates the soil, water and the environment and creates infections for humans, especially children. The third link between WASH and malnutrition is through environmental enteropathy. In the environment of inadequate sanitation infrastructure and poor sanitary conditions, there exist plenty of pathogens. These pathogens are ingested by the children in many ways and may damage the gut and lead to poor absorption of nutrients which is known as environmental enteropathy or environmental enteric dysfunction (EED). Apart from this systematic direct effect there are other indirect effects that exist for the WASH and nutrition relationship. Among these the economic factor is the most prominent, whereby time for water collection, income, education, market, geographical locations, culture and institutions are the most important factors. For the nutritional outcomes of children under-five, time and money has a significant trade off with care as the more time is invested in water collection, purification and hygiene maintenance, the less time there is for child care. Significant investment of water and sanitation infrastructure is needed at the household and community level.

Using a nationally representative panel data from IFPRI on rural Bangladesh, this study finds that improved water and sanitation infrastructure has reduced diarrhoea related morbidity both in child and adult members. Education, household dietary diversity score and water purification are found to reduce the diarrhoea incidence in children under-five. However, household income does not have any impact on reducing diarrhoea incidence. Irrigating households poses some risk of diarrhoea incidence as it may worsen the situation if this is not followed by adequate hygiene and water purification. The study also finds that access to improved sanitation and water infrastructure has a positive association with child nutrition. Agriculture plays a dual role of nutrition sensitive and nutrition specific objectives. Agriculture plays a positive role in reducing malnutrition if and only if the personal, food and environmental hygiene is maintained properly. Therefore, it is the hygiene which mostly matters for a reduction of malnutrition even after controlling for the other household characteristics such as household size, income, education and location. For maintaining proper hygiene, investment is required for personal, food and environmental cleanliness. Expenditure on cleanliness and hygiene is a long term investment which provides not only nutritional benefit for children under-five, but also reduces other diseases and morbidity.

The study finds that in rural Bangladesh the role of improved water and sanitation infrastructure is weakly related to malnutrition in children under-five. The findings only show that the reduction of the percentage of stunted and underweight children is due to access to improved water infrastructure but did not indicate any significant impact on it of access to improved sanitation. Improved sanitation access is found to increase the height-for-age z-scores a small amount, which does not guarantee the reduction in stunting. A similar result is found in the meta-analysis of the Cochrane review, in which WASH intervention only moderately increased weight and height but did not significantly have an impact on reducing malnutrition. Therefore, access to improved water and sanitation infrastructure is not adequate to reduce malnutrition in children under-five. As discussed above, it is partly the environmental enteropathy which also causes malnutrition in Bangladeshi children under-five. Several national surveys in Bangladesh have found that almost 40% of households do not have any arrangement for handwashing in their premises and even if they have an arrangement, adequate water and soap are not present there.

A multi-sectoral approach is needed to address the severe problem of malnutrition in children. Among these, adequate food, environmental health and child care are associated with a reduction of stunting in children. Adequate environmental health means improved water and sanitation infrastructure, and handwashing and child care means antenatal care, immunization, exclusive breast- feeding, Mother's BMI, iron-folic acid supplementation for mother and access to health clinics. One study found that Bangladeshi children who have all three dimensions, such as adequate food, environmental health and care, possess a 30% lower prevalence of stunting than those who have none of these. In Bangladesh all these three dimensions –food, environmental health and care- are equally needed; one alone cannot tackle the problem. Water and sanitation quality is a necessary condition but not sufficient. To maintain lower diarrhoea rates, infections and environmental enteropathy, proper hygiene should be maintained from human and animal waste, agricultural activities and industrial pollution. Therefore time, money, knowledge and effort are necessary to invest in to combat malnutrition in children.

The second objective of this study was to analyse the impact of a publicly provided piped water supply on food and water quality, sanitation, hygiene and the health of rural households in north-western Bangladesh. Using primary data from 512 households from the BMDA irrigation area of north-western Bangladesh, the study identified the number of households with the piped drinking water facilities in their premises and also analysed the impact of it considering the non-piped water households counterpart. Using the quasi-experimental setting and propensity score matching, it is found that although having pure drinking water from the piped water network, households do not gain any benefit in water quality, sanitation, hygiene and health outcomes over the non-piped water household counterpart. In terms of food safety, no improvement was found in the quality of drinking water measured by *E. coli* count per 100 ml of water at the POU (i.e. the pots and jars used to store it). Food utensils were tested positive for *E. coli* in both the control and treatment group, thus showing no improvement through the BMDA intervention. One of the explanations for the lack of any gain from piped water is that households in both groups did not maintain adequate hygiene practices. Hygiene behaviour such as handwashing with soap after defecation or before feeding children also did not improve. Finally, the study did not find evidence of health benefits, such as decreased diarrhoea incidence in children under-five or improved nutritional outcomes such as stunting, underweight and wasting. Although access to BMDA piped water in the premises is subject to a fee, it seems this incentive mechanism is not strong enough to improve water behaviour or its outcomes: treated households are as poor as the non-treated in terms of maintaining hygiene and water quality, possibly because of a lack of information.

There exists a low demand for health prevention measures when the possible benefit comes after a substantial time period; and in most cases people underestimate it and are less likely to follow the measures. In such cases the natural response is to provide them with the information of prevention measures which may bring behavioural changes for better health. As the households in the study area had no prior knowledge of contamination of *E. coli* bacteria with drinking water and food preparing utensils and its perniciousness, a FHE experiment was conducted to observe their adaptation in favour of hygiene education and how much it can add value, on top of water and sanitation infrastructure, towards health outcomes.

Applying an RCT experiment, this study investigates the impact of FHE on the quality of drinking water and food utensils, sanitation, hygiene and health outcomes in marginalized rural households in north-western Bangladesh. The treatment combined three elements- microbiological test results of contamination from *E. coli* bacteria in drinking water and on food preparing utensils, training to maintain food hygiene at household level and a poster of hygiene messages to be hung in the dining area. These three elements were applied uniformly to all treated households. The findings show that the FHE treatment has a positive impact on the microbiological quality of drinking water and kitchen utensils. The percentage of households with *E. coli* in the drinking water was reduced after one and two months of intervention, compared with the control group. Households' handwashing with soaps after defecation and before eating meals have increased too, and households' hygiene practices and cleanliness have increased significantly in the treated households. These improvements in the hygiene practices did not increase the water, sanitation and hygiene related investment significantly more than the control counterpart. By only increasing their cleanliness in the water management and handwashing practices with soaps, households could reduce the percentage of child diarrhoea by 12% after one month and 8.4% in two months. In addition, the FHE treatment has significantly contributed to reducing wasting of children under-five by 5% in the treated households. The other nutritional statuses such as stunting and underweight are also showing progress but are not statistically significant in only a two month period. This result indicates that with the presence of improved water and sanitation infrastructure, hygiene education could make a considerably large difference for those who observe it.

This RCT result of the FHE establishes the relationship that is found in the first and second question of the study. As an answer to the first question, the findings show that the synergy effect of the three domains only works when there is adequate water, sanitation and hygiene practices present in the household. Otherwise one will reduce the effect of others. When the FHE experiment was applied to the treatment and control household with the same settings of water and sanitation infrastructure, it produced a significant effect on nutritional outcomes. This RCT result also supports the findings of the second question. For the answer to the second question, the findings show that BMDA piped water accessed households observes the same level of hygiene as the non-piped accessed areas households, which does not lead to any significant nutritional difference for them. RCT intervention has changed the outcome of the second question and produced a significant impact following the intervention.

The economic interpretation of this study is that significant investment is required for WASH and nutrition. WASH is a system issue and there is a need to ensure that all the domains of water, sanitation and hygiene work properly. After the WASH infrastructure is established, the use of this infrastructure needs to be ensured; however, the optimal outcome has not been reached here. Bangladesh is currently facing this dilemma. Despite the 97% coverage of improved water, 88% coverage of improved sanitation and 1% of open defecation, the percentage of stunting and underweight in children under-five is above 40 percent. The water and sanitation infrastructure and the reduction of diarrhoea did not solve the problem of malnutrition in Bangladesh. Different surveys including this one have found that the coverage of adequate hygiene at different levels (personal, household, work, school) is very low. As a result, the benefit of WASH is not fully visible in the nutritional outcome. It could be argued that this it is mostly the income factor that determines the nutritional outcome. But this study also finds that income is not the only determinant of malnutrition. Income produces only 15% deference between the lowest income quintile and the highest income quintile for stunting and underweight of children under-five. Even in the highest income quintile, 33% of children are stunted and underweight in rural Bangladesh. Therefore, besides income there are other factors such as parental education, hygiene knowledge, children immunization and household dietary diversity that determine the nutritional status of children under-five.

To reduce the malnutrition problem in Bangladesh, both nutrition sensitive and nutrition specific intervention is important. WASH intervention is nutrition sensitive and partly affects the nutritional outcome. Investment in WASH and nutrition has a higher return than the cost. The CBA of the FHE experiment has been established in this study. The findings show that for one euro invested in the FHE experiment, there is a return of 20 euros. Therefore, hygiene education is a cost effective way to increase the nutritional status of children under-five.

5.1 Policy implication

The current study identifies some policies implications for the WASH and nutrition sector, as follows:

1) WASH is a system issue, so investment is required to establish improved water and sanitation infrastructure. Without improved water and sanitation infrastructure, health benefits are greatly hampered. Policies may be implemented to encourage the establishment of proper water and sanitation infrastructure, especially in the marginalized areas where potable water is very scarce. Government and non-governmental organizations may take initiatives to make sanitation infrastructure available to those areas, as the market does not work in those places.

2) Water quality is an important determinant of health. The study found *E. coli* bacteria in the drinking water of the rural households. Investment is required to purify water in the

households by filtering, boiling or any other methods. Households most often do not know about this faecal contamination of drinking water because of the unavailability of water testing in the rural setting. Government public health institutes should test water in the rural households and also offer the rural households a chance to test their drinking water by themselves.

3) Food hygiene is an important determinant of health. Food is contaminated by many other bacteria including the pathogen bacteria *E. coli*. Food and food preparing utensils are contaminated through poor water quality, unhygienic handing of water and food utensils, cross contamination of raw meat and fish, uncooked food etc. Proper food hygiene maintenance is required to ensure the food safety at the household level. In this regard, government and non-governmental organizations should educate and train the household members about the possible contamination of food by pathogen bacteria as a result of inadequate hygiene. Food hygiene promotion should be continuous so that each and every member in the household understands the urgency of maintaining proper hygiene.

4) Agriculture plays a vital role in nutrition. Studies have found that the improper maintenance of agricultural activities from livestock and poultry can create poor environmental conditions which may cause an infection in the intestine and environmental enteropathy for children. Therefore, proper hygiene should be maintained in the agricultural area. Unfortunately most of the agricultural households in the rural areas do not follow adequate hygiene methods to maintain better environmental cleanliness, and as a result nutritional benefit is not reached. Proper hygiene programs should address these issues to make the farmers and the households more aware.

5) Households should invest more money to maintain food hygiene at the household level by purchasing water containers which can be cleaned easily, separating meat and vegetable knives, washing food utensils with improved water and keeping the food in a safe place away from dust, dirt and animals. Therefore, households should invest some money to buy the necessary equipment. Boiling water may be costly for them, so using a water filter can greatly benefit the households with a lower cost. The government can facilitate low priced good quality water filters for the marginalized areas where potable water is scarce, as there is a trade-off between water quantity and hygiene maintenance.

6) In addition to all other interventions, income and education are also relevant factors for determining health. The government should offer adequate health services to the rural areas, as in many places the health services are not available. Government and NGOs should work together to educate them in how to deal with WASH to benefit nutrition, especially when there is a natural disaster, flood, drought and any other crisis time. Proper WASH maintenance is also required in the community level, workplaces, hospitals and schools. Government should also provide income and health support to the marginalized poor people who cannot access the market.

5.2 Outlook for further research

WASH and nutrition requires further research in the following areas:

1) An integrated approach to water, sanitation and hygiene to address nutrition is not yet adequate. The substitution effects among the three domains are not known for addressing malnutrition.

2) Agriculture and WASH is poorly researched; proper experimental design of agriculture and WASH is required.

3) Most research studies water, sanitation and hygiene with nutritional outcomes separately but a major part of malnutrition is unexplained or poorly explained with regards to Bangladesh. An experimental design is necessary to observe how diarrhoea, infections and environmental enteropathy explain the level of malnutrition and their effect of substitution.

4) The experimental research outcome of water collection and water storage in the household is not known with regards to water quality and their possible trade-offs. Household demand for water purification also needs to be tested for rural households.

5) The FHE experiment comprises three components: water quality information, hygiene training and a hygiene message poster. All three are given as a package, but their individual effect on health outcomes and their level of substitution is not known. Further research is needed for rural as well as urban settings.

6) The RCT experiment of FHE could only measure the short term effect (after one month) and the medium term effect (after two months). The long term effect of FHE is not known in the same rural setting. Therefore, further research is needed to test the long term effect of FHE and the sustainability of a hygiene education programme.

7) Further research is needed to capture the effect of an incentive mechanism for WASH and the nutritional behaviour of the household. An experimental design of a gender specific intervention could also add value in this regard.

6 Reference

Abadie, Alberto et al. 2004. "Implementing Matching Estimators for Average Treatment Effects in Stata." *Stata journal* (1):1–18. Retrieved (http://scholar.harvard.edu/files/imbens/files/sjpdf-1.html_.pdf).

Agustina, Rina et al. 2013. "Association of Food-Hygiene Practices and Diarrhea Prevalence among Indonesian Young Children from Low Socioeconomic Urban Areas." *BMC public health* 13(1):977. Retrieved May 21, 2014 (http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3813984&tool=pmcentrez&rendertype=abstract).

Ahmed, Akhter. 2013. *Bangladesh Integrated Household Survey (BIHS) 2011-2012 (Dataset)*. International Food Policy Research Institute (IFPRI), Washington, D.C.

Anderson, Andrea, and Erin Harris. 2005. "An Introduction to Theory of Change." *The Evaluation Exchange (produced by Harvard Family Research Project)* XI(2):12.

Assefa, Mulubirhan, and Abera Kumie. 2014. "Assessment of Factors Influencing Hygiene Behaviour among School Children in Mereb-Leke District, Northern Ethiopia: A Cross-Sectional Study." *BMC Public Health* 14(1):1000. Retrieved (http://www.biomedcentral.com/1471-2458/14/1000).

Baker, Sarah M., and Jeroen H. J. Ensink. 2012. "Helminth Transmission in Simple Pit Latrines." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 106(11):709–10.

Becker, Gary S. 1976. *The Economic Approach to Human Behavior*. Chicago, IL: University of Chicago Press.

Becker, SO, and M. Caliendo. 2007. "Sensitivity Analysis for Average Treatment Effects." *The stata journal* 7(1):71–83. Retrieved (http://papers.ssrn.com/sol3/papers.cfm?abstract_id=958699).

Becker, So, and a Ichino. 2002. "Estimation of Average Treatment Effects Based on Propensity Scores." *Stata Journal* 2(4):358–77. Retrieved (http://www.labor-torino.it/pdf_doc/ichino.pdf).

Briscoe, J., R. G. Feachem, and MM Rahaman. 1986. *Evaluating Health Impact: Water Supply, Sanitation, and Hygiene Education*. Ottawa, Ontario: IDRC, ICDDR,B and London School of Hygiene and Tropical Medicine.

Brown, Joe et al. 2013. "Relative Benefits of on-Plot Water Supply over Other 'Improved' Sources in Rural Vietnam." *Tropical Medicine and International Health* 18(1):65–74.

Brown, Kenneth H. 2003. "Diarrhea and Malnutrtion at Symposium: Nutrition and Infection, Prologue and Progress Since 1968." *Journal of Nutrition* 133:328S – 332S. Retrieved (http://jn.nutrition.org/content/133/1/328S.full.pdf).

Cairncross, Sandy, and Vivian Valdmanis. 2006. *Water Supply, Sanitation, and Hygiene Promotion*. 2nd ed. edited by Dean T. Jamison et al. Oxford University Press and the World Bank.

Caliendo, Marco, and Sabine Kopeinig. 2008. “Some Practical Guidance for the Implementation of Propensity Score Matching.” *Journal of Economic Surveys* 22(1):31–72.

Cameron, John, Paul Hunter, Paul Jagals, and Katherine Pond. 2011. *Valuing Water, Valuing Livelihoods Guidance on Social Cost-Benefit Analysis of Drinking-Water Interventions, with Special Reference to Small Community Water Supplies*. London, UK: WHO, IWA. Retrieved (http://apps.who.int/iris/bitstream/10665/44635/1/9781843393108_eng.pdf).

Cawley, John, and Christopher J. Ruhm. 2011. “The Economics of Risky Health Behaviors.” *Handbook of Health Economics* 2:95–199.

Chen, Yu et al. 2007. “Reduction in Urinary Arsenic Levels in Response to Arsenic Mitigation Efforts in Araihazar, Bangladesh.” *Environmental health perspectives* 115:917–23.

Colwell, Rita R. et al. 2003. “Reduction of Cholera in Bangladeshi Villages by Simple Filtration.” *Proceedings of the National Academy of Sciences of the United States of America* 100:1051–55.

Curtis, Val et al. 2011. “Hygiene: New Hopes, New Horizons.” *The Lancet infectious diseases* 11(4):312–21. Retrieved May 8, 2014 (http://www.ncbi.nlm.nih.gov/pubmed/21453872).

Dangour Alan, D. et al. 2013. “Interventions to Improve Water Quality and Supply, Sanitation and Hygiene Practices, and Their Effects on the Nutritional Status of Children.” *Cochrane Database of Systematic Reviews* (8). Retrieved (http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD009382.pub2/abstract).

Devoto, Florencia, Esther Duflo, Pascaline Dupas, William Parienté, and Vincent Pons. 2012. “Happiness on Tap: Piped Water Adoption in Urban Morocco.” *American Economic Journal: Economic Policy* 4(4):68–99.

DFID. 2013. *Water, Sanitation and Hygiene*. Evidence Paper. UKaid, London.

DiPrete, Thomas a, and Markus Gangl. 2004. “Assessing Bias in the Estimation of Causal Effects: Rosenbaum Bounds on Matching Estimators and Instrumental Variables Estimation with Imperfect Instruments.” *Sociological Methodology* 34:271–310.

Dube, Blessing, and James January. 2012. “Factors Leading to Poor Water Sanitation Hygiene among Primary School Going Children in Chitungwiza.” *Journal of Public Health in Africa* 3(1):7. Retrieved (http://publichealthinafrica.org/index.php/jphia/article/view/jphia.2012.e7).

Engle, Patrice L., Purnima Menon, and Lawrence Haddad. 1999. “Care and Nutrition: Concepts and Measurement.” *World Development* 27(8):1309–37.

Escamilla, V. et al. 2011. “Effect of Deep Tube Well Use on Childhood Diarrhoea in Bangladesh.” *Bulletin of the World Health Organization* 89:521–27.

Esrey, S. A., J. B. Potash, L. Roberts, and C. Shiff. 1991a. “Effects of Improved Water Supply and Sanitation on Ascariasis, Diarrhoea, Dracunculiasis, Hookworm Infection, Schistosomiasis and Trachoma.” *Bulletin of the World Health Organization* 69(5):609–

21.

Esrey, S. A., J. B. Potash, L. Roberts, and C. Shiff. 1991b. “Effects of Improved Water Supply and Sanitation on Ascariasis, Diarrhoea, Dracunculiasis, Hookworm Infection, Schistosomiasis, and Trachoma.” *Bulletin of the World Health Organization* 69(5):609–21.

Esrey, Steven A. 1996. “Water , Waste , and Well-Being : A Multicountry Study.” *American Journal of Epidemiology* 143(6):608–23.

European Commission. 2013. *Investing in Health*. Brussels.

Fewtrell, Lorna et al. 2005a. “Water, Sanitation, and Hygiene Interventions to Reduce Diarrhoea in Less Developed Countries: A Systematic Review and Meta-Analysis.” *The Lancet infectious diseases* 5(1):42–52. Retrieved (http://www.ncbi.nlm.nih.gov/pubmed/15620560).

Fewtrell, Lorna et al. 2005b. “Water, Sanitation, and Hygiene Interventions to Reduce Diarrhoea in Less Developed Countries: A Systematic Review and Meta-Analysis.” *The Lancet infectious diseases* 5(1):42–52.

Gamper-Rabindran, Shanti, Shakeeb Khan, and Christopher Timmins. 2010. “The Impact of Piped Water Provision on Infant Mortality in Brazil: A Quantile Panel Data Approach.” *Journal of Development Economics* 92(2):188–200. Retrieved (http://dx.doi.org/10.1016/j.jdeveco.2009.02.006).

Gatzweiler, Franz W., and Heike Baumüller. 2014. “Marginality—A Framework for Analyzing Causal Complexities of Poverty.” Pp. 27–40 in *Marginality: Addressing the Nexus of Poverty, Exclusion and Ecology*, edited by Joachim Von Braun and Franz W. Gatzweiler. SpringerOpen.

George, C. M. et al. 2015. “Fecal Markers of Environmental Enteropathy Are Associated with Animal Exposure and Caregiver Hygiene in Bangladesh.” *American Journal of Tropical Medicine and Hygiene* 93(2):269–75. Retrieved (http://www.ajtmh.org/cgi/doi/10.4269/ajtmh.14-0694).

GoB. 2012. *The MDGs: Bangladesh Progress Report 2011*. Gerneral Economics Division, Bangladesh Planning Commission, Dhaka.

GoB, and UNDP. 2009. *Millennium Development Goals Need Assessment & Costing 2009-2015 Bangladesh*. Dhaka.

Grossman, Michael. 1972a. “On the Concept of Health Capital and the Demand for Health.” *Journal of Political Economy* 80(2):223–55. Retrieved (http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=5052415&lang=pt-br&site=eds-live&authtype=sso).

Grossman, Michael. 1972b. “The Shadow Price of Health BT - The Demand for Health: A Theoretical and Empirical Investigation.” Pp. 11–30 in *The Demand for Health: A Theoretical and Empirical Investigation*. Retrieved (http://www.nber.org/chapters/c3484.pdf\npapers2://publication/uuid/91451448-718A-428F-ACCF-0B5BE3CEF0B3).

Günther, Isabel, and Youdi Schipper. 2013. "PUMPS, GERMS AND STORAGE: THE IMPACT OF IMPROVED WATER CONTAINERS ON WATER QUALITY AND HEALTH." *Health Economics* 22(7):757–74. Retrieved (http://doi.wiley.com/10.1002/hec.2852).

Guiteras, R., J. Levinsohn, and a. M. Mobarak. 2015. "Encouraging Sanitation Investment in the Developing World: A Cluster-Randomized Trial." *Science* (April):science.aaa0491 – . Retrieved (http://www.sciencemag.org/content/early/2015/04/15/science.aaa0491).

Guiteras, Raymond, James Levinsohn, and Ahmed Mushfiq Mobarak. 2015. "Encouraging Sanitation Investment in the Developing World: A Cluster-Randomized Trial." *Science* 348(6237):903–6. Retrieved (http://www.sciencemag.org/cgi/doi/10.1126/science.aaa0491).

Hasan, Mohammad Monirul. 2015. "Food Hygiene Education (FHE) for the Rural Households in Bangladesh." Retrieved (http://www.zef.de/fileadmin/webfiles/downloads/projects/watsan/poster_food_save_and_clean_en.jpg).

Hasan, Mohammad Monirul, and Nicolas Gerber. 2016. *The Impacts of Piped Water on Water Quality, Sanitation, Hygiene and Health in Rural Households of North-Western Bangladesh - a Quasi-Experimental Analysis*. Bonn, Germany.

Hawkes, Corinna, and Marie Ruel. 2006. "The Links between Agriculture and Health: An Intersectoral Opportunity to Improve the Health and Livelihoods of the Poor." *Bulletin of the World Health Organization* 84:984–90.

Headey, D. et al. 2016. "Is Exposure to Animal Feces Harmful to Child Nutrition and Health Outcomes? A Multicountry Observational Analysis." *American Journal of Tropical Medicine and Hygiene*. Retrieved (http://www.ajtmh.org/cgi/doi/10.4269/ajtmh.16-0270).

Headey, Derek, and Kalle Hirvonen. 2016. "Is Exposure to Poultry Harmful to Child Nutrition? An Observational Analysis for Rural Ethiopia" edited by Jacobus van Wouwe. *PLOS ONE* 11(8):e0160590. Retrieved (http://dx.plos.org/10.1371/journal.pone.0160590).

Heinrich, Carolyn, Alessandro Maffioli, and Gonzalo Vazquez. 2010. *A Primer for Applying Propensity-Score Matching: Impact-Evaluation Guidelines*. Retrieved (http://www.iadb.org/document.cfm?id=35320229).

HLPE. 2015. *Water for Food Security and Nutrition*. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Hoddinott, John, Harold Alderman, Jere R. Behrman, Lawrence Haddad, and Susan Horton. 2013. "The Economic Rationale for Investing in Stunting Reduction." *Maternal & Child Nutrition* 9:69–82. Retrieved (http://doi.wiley.com/10.1111/mcn.12080).

Hoddinott, John, Mark Rosegrant, and Maximo Torero. 2012. *Copenhagen Consensus Challenge Paper on Hunger and Malnutrition*. Washington D.C. Retrieved (http://www.copenhagenconsensus.com/sites/default/files/hungerandmalnutrition.pdf).

van der Hoek, Wim, Sabiena G. Feenstra, and Flemming Konradsen. 2002. "Availability of Irrigation Water for Domestic Use in Pakistan: Its Impact on Prevalence of Diarrhoea and Nutritional Status of Children." *Journal of health, population, and nutrition* 20(1):77–84. Retrieved (http://www.ncbi.nlm.nih.gov/pubmed/12022163).

Hoque, Bilqis, T. Juncker, RB Sack, M. Ali, and KMA Aziz. 1996. "Sustainability of a Water, Sanitation and Hygiene Education Project in Rural Bangladesh: A 5-Year Follow-Up." *Bulletin of the World Health Organization* 74:431–37. Retrieved (http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2486877&tool=pmcentrez&rendertype=abstract).

Hubley, J. 1993. *Communicating Health: An Action Guide to Health Education and Health Promotion*. Macmillan. Retrieved (https://books.google.de/books?id=BbeFAAAAIAAJ).

Humphrey, Jean H. 2009. "Child Undernutrition, Tropical Enteropathy, Toilets, and Handwashing." *Lancet* 374(9694):1032–35. Retrieved April 30, 2014 (http://www.ncbi.nlm.nih.gov/pubmed/19766883).

Hunter, Paul R., Alan M. MacDonald, and Richard C. Carter. 2010. "Water Supply and Health." *PLoS Medicine* 7.

Huo, A. et al. 1996. "A Simple Filtration Method to Remove Plankton-Associated Vibrio Cholerae in Raw Water Supplies in Developing Countries." *Applied and environmental microbiology* 62:2508–12.

Huq, Anwar et al. 2010. "Simple Sari Cloth Filtration of Water Is Sustainable and Continues to Protect Villagers from Cholera in Matlab, Bangladesh." *mBio* 1.

Hutton, Guy, and Laurence Haller. 2004. *Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level*. Geneva, Switzerland. Retrieved (http://www.who.int/water_sanitation_health/wsh0404.pdf).

IFPRI. 2016. "Bangladesh Integrated Household Survey (BIHS) 2015." Retrieved (http://dx.doi.org/10.7910/DVN/BXSYEL).

ILO. 2012. *Working towards Sustainable Development: Opportunities for Decent Work and Social Inclusion in a Green Economy*. Geneva, Switzerland. Retrieved (http://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_181836.pdf).

ILO. 2014. *World of Work Report 2014: Developing with Jobs*. Geneva, Switzerland. Retrieved (http://www.ilo.org/wcmsp5/).

Jalan, J., and M. Ravallion. 2003. "Does Piped Water Reduce Diarrhoea for Children in Rural India." *Journal of Econometrics* 112:153–73.

Jalan, Jyotsna, and Martin Ravallion. 2003. "Estimating the Benefit Incidence of an Antipoverty Program by Propensity-Score Matching." *Journal of Business & Economic Statistics* 21(March 2015):19–30.

James, C. 2011. *Theory of Change Review. A Report Commissioned by Comic Relief*. Retrieved (http://mande.co.uk/blog/wp-content/uploads/2012/03/2012-Comic-Relief-Theory-of-Change-Review-FINAL.pdf).

Javaid, N. et al. 1991. *Interactions between Infections, Malnutrition and Iron Nutritional Status in Pakistani Infants. A Longitudinal Study.*

Kaiser, J. 2015. "For Toilets, Money Matters." *Science* 348(6232):272–272. Retrieved (http://www.sciencemag.org/cgi/doi/10.1126/science.348.6232.272).

Keusch, Gerald T. et al. 2006. "Diarrheal Diseases." Pp. 371–87 in *Disease control priorities in developing countries*, edited by Dean T. Jamison et al. Oxford University Press and the World Bank.

Kinley, Britt T. 2011. *Identifying and Modeling Perceptions of Risk Factors in Hand Hygiene during Healthcare Operations*. North Carolina.

Klasen, Stephan, Tobias Lechtenfeld, Kristina Meier, and Johannes Rieckmann. 2012. "Benefits Trickling Away: The Health Impact of Extending Access to Piped Water and Sanitation in Urban Yemen." *Journal of Development Effectiveness* 4(4):537–65. Retrieved (http://www.tandfonline.com/doi/abs/10.1080/19439342.2012.720995).

Konikow, Leonard F. 2011. "Contribution of Global Groundwater Depletion since 1900 to Sea-Level Rise." *Geophysical Research Letters* 38(17).

Kremer, Michael, and Rachel Glennerster. 2011. "Improving Health in Developing Countries." Pp. 201–315 in *Handbook of Health Economics*, edited by Mark V. Pauly, Thomas G. Mcguire, and Pedro P. Barros. Elsevier B.V. Retrieved (http://linkinghub.elsevier.com/retrieve/pii/B9780444535924000049).

Kremer, Michael, Jessica Leino, Edward Miguel, and Alix Peterson Zwane. 2011. "Spring Cleaning: Rural Water Impacts, Valuation, and Property Rights Institutions." *Quarterly Journal of Economics* 126:145–205.

Larsen, B. 2003. "Hygiene and Health in Developing Countries: Defining Priorities through Cost - Benefit Assessments." *International journal of environmental health research* 13 Suppl 1:S37–46. Retrieved (http://www.ncbi.nlm.nih.gov/pubmed/12775378).

Lim, Stephen S. et al. 2012. "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990–2010: A Systematic Analysis for the Global Burden of Disease Study 2010." *The Lancet* 380(9859):2224–60. Retrieved (http://linkinghub.elsevier.com/retrieve/pii/S0140673612617668).

List, John a., Sally Sadoff, and Mathis Wagner. 2011. "So You Want to Run an Experiment, Now What? Some Simple Rules of Thumb for Optimal Experimental Design." *Experimental Economics* 14(4):439–57.

Luoto, Jill, David Levine, and Jeff Albert. 2011. *Information and Persuasion: Achieving Safe Water Behaviors in Kenya*. CA, USA.

Mahmud, Iffat, and Nkosinathi Mbuya. 2015. *Water, Sanitation, Hygiene, and Nutrition in Bangladesh: Can Building Toilets Affect Children's Growth?* Washington D.C.: The World Bank. Retrieved (http://elibrary.worldbank.org/doi/book/10.1596/978-1-4648-0698-8).

Mahmud, Minhaj. 2006. *Contingent Valuation of Mortality Risk Reduction in Developing Countries: A Mission Impossible?*

Mantel, N., and W. Haenszel. 1959. "Statistical Aspects of the Analysis of Data from Retrospective Studies of Disease." *Journal of the National Cancer Institute* 22(4):719–48.

Mara, Duncan, Jon Lane, Beth Scott, and David Trouba. 2010. "Sanitation and Health." *PLoS Medicine* 7.

Martines, J., M. Phillips, and RGA Feacham. 1993. "Diarrheal Diseases." in *Disease Control Priorities in Developing Countries*, edited by DT Jameson, WH Mosley, AR Measham, and JL Bobadillo. Oxford: Oxford University Press.

Mathers, Colin D., Majid Ezzati, and Alan D. Lopez. 2007. "Measuring the Burden of Neglected Tropical Diseases: The Global Burden of Disease Framework" edited by Simon Brooker. *PLoS Neglected Tropical Diseases* 1(2):e114. Retrieved (http://dx.plos.org/10.1371/journal.pntd.0000114).

Miller, Ted R. 2000. "Variations between Countries in Values of Statistical Life." *Journal of Transport Economics and Policy* 34(2):169–88.

MOF. 2016. *Bangladesh Economic Review*. Dhaka, Bangladesh: Ministry of Finance, Government of Bangladesh. Retrieved (http://mof.gov.bd/en/budget1/16_17/ber/en/D. Appendices_BER-2016-Final.pdf).

Nath, K. J., Sally Bloomfield, and Martin Jones. 2006. "Household Water Storage , Handling and Point-of-Use Treatment." *Http://Www.Ifh-Homehygiene.Org*.

Newman, J. 2013. *How Stunting Is Related to Having Adequate Food, Environmental Health and Care: Evidence from India, Bangladesh, and Peru.* Washington D.C.: The World Bank.

OECD. 2011. *Benefits of Investing in Water and Sanitation: An OECD Perspective*. Paris.

OECD. 2012. *OECD Environmental Outlook to 2050: The Consequences of Inaction*. Paris.

Pathela, Preeti et al. 2006. "Diarrheal Illness in a Cohort of Children 0–2 Years of Age in Rural Bangladesh: I. Incidence and Risk Factors." *Acta Paediatrica* 95(4):430–37. Retrieved (http://doi.wiley.com/10.1080/08035250500444875).

Pope, Jaren C. 2006. *Limited Attention, Asymmetric Information, and the Hedonic Model*. ProQuest.

Prüss, Annette, David Kay, Lorna Fewtrell, and Jamie Bartram. 2002a. "Estimating the Burden of Desease from Water, Sanitation and Hygiene at a Global Level." *Environmental Health Perspectives* 110(5):537–42.

Prüss, Annette, David Kay, Lorna Fewtrell, and Jamie Bartram. 2002b. "Estimating the Burden of Disease from Water, Sanitation, and Hygiene at a Global Level." *Environmental health perspectives* 110:537–42.

Prüss-Üstün, Annette, Robert Bos, Fiona Gore, and Jamie Bartram. 2008. "Safer Water, Better Health." *World Health Organization* 53. Retrieved (http://www.who.int/quantifying_ehimpacts/publications/saferwater/en/).

Prüss-Ustün, Annette et al. 2014. "Burden of Disease from Inadequate Water, Sanitation and Hygiene in Low- and Middle-Income Settings: A Retrospective Analysis of Data from 145 Countries." *Tropical Medicine and International Health* 19(8):894–905. Retrieved (http://doi.wiley.com/10.1111/tmi.12329).

Rodell, Matthew, Isabella Velicogna, and James S. Famiglietti. 2009. "Satellite-Based Estimates of Groundwater Depletion in India." *Nature* 460(7258):999–1002.

Root, Graham P. M. 2001. "Sanitation, Community Environments, and Childhood Diarrhoea in Rural Zimbabwe." *Journal of Health, Population and Nutrition* 19(2):73–82. Retrieved (http://www.jhpn.net/index.php/jhpn/article/view/79/68).

Rosenbaum, Paul R. 2002. "Sensitivity to Hidden Bias." Pp. 105–70 in *Observational Studies*. New York: Springer-Verlag New York.

Rosenbaum, PR, and DB Rubin. 1983. "The Central Role of the Propensity Score in Observational Studies for Causal Effects." *Biometrika* 70(1):41–55. Retrieved (http://biomet.oxfordjournals.org/content/70/1/41.short).

Rubin, Donald, and Neal Thomas. 2000. "Combining Propensity Score Matching with Additional Adjustments for Prognostic Covariates." *Journal of the American Statistical Association* 95(450):573–85. Retrieved (http://www.jstor.org/stable/2669400\npapers2://publication/uuid/448D5D3C-3E5F-4969-A58A-07CC97C934C2).

Rufener, Simonne, Daniel Mäusezahl, Hans Joachim Mosler, and Rolf Weingartner. 2010. "Quality of Drinking-Water at Source and Point-of-Consumption-Drinking Cup as a High Potential Recontamination Risk: A Field Study in Bolivia." *Journal of Health, Population and Nutrition* 28(1):34–41.

Schmidt, Wolf-Peter. 2014. "The Elusive Effect of Water and Sanitation on the Global Burden of Disease." *Tropical medicine & international health : TM & IH* 00(00):1–6. Retrieved May 9, 2014 (http://www.ncbi.nlm.nih.gov/pubmed/24576060).

Shamsudduha, Mohammad, Richard G. Taylor, Kazi M. Ahmed, and Anwar Zahid. 2011. "The Impact of Intensive Groundwater Abstraction on Recharge to a Shallow Regional Aquifer System: Evidence from Bangladesh." *Hydrogeology Journal* 19(4):901–16. Retrieved (http://link.springer.com/10.1007/s10040-011-0723-4).

Shields, Katherine F., Robert E. S. Bain, Ryan Cronk, Jim a Wright, and Jamie Bartram. 2015. "Association of Supply Type with Fecal Contamination of Source Water and Household Stored Drinking Water in Developing Countries: A Bivariate Meta-Analysis." *Environmental Health Perspectives* 123(12):1222–31. Retrieved (http://www.ncbi.nlm.nih.gov/pubmed/25956006).

Shiklomanov, I. A., and John C. Rodda. 2003. *World Water Resources at the Beginning of the Twenty-First Century*. Retrieved (http://catdir.loc.gov/catdir/samples/cam034/2002031201.pdf).

Sijbesma, Christine, and Trea Christoffers. 2009. "The Value of Hygiene Promotion: Cost-Effectiveness Analysis of Interventions in Developing Countries." *Health Policy and Planning* 24(6):418–27.

Smith, Jeffrey a., and Petra E. Todd. 2005. *Does Matching Overcome LaLonde's Critique of*

Nonexperimental Estimators?

Spears, Dean, and Lawrence James Haddad. 2015. *The Power of WASH: Why Sanitation Matters for Nutrition*. Washington D.C.: International Food Policy Research Institute (IFPRI). Retrieved (http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129074).

Steele, Marina, and Joseph Odumeru. 2004. "Irrigation Water as Source of Foodborne Pathogens on Fruit and Vegetables." *Journal of food protection* 67(12):2839–49.

Stern, E. et al. n.d. *Broadening the Range of Designs and Methods for Impact Evaluations. Report of a Study Commissioned by the Department of International Development*. London, UK.

Takanashi, Kumiko et al. 2009. "Survey of Food-Hygiene Practices at Home and Childhood Diarrhoea in Hanoi, Viet Nam." *Journal of health, population, and nutrition* 27(5):602–11. Retrieved (http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2928088&tool=pmcentrez&rendertype=abstract).

Taylor, Richard G. 2013. "Ground Water and Climate Change." *Nature Climate Change* 3(4):322–29.

Tsegai, Daniel, Florence Mcbain, and Bernhard Tischbein. 2013. *Water, Sanitation and Hygiene: The Missing Link with Agriculture*. Bonn.

UNDP. 2016. *UNDP Support to the Implementation of the 2030 Agenda for Sustainable Development*. New York, NY. Retrieved (http://www.undp.org/content/undp/en/home/librarypage/sustainable-development-goals/undp-support-to-the-implementation-of-the-2030-agenda/).

UNEP. 2012. *Greening Economy. Briefing Paper: Finance*. Geneva, Switzerland. Retrieved (http://www.unep.org/greeneconomy/).

UNICEF. 1990. *Strategy for Improved Nutrition of Children and Women in Developing Countries*. New York, NY.

Unicef, and WHO. 2015. *Progress on Sanitation and Drinking Water- 2015 Update and MDG Assessment*. Geneva, Switzerland: WHO Press.

United Nations. 2015. *The Millennium Development Goals Report 2015*. New York, NY. Retrieved (https://visit.un.org/millenniumgoals/2008highlevel/pdf/MDG_Report_2008_Addendum.pdf).

UN-WATER. 2015. *UN Water Annual Report*. Geneva, Switzerland. Retrieved (http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/UN-Water_Annual_Report_2015_web.pdf).

Viscusi, W. Kip, and Joseph E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates Throughout the World." *Journal of Risk and Uncertainty* 27(1):5–76.

Waddington, Hugh, Birte Snilstveit, Howard White, and Lorna Fewtrell. 2009. "Water , Sanitation and Hygiene Interventions to Combat Childhood Diarrhoea in Developing

Countries." *International Initiative for Impact Evaluation (3ie)* (August).

Webb, Amy L. et al. 2006. "A Simple Index to Measure Hygiene Behaviours." *International Journal of Epidemiology* 35(6):1469–77.

WHO. 2012. *Global Costs and Benefits of Drinking-Water Supply and Sanitation Interventions to Reach the MDG Target and Universal Coverage*. Geneva, Switzerland. Retrieved (http://www.who.int/water_sanitation_health/publications/2012/global_costs/en/).

WHO. 2014. *Levels and Trends in Child Mortality*. World Health Organization, Geneva.

WHO. 2016. "Causes of Child Death: Global Health Observatory Data Repository." Retrieved March 2, 2016 (http://apps.who.int/gho/data/view.main.CM3002015WBDCP-CH3?lang=en).

WHO. 2017. *WHO Methods and Data Sources for Global Burden of Disease Estimates 2000-2015*. Geneva, Switzerland. Retrieved (http://www.who.int/healthinfo/global_burden_disease/GlobalDALYmethods_2000_2015.pdf?ua=1).

van Wikj, Christine, and Tineke Murre. 2003. "Motivating Better Hygiene Behaviour." P. 47 in *Importance for Public Health Mechanism of Change*, edited by Steven Esrey. The Hague, The Netherlands. Retrieved (http://www.unicef.org/wash/files/behav.pdf).

Wilson, Jane M., and Glenys N. Chandler. 1993. "Sustained Improvements in Hygiene Behaviour amongst Village Women in Lombok, Indonesia." *Transactions of the Royal Society of Tropical Medicine and Hygiene* 87(6):615–16.

Wolf, Jennyfer et al. 2014. "Systematic Review: Assessing the Impact of Drinking Water and Sanitation on Diarrhoeal Disease in Low- and Middle-Income Settings: Systematic Review and Meta-Regression." *Tropical Medicine and International Health* 19(8):928–42.

World Bank. 2006. *Repositioning Nutrition as Central to Development : A Strategy for Large Scale Action*. Washington DC: World Bank. Retrieved (https://openknowledge.worldbank.org/handle/10986/7409).

World Bank. 2012. *Global Monitoring Report 2012: Food Prices, Nutrition, and the Millennium Development Goals*. Washington D.C.: The World Bank. Retrieved (http://elibrary.worldbank.org/doi/book/10.1596/978-0-8213-9451-9).

Wright, Jim, Stephen Gundry, and Ronan Conroy. 2004. "Household Drinking Water in Developing Countries: A Systematic Review of Microbiological Contamination between Source and Point-of-Use." *Tropical Medicine and International Health* 9(1):106–17.

WSP. 2012. *The Economic Impacts of Inadequite Sanitation in Bangladesh*. Washington D.C.

Yosef, Sivan. 2016. "Clean Is Nourished: The Links between WASH and Nutrition." Pp. 73–78 in *Nourishing millions: Stories of change in nutrition*, edited by Stuart Gillespie, Judith Hodge, Sivan Yosef, and Rajul Pandya-Lorch. Washington D.C.: International Food Policy Research Institute (IFPRI). Retrieved (http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/130403).

Zwane, Alix Peterson, and Michael Kremer. 2007. *What Works in Fighting Diarrheal Diseases in Developing Countries? A Critical Review*.

7 Appendices

7.1 Appendix: Definition

Improved drinking water	According to the WHO guidelines, water from piped-water network, private tube-well, community tube-well, rainwater, protected springs or protected ring well.
Unimproved drinking water	According to the WHO guidelines, water from river, pond, canal, or irrigation water from shallow or deep tube well.
Improved sanitation	According to the WHO guidelines, access to improved sanitation is characterized as bricked toilet, sanitary toilet with or without flash.
Unimproved sanitation	According to the WHO guidelines, open defecation, hanging toilet, community latrine and other kind of latrines are regarded as unimproved sanitation.
Irrigating households	Irrigating households are the households those who are actively engaged with irrigation for agriculture.
Food Hygiene Education	Food Hygiene Education is the package of three component such as: (1) Information of *E. coli* test results of drinking water and food utensils, (2) Group training on Food Hygiene, and (3) Hygiene information poster for each households.
Stunted/underweight/wasted	Defined as when z -scores are less than -2SD (standard deviation)
Severely stunted/ severely underweight/ severely wasted	Defined as when z -scores are less than -3SD (standard deviation)
E. *coli*	Escherichia coli O157 (E. *coli*) is the most commonly recommended indicator of fecal contamination in water and food utensils prescribed by the WHO. E. *coli* is the type of pathogenic bacteria which may lead to hemorrhagic diarrhoea, and to kidney failure leading to cause the deaths of under five children, old parents and person with challenged immune system.
Child Dietary Diversity Score (CDDS)	CDDS is the simple average of 8 food groups consumed by household in a specific period of time prescribed by the Food and Nutrition Technical Assistance (FANTA) of USAID.

Household Dietary Diversity Scores (HDDS)	HDDS is the simple average of 12 food groups consumed by household in a specific period of time prescribed by the Food and Nutrition Technical Assistance (FANTA) of USAID.
Handwashing scores	Household handwashing score is the average of handwashing in different critical times of a day. The score ranges between 0 (lowest) and 9 (highest). It implies that household with handwashing score of 9 wash their hand in all critical or recommended times.
WATSAN hygiene Index	WATSAN hygiene index is the simple average of cleanliness of the water, sanitation, food, personal and surroundings of the house. It ranges from 1(worst) to 3(best). This index is based on the interviewer observation of the household and their cleanliness.
Food Hygiene Index	Households' food hygiene index is the average of different food hygiene related information that households practices after the intervention. It ranges from 0 (worst) to 14 (best).
Socio-environmental Cleanliness Index	Socio-environmental cleanliness index is average of different cleanliness related information which is observed by the Interviewer. It ranges from 1 (good) to 3 (bad).

7.2 Appendix of chapter two

Table A. 7.1: Types of water source infrastructure in rural Bangladesh

Types of water source	BIHS 2011-12 (N=5098)		BIHS 2015 (N=5098)	
	N	%	N	%
Supply Water (piped) inside house	55	1.08	33	0.65
Supply Water (piped), outside	19	0.37	85	1.67
Own tube well	2,467	48.39	2,870	56.3
Community tube-well	1,788	35.07	1,905	37.37
Rain water	6	0.12	4	0.08
Ring Well/ Indara	8	0.16	28	0.55
Pond/River/ Canal	145	2.84	142	2.79
Shallow tube-well for irrigation	0	0	3	0.06
Deep tube-well for irrigation	1	0.02	14	0.27
Others	609	11.95	14	0.27

Source: Author's calculation from IFPRI BIHS data sets.

Table A. 7.2: Types of toilet facilities in rural Bangladesh

Types of toilet facilities	BIHS 2011-12 (N=5098)		BIHS 2015 (N=5098)	
	N	%	N	%
Open defecation	168	3.3	121	2.37
Hanging toilet (fixed place)	972	19.07	452	8.87
Pucca/ bricked toilet (unsealed)	2,480	48.65	2,282	44.76
Sanitary toilet without flush (water sealed)	1,323	25.95	2,147	42.11
Sanitary toilet with flash (water sealed)	27	0.53	72	1.41
community latrine	122	2.39	13	0.26
other	6	0.12	11	0.22
Pearson chi2(6) = 543.2907 Pr = 0.000				

Source: Author's calculation from IFPRI BIHS data sets.

Table A. 7.3: Nutritional status of under five children in Bangladesh

	Round 1 (2011-12) full sample of Under five children (N=2399)	Round 2 (2015) full sample of Under five children (N=2806)	Difference R1-R2
Stunted	47%	38%	9%
Severely stunted	18%	12%	6%
Underweight	33%	33%	0%
Severely underweight	9%	8%	1%
Wasted	12%	16%	-4%
Severely wasted	4%	4%	0%

Source: Author's calculation from IFPRI BIHS data sets.

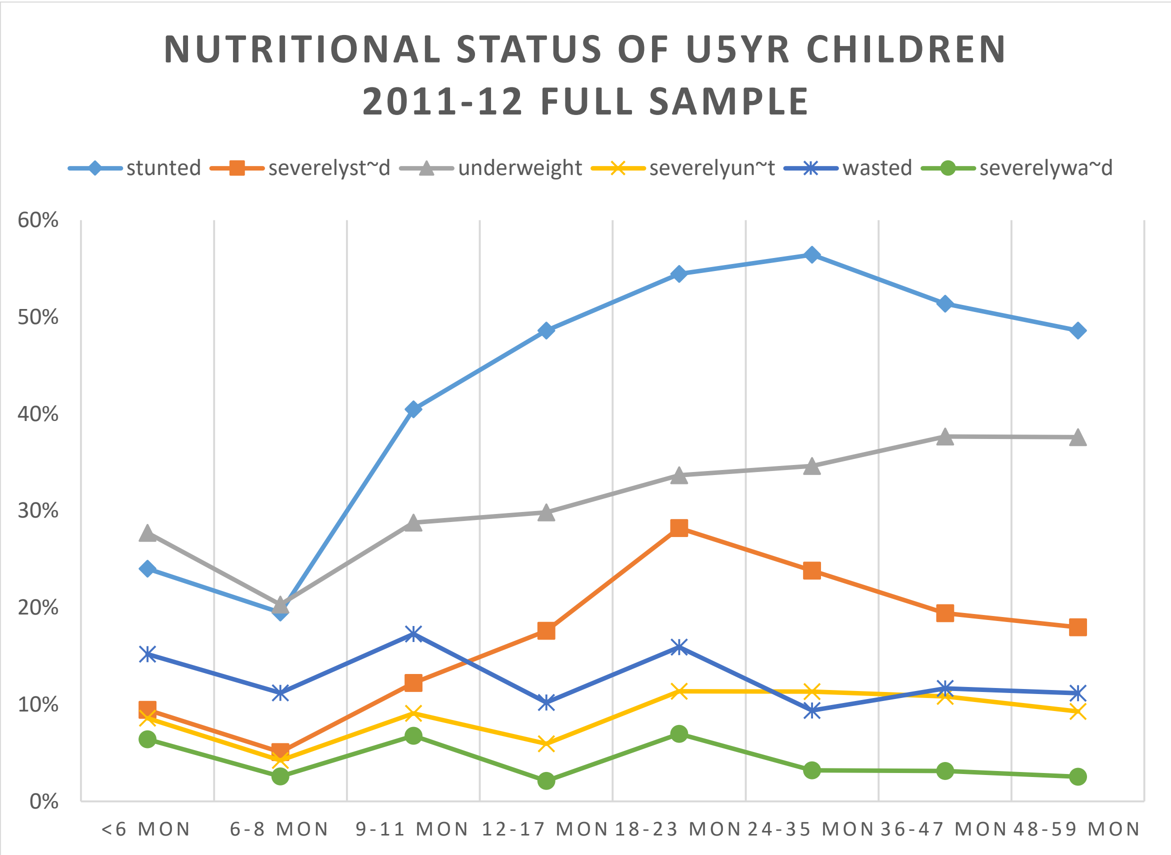


Figure A. 7.1: Nutritional status of under five children in 2011-12 (full sample, N=2402)
Source: Author's calculation based on IFPRI BIHS data sets.

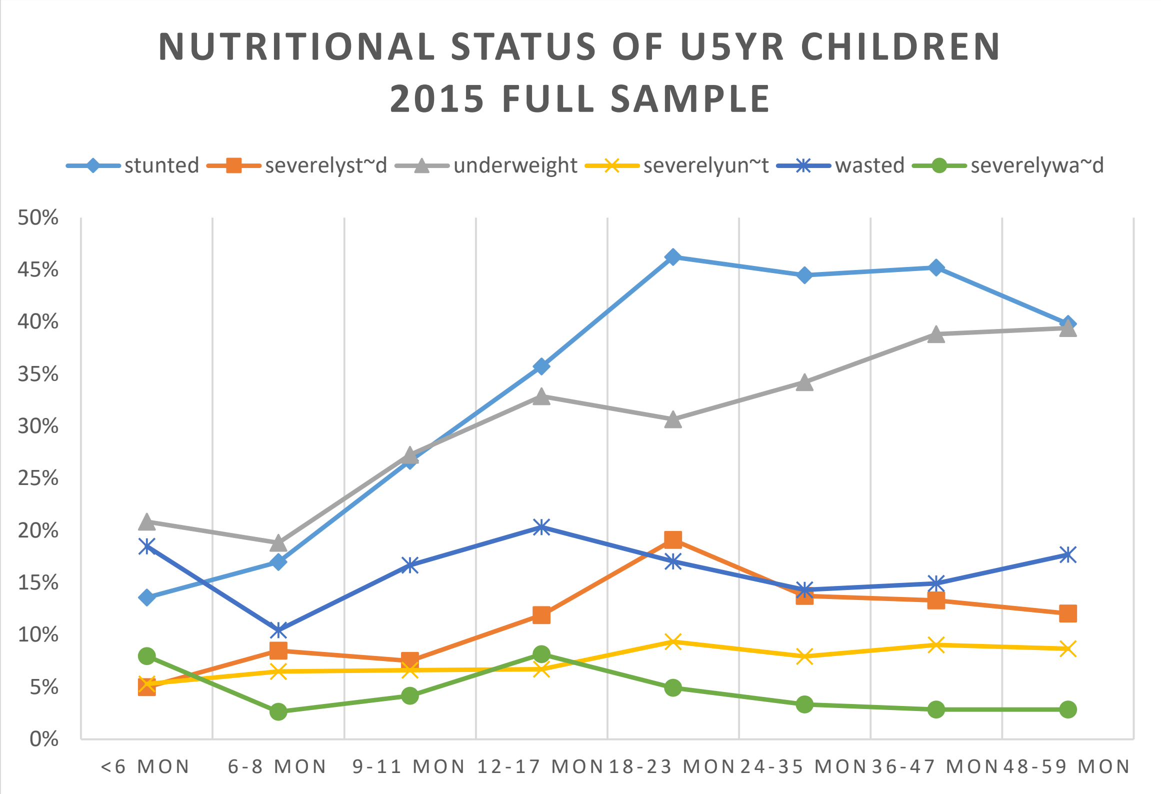


Figure A. 7.2: Nutritional status of under five children in 2015 (full sample, N=2806)
Source: Author's calculation based on IFPRI BIHS datasets.

Table A. 7.4: Panel data regression results on nutritional outcomes

	height-for- age z-score	Weight-for- age z-score	Weight-for-height z-score
	co-efficient (standard error)	co-efficient (standard error)	co-efficient (standard error)
Improved Sanitation	1.194*** (0.433)	0.248 (0.304)	-0.559 (0.388)
Improved drinking Water access	1.576* (0.829)	1.711*** (0.664)	0.553 (0.715)
Improved general Water access	0.398 (0.400)	0.123 (0.351)	-0.179 (0.402)
Percentage of unimproved san user in village	0.017 (0.013)	0.008 (0.011)	0.003 (0.013)
Child age month	-0.003 (0.034)	-0.005 (0.026)	-0.033 (0.026)
Age-sq of child	0.000 (0.001)	-0.000 (0.000)	0.000 (0.000)
Immunization as of date complete for youngest child	1.155** (0.560)	0.593 (0.429)	-0.287 (0.304)
Child Dietary Diversity Score	-0.122* (0.071)	-0.118* (0.071)	-0.033 (0.081)
Mother's BMI	0.089 (0.127)	0.136** (0.062)	0.112 (0.111)
Received antenatal service more than once	0.060 (0.458)	-0.043 (0.337)	0.052 (0.452)
Knowledge on exclusive breastfeeding (yes=1)	-0.452 (0.364)	-0.273 (0.333)	-0.139 (0.399)
When to give supplementary food?(six month=1)	-0.060 (0.340)	-0.090 (0.259)	-0.095 (0.255)
Maximum years of schooling	0.097 (0.068)	0.122* (0.067)	0.079 (0.070)
Household size	-0.044 (0.145)	0.170* (0.098)	0.267 (0.166)
HH total income (BDT)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
Cultivatable land (Acre)	-0.875** (0.360)	-0.761** (0.298)	-0.006 (0.309)
Irrigating households	1.428*** (0.512)	0.757** (0.377)	-0.275 (0.461)
Number of livestock	0.311*** (0.082)	0.193*** (0.068)	-0.023 (0.076)
Tested for arsenic contamination	0.655** (0.316)	0.334 (0.284)	-0.031 (0.347)
Monthly expenditure on HH cleanliness	-0.003* (0.002)	-0.007*** (0.002)	-0.005*** (0.002)
Floor (Square-feet)	-0.000*** (0.000)	-0.000** (0.000)	0.000 (0.000)
Roof: tin	-3.022*** (0.912)	-2.332*** (0.758)	-0.016 (0.458)
Distance: health centre (Km)	-0.061*	-0.038	0.017

	(0.037)	(0.029)	(0.026)
Distance: small market (Km)	0.135	0.045	-0.057
	(0.095)	(0.098)	(0.097)
Distance: nearest town (Km)	-0.031*	-0.003	0.034**
	(0.017)	(0.011)	(0.016)
_cons	-3.420*	-3.822***	-3.303*
	(1.943)	(1.014)	(1.977)

Source: Author's calculation based on IFPRI BIHS datasets. Note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.5: Panel data regression results on child nutritional categories

	Stunted	Severely stunted	Underweight	Wasted
Access to improved sanitation	0.026	-0.000	0.011	0.006
	(0.049)	(0.023)	(0.048)	(0.025)
Improved drinking Water access	-0.305**	-0.101	-0.233*	-0.085
	(0.148)	(0.072)	(0.133)	(0.063)
Improved general Water access	0.001	-0.006	0.024	0.015
	(0.038)	(0.019)	(0.041)	(0.021)
Percentage of unimproved sanitation in village	0.001	0.001*	0.001	0.000
	(0.001)	(0.000)	(0.001)	(0.001)
Child age month	0.033***	0.009***	0.017***	-0.002
	(0.004)	(0.003)	(0.004)	(0.002)
Child age squared	-0.001***	-0.000***	-0.000***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Total income (BDT)	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Household size	0.023*	0.007	0.023*	-0.001
	(0.012)	(0.006)	(0.013)	(0.007)
Household Dietary Diversity Score	0.000	-0.007	-0.000	-0.009
	(0.014)	(0.007)	(0.014)	(0.008)
Irrigating household	-0.046	-0.035*	-0.085**	-0.026
	(0.039)	(0.020)	(0.041)	(0.02)
Body Mass Index of mother	-0.012**	-0.002	-0.019***	-0.005
	(0.005)	(0.003)	(0.006)	(0.003)*
Cultivatable land (Acre)	-0.001	0.005	-0.031	-0.007
	(0.023)	(0.01)	(0.025)	(0.011)
Maximum education in HH (Years)	-0.014**	-0.005*	-0.014**	0.002
	(0.006)	(0.003)	(0.006)	(0.003)
asset (BDT)	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Distance from health care centre (Km)	-0.004	-0.001	-0.000	0.004
	(0.003)	(0.002)	(0.003)	(0.002)**
Distance from small market (Km)	0.016*	0.012**	0.014	0.003
	(0.010)	(0.005)	(0.01)	(0.005)
Distance from town (Km)	0.004*	0.001	0.004*	0.000
	(0.002)	(0.001)	(0.002)	(0.001)
Roof: Tin	0.007	0.015	0.127*	0.000
	(0.065)	(0.033)	(0.067)	(0.034)

Floor of house Square feet	-0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
HH did arsenic test	0.026	0.003	0.029	-0.022
	(0.036)	(0.018)	(0.035)	(0.018)
Expenditure on cleanliness (BDT)	-0.000	-0.000*	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Drink untreated unimproved water	-0.301**	-0.068	-0.209	-0.095
	(0.151)	(0.073)	(0.135)	(0.065)
N	1,229	1,229	1,231	1,225

Source: Author’s calculation based on IFPRI BIHS datasets. Note: *** p<0.01, ** p<0.05, * p<0.1

7.3 Appendix of chapter three

Table A. 7.6: Sensitivity analysis- Rosenbaum bounds for continuous variables (only significant variables from the matchings are shown)

Outcome	Gamma*	Matched pairs	Significance level		Hodges-Lehman Point estimate		95% Confidence interval	
			Upper bounds	Lower bounds	Upper bounds	Lower bounds	Upper bounds	Lower bounds
Time to collect drinking water (min/day)	1	183	0.0000	0.0000	-5.0000	-5.0000	-7.0000	-2.0000
	2		0.0000	0.4036	-10.0000	0.0000	-13.0000	2.0000
	3		0.0000	0.9689	-13.5000	2.5000	-17.0000	6.0000
Distance of drinking water source (meter)	1	183	0.0000	0.0000	-0.5000	-0.5000	-1.0000	-0.5000
	2		0.0000	0.0337	-1.0000	0.0000	-1.0000	0.0000
	3		0.0000	0.5150	-1.0000	0.0000	-1.5000	0.5000
Drinking water container capacity (liter)	1	183	0.0007	0.0007	3.5000	3.5000	1.5000	5.5000
	2		0.7557	0.0000	-1.0000	8.0000	-2.5000	11.0000
	3		0.9985	0.0000	-2.5000	11.0000	-5.0000	14.5000
Water cost (BDT)	1	183	0.0000	0.0000	528.0000	528.0000	480.0000	582.0000
	2		0.0000	0.0000	432.0000	648.0000	396.0000	720.0000
	3		0.0000	0.0000	390.0000	726.0000	354.0000	810.0000

Source: Authors' calculation based on primary survey data.
* gamma is the log odds of differential assignment due to unobserved factors

Table A. 7.7: Sensitivity analysis- Rosenbaum bounds for binary variables (only significant variables from the matchings are shown)

Outcome variables	Gamma*	Mantel-Haenszel statistic		significance level	
		Overestimation	Underestimation	Overestimation	Underestimation
Access to improved drinking-water (dummy)	1	1.525	1.525	0.064	0.064
	1.1	1.404	1.654	0.080	0.049
	1.2	1.294	1.772	0.098	0.038
	1.3	1.195	1.884	0.116	0.030
	1.4	1.105	1.990	0.135	0.023
	1.5	1.022	2.091	0.153	0.018
	1.6	0.946	2.188	0.172	0.014
	1.7	0.876	2.281	0.191	0.011
	1.8	0.810	2.370	0.209	0.009
	1.9	0.748	2.456	0.227	0.007
	2	0.690	2.540	0.245	0.006
Hand wash with soap before feeding child (dummy)	1	2.053	2.053	0.020	0.020
	1.1	1.896	2.221	0.029	0.013
	1.2	1.753	2.375	0.040	0.009
	1.3	1.625	2.520	0.052	0.006
	1.4	1.507	2.658	0.066	0.004
	1.5	1.400	2.789	0.081	0.003
	1.6	1.301	2.914	0.097	0.002
	1.7	1.209	3.035	0.113	0.001
	1.8	1.123	3.151	0.131	0.001
	1.9	1.043	3.262	0.148	0.001
	2	0.968	3.370	0.167	0.000

Source: Authors' calculation based on primary survey data.
* Odds of differential assignment due to unobserved factors

Table A. 7.8: Sensitivity analysis- Rosenbaum bounds for continuous variables (only significant variables from the matchings are shown here)

Outcome	Gamma*	Matched pairs	Significance level		Hodges-Lehman Point estimate		95% Confidence interval	
			Upper bounds	Lower bounds	Upper bounds	Lower bounds	Upper bounds	Lower bounds
Weight-for-age z-score	1	205	0.048	0.048	0.160	0.160	-0.025	0.355
	1.1		0.142	0.012	0.105	0.225	-0.085	0.405
	1.2		0.296	0.003	0.050	0.270	-0.140	0.460
	1.3		0.483	0.000	0.005	0.315	-0.180	0.510
	1.4		0.660	0.000	-0.035	0.365	-0.235	0.555
	1.5		0.799	0.000	-0.080	0.400	-0.275	0.600
	1.6		0.892	0.000	-0.115	0.440	-0.310	0.640
	1.7		0.946	0.000	-0.150	0.475	-0.350	0.670
	1.8		0.975	0.000	-0.180	0.505	-0.390	0.710
	1.9		0.989	0.000	-0.215	0.535	-0.420	0.745
	2		0.996	0.000	-0.245	0.570	-0.450	0.775
Weight-for-height z-score	1	205	0.022	0.022	0.200	0.200	0.005	0.415
	1.1		0.078	0.005	0.140	0.260	-0.060	0.480
	1.2		0.189	0.001	0.090	0.320	-0.120	0.540
	1.3		0.348	0.000	0.040	0.375	-0.175	0.595
	1.4		0.525	0.000	-0.010	0.430	-0.225	0.650
	1.5		0.686	0.000	-0.055	0.475	-0.275	0.695
	1.6		0.811	0.000	-0.095	0.515	-0.320	0.745
	1.7		0.895	0.000	-0.135	0.555	-0.365	0.780
	1.8		0.946	0.000	-0.175	0.595	-0.410	0.820
	1.9		0.974	0.000	-0.205	0.635	-0.445	0.860
	2		0.988	0.000	-0.240	0.665	-0.475	0.900

Source: Authors' calculation based on primary survey data.
* gamma is the log odds of differential assignment due to unobserved factors

Table A. 7.9: Sensitivity analysis- Rosenbaum bounds for binary variables (only significant variables from the matchings are shown here)

Outcome variables	Gamma*	Mantel-Haenszel statistic		significance level	
		Overestimation	Underestimation	Overestimation	Underestimation
Underweight children (dummy)	1	1.310	1.310	0.095	0.095
	1.1	1.748	0.877	0.040	0.190
	1.2	2.148	0.480	0.016	0.316
	1.3	2.517	0.115	0.006	0.454
	1.4	2.860	0.003	0.002	0.499
	1.5	3.181	0.317	0.001	0.376
	1.6	3.482	0.611	0.000	0.271
	1.7	3.766	0.887	0.000	0.188
	1.8	4.035	1.147	0.000	0.126
	1.9	4.290	1.394	0.000	0.082
	2	4.534	1.629	0.000	0.052

Source: Authors' calculation based on primary survey data.
* Odds of differential assignment due to unobserved factors

7.4 Appendix of chapter four

Table A. 7.10: Summery statistics of outcome variables

Outcome variables	Baseline (N=512)	Midline (N=512)	Endline (N=512)
100ml drinking water *E.coli* count (cfu)	44.5	36.6	19.4
100ml drinking water *Coliform* count (cfu)	400.6	477.0	540.3
E.coli count in the food utensils (cfu)	36.5	11.7	2.9
Coliform count in the food utensils (cfu)	78.1	69.0	85.8
Presence of *E. coli* in the 100 ml water (dummy)	78%	72%	74%
Presence of *Coliform* in the 100 ml water (dummy)	97%	96%	99%
Presence of *E. coli* in food preparing utensils (dummy)	60%	36%	33%
Presence of *Coliform* in food preparing utensils (dummy)	94%	75%	76%
Access to improved drinking water (dummy)	96%	100%	99%
Access to improved water for general use (dummy)	63%	84%	80%
Monthly cost for water (BDT)	19.3	34.1	38.5
Size of the water container (liter)	17.9	16.5	18.0
Draw water with a mug from jar (dummy)	35%	28%	26%
Time spend to collect drinking water in a day (minute)	12.8	13.4	9.9
Total soap consumed per month (number, 1 soap =100gr.)	2.3	6.2	6.3
Hand wash with soap after coming from toilet (dummy)	68%	89%	97%
Hand wash with soap before feeding child (dummy)	3%	19%	29%
Clean water container with soap (dummy)	26%	36%	50%
Access to improved sanitation (dummy)	68%	83%	87%
Socio-environmental status (from 1=good to 3=bad)	1.7	1.8	1.7
Household having child diarrhoea in last month (%)	13%	11%	11%
Number of child diarrhoea episode in last month (count)	47	67	64
Diarrhoea episode for any member in last month (count)	50	77	60
Number of WATSAN related disease in last month (count)	139	129	108
Household WATSAN-hygiene related investment (BDT)	203	365	373
Household handwashing score (1=worst, 9= best)	1.43	1.91	2.35
Household WATSAN index (1=worst, 3=best)	2.4	2.5	2.6
Household food hygiene index (0=bad, 14=best)	3.9	5.9	7.1

Source: Author’s calculation based on primary survey data.

Table A. 7.11: Child nutritional status by treatment and control household in both rounds.

Anthropometric measurements	Baseline			Endline		
	Treatment (N=283)	Control (N=274)	P-value	Treatment (N=272)	Control[1] (N=266)	P-value
Height-for-age z-score	-1.54	-1.64	0.328	-1.57	-1.60	0.775
	(0.08)	(0.07)		(0.07)	(0.07)	
Weight-for-age z-score	-1.52	-1.49	0.785	-1.47	-1.54	0.387
	(0.07)	(0.06)		(0.06)	(0.06)	
Weight-for-height z-score	-0.92	-0.80	0.184	-0.86	-0.94	0.414
	(0.07)	(0.06)		(0.06)	(0.06)	
Stunted	36%	37%	0.774	33%	35%	0.713
	(3%)	(3%)		(3%)	(3%)	
Severely stunted	11%	11%	0.995	10%	9%	0.836
	(2%)	(2%)		(2%)	(2%)	
Underweight	35%	31%	0.319	28%	29%	0.724
	(3%)	(3%)		(3%)	(3%)	
Severely underweight	7%	7%	0.825	5%	6%	0.416
	(2%)	(2%)		(1%)	(2%)	
Wasted	15%	10%	0.058	12%	14%	0.628
	(2%)	(2%)		(2%)	(2%)	
Severely wasted	1%	3%	0.115	2%	3%	0.408
	(1%)	(1%)		(1%)	(1%)	

Source: Author's calculation based on primary survey data. [1] Denotes that in the endline there is no absolute control household. Both groups received the treatment but this control group has only one month of exposure and the treatment in baseline has two months of exposure.

Table A. 7.12: Impact of FHE on microbiological quality of drinking water and food utensils on percentage of households

	Percentage of households with E. coli in drinking water					Percentage of households with E. coli in food preparing utensils				
	Short term			Medium term		Short term		Medium term		
	Coefficient		Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient		Marginal effect
Treatment (FHE)	0.385 (0.344)	0.113 (0.302)	0.029 (0.078)	0.214 (0.296)	0.055 (0.075)	-0.197 (0.253)	-0.272 (0.229)	-0.098 -0.081	-0.245 (0.222)	-0.089 (0.081)
Time	0.182 (0.146)	0.180 (0.146)	0.047 (0.039)	0.159 (0.189)	0.041 (0.049)	-0.445* (0.250)	-0.445* (0.249)	-0.161* (0.088)	-0.706*** (0.205)	-0.258*** (0.070)
Treatment* Time (Impact)	-0.820*** (0.250)	-0.816*** (0.247)	-0.212*** (0.063)	-0.645** (0.283)	-0.166** (0.071)	-0.401 (0.295)	-0.398 (0.294)	-0.144 -0.108	0.040 (0.261)	0.015 (0.095)
BMDA operated area	0.042 (0.274)	0.173 (0.208)	0.045 (0.053)	0.001 (0.168)	0.000 (0.043)	-0.001 (0.176)	0.018 (0.166)	0.006 -0.06	-0.121 (0.130)	-0.044 (0.047)
HH characteristics	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Constants	0.817*** (0.253)	0.079 (0.499)		0.238 (0.457)		0.382** (0.185)	1.024** (0.436)		0.953*** (0.310)	
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.13: Impact of FHE on improved water for general use and willingness to treat water

	Percentage of households uses improved water for general use					Households treat water before drinking				
	Short term			Medium term		Short term			Medium term	
	Coefficient		Marginal effect	Co-efficient	Marginal effect	Coefficient		Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	-0.230 (0.296)	-0.034 (0.260)	-0.008 (0.064)	-0.126 (0.267)	-0.034 (0.071)	-0.004 (0.004)	-0.008 (0.007)	-0.008 (0.007)	-0.001 (0.008)	-0.001 (0.008)
Time	0.653** (0.263)	0.635** (0.257)	0.156*** (0.057)	0.554*** (0.160)	0.149*** (0.041)	0.012 (0.010)	0.012 (0.010)	0.012 (0.010)	0.023* (0.014)	0.023* (0.014)
Treatment* Time (Impact)	0.469 (0.357)	0.533 (0.358)	0.131 (0.091)	0.237 (0.271)	0.064 (0.073)	0.047** (0.021)	0.047** (0.021)	0.047** (0.021)	0.008 (0.019)	0.008 (0.019)
BMDA operated area	0.456* (0.260)	0.237 (0.187)	0.058 (0.045)	0.407** (0.178)	0.109** (0.048)	0.016 (0.010)	0.015* (0.008)	0.015* (0.008)	0.003 (0.007)	0.003 (0.007)
Household characteristics	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Constants	0.337 (0.247)	-0.297 (0.565)		-0.309 (0.527)		-0.004 (0.006)	-0.010 (0.023)			
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.14: Impact of Food Hygiene Education (FHE) on hygiene means and practices

	Number of soap use per month					Draw drinking water with mug (unhygienic way)				
	Short term			Medium term		Short term			Medium term	
	Coefficient		Marginal effect	Co-efficient	Marginal effect	Coefficient		Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	-0.262	-0.277*	-0.277*	-0.423***	-0.423***	-0.226	-0.196	-0.063	-0.242	-0.08
	(0.173)	(0.149)	(0.149)	(0.127)	(0.127)	(0.251)	(0.238)	(0.076)	(0.210)	(0.068)
Time	3.508***	3.508***	3.508***	3.926***	3.926***	-0.356**	-0.355**	-0.114**	-0.303**	-0.101**
	(0.268)	(0.270)	(0.270)	(0.255)	(0.255)	(0.175)	(0.174)	(0.056)	(0.151)	(0.049)
Treatment* Time (Impact)	0.703*	0.703*	0.703*	0.211	0.211	0.242	0.247	0.079	0.068	0.022
	(0.367)	(0.369)	(0.369)	(0.399)	(0.399)	(0.277)	(0.278)	(0.089)	(0.259)	(0.086)
BMDA operated area	0.332	0.034	0.034	0.081	0.081	-0.030	-0.084	-0.027	-0.012	-0.004
	(0.228)	(0.173)	(0.173)	(0.204)	(0.204)	(0.204)	(0.195)	(0.062)	(0.150)	(0.05)
Household characteristics	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Constants	2.279***	0.247		-0.926***		-0.362**	-0.248		-0.337	
	(0.166)	(0.474)		(0.325)		(0.172)	(0.415)		(0.292)	
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.15: Impact of Food Hygiene Education (FHE) on household cleanliness

	Cleaning water jar with soap					Cleaning toilet with soap materials				
	Short term			Medium term		Short term			Medium term	
	Coefficient		Marginal effect	Co-efficient	Marginal effect	Coefficient		Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	-0.319	-0.185	-0.052	-0.182	-0.058	0.006	0.174	0.041	0.082	0.022
	(0.256)	(0.205)	(0.058)	(0.194)	(0.061)	(0.366)	(0.281)	(0.066)	(0.254)	(0.069)
Time	0.090	0.089	0.025	0.764***	0.241***	0.232	0.225	0.053	0.765***	0.209***
	(0.138)	(0.137)	(0.038)	(0.161)	(0.049)	(0.190)	(0.189)	(0.045)	(0.180)	(0.048)
Treatment* Time (Impact)	0.573**	0.544**	0.154**	0.030	0.01	0.078	0.087	0.021	-0.078	-0.021
	(0.233)	(0.228)	(0.064)	(0.215)	(0.068)	(0.271)	(0.270)	(0.064)	(0.329)	(0.09)
BMDA operated area	0.098	-0.171	-0.048	-0.010	-0.003	0.482	0.085	0.02	0.032	0.009
	(0.234)	(0.144)	(0.04)	(0.144)	(0.046)	(0.358)	(0.201)	(0.047)	(0.195)	(0.053)
Household characteristics	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Constants	-0.764***	-0.765**		-0.934***		-0.784***	-2.240***		-1.785***	
	(0.192)	(0.355)		(0.352)		(0.268)	(0.488)		(0.488)	
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.16: Impact of FHE on medical expenditure and WATSAN investment

	Household medical expenditure for WATSAN diseases in last month (BDT)			Household medical expenditure for WATSAN diseases in last month for children (BDT)			WATSAN Investment (BDT)		
	Short term		Medium term	Short term		Medium term	Short term		Medium term
Treatment (FHE)	38.738 (152.936)	32.026 (159.242)	26.287 (161.847)	15.508 (120.527)	24.037 (121.734)	20.200 (123.037)	-26.675 (41.975)	-37.543 (42.558)	-24.490 (41.888)
Time	-184.508** (91.898)	-184.508** (92.490)	-271.832*** (59.390)	-232.184*** (69.842)	-232.184*** (70.291)	-216.113*** (65.708)	107.965*** (37.967)	107.836*** (38.150)	75.370 (47.488)
Treatment* Time (Impact)	-129.266 (168.269)	-129.266 (169.352)	-23.254 (149.289)	-27.074 (118.218)	-27.074 (118.980)	-15.000 (119.290)	70.504 (64.356)	70.633 (64.738)	6.220 (52.488)
BMDA operated area	44.398 (76.346)	44.604 (67.347)	39.135 (76.001)	43.557 (61.779)	51.962 (58.299)	34.942 (59.068)	-1.311 (33.166)	-18.684 (28.856)	-48.185** (24.402)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Constants	342.586*** (83.649)	125.643 (235.869)	167.275 (232.515)	239.647*** (86.535)	47.152 (203.897)	61.971 (196.326)	136.339*** (46.245)	50.980 (89.091)	69.994 (69.160)
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.17: Impact FHE on medical expenditure and WATSAN investment (contd.)

	Monthly cost of water (BDT)			Sanitation maintenance cost (BDT)			Handwashing score (0=worst, 9=Best)		
	Short term		Medium term	Short term		Medium term	Short term		Medium term
Treatment (FHE)	2.656 (5.805)	2.001 (4.704)	0.482 (4.778)	34.023 (41.079)	38.054 (40.954)	32.223 (39.953)	0.029 (0.209)	0.009 (0.164)	0.077 (0.158)
Time	12.313*** (3.058)	12.313*** (3.077)	22.906*** (6.329)	103.227*** (27.330)	103.227*** (27.506)	16.289 (22.477)	0.250 (0.154)	0.250 (0.155)	0.927*** (0.140)
Treatment* Time (Impact)	5.070 (5.910)	5.070 (5.948)	-7.320 (7.343)	-22.043 (51.424)	-22.043 (51.755)	-35.328 (49.495)	0.473** (0.203)	0.473** (0.204)	-0.008 (0.181)
BMDA operated area	29.586*** (6.101)	24.613*** (4.815)	29.642*** (4.468)	86.123** (36.495)	49.044** (22.979)	0.335 (19.429)	0.074 (0.147)	-0.047 (0.085)	-0.080 (0.106)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Constants	3.180 (3.174)	-40.597*** (8.614)	-38.421*** (9.520)	113.267*** (25.382)	-125.785* (66.432)	30.866 (55.214)	1.377*** (0.207)	0.714*** (0.273)	0.715*** (0.251)
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.18: Impact of FHE on WATSAN indexes and FHE indexes

	WATSAN hygiene index (1= worst, 3=best)			Food Hygiene Index (0=worst, 14=best)			Socio-environmental cleanliness Index (1=good, 3= bad)		
	Short term		Medium term	Short term		Medium term	Short term		Medium term
Treatment (FHE)	-0.017 (0.049)	-0.023 (0.044)	-0.029 (0.046)	-0.340 (0.304)	-0.270 (0.245)	-0.294 (0.258)	0.041 (0.062)	0.033 (0.065)	0.033 (0.064)
Time	0.009 (0.038)	0.009 (0.038)	0.166*** (0.027)	1.262*** (0.220)	1.262*** (0.221)	2.949*** (0.276)	0.177*** (0.055)	0.177*** (0.055)	0.006 (0.041)
Treatment* Time (Impact)	0.141*** (0.052)	0.141*** (0.052)	-0.023 (0.052)	1.465*** (0.330)	1.465*** (0.332)	0.500 (0.358)	-0.093 (0.081)	-0.093 (0.082)	0.022 (0.078)
BMDA operated area	0.025 (0.037)	-0.002 (0.025)	0.001 (0.028)	0.256 (0.252)	-0.009 (0.192)	-0.017 (0.177)	0.074 (0.046)	0.079** (0.036)	0.052 (0.033)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Constants	2.412*** (0.043)	2.269*** (0.057)	2.265*** (0.064)	3.938*** (0.306)	2.841*** (0.428)	2.960*** (0.340)	1.651*** (0.039)	1.586*** (0.094)	1.681*** (0.091)
Observation	1024	1024	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.19: Impact of FHE on diarrhoea for any member in last one month

	Short term			Medium term		Elasticity	
	Coefficient		Marginal effect	Coefficient	Marginal effect	Short term	Medium term
Treatment (FHE)	0.720*** (0.205)	0.760*** (0.238)	0.123*** (0.038)	0.700*** (0.166)	0.097*** (0.024)	0.38*** (0.119)	0.35*** (0.083)
Time	0.738*** (0.193)	0.738*** (0.193)	0.119*** (0.030)	0.492*** (0.155)	0.068*** (0.022)	0.369*** (0.096)	0.246*** (0.078)
Treatment* Time (Impact)	-0.574* (0.333)	-0.574* (0.333)	-0.093* (0.053)	-0.662*** (0.252)	-0.091** (0.036)	-0.143* (0.083)	-0.165*** (0.063)
BMDA operated area	-0.202*** (0.051)	-0.276*** (0.081)	-0.045*** (0.013)	-0.129 (0.112)	-0.018 (0.015)	-0.138*** (0.040)	-0.065 (0.056)
Household characteristics	No	Yes	Yes	Yes	Yes	Yes	Yes
Constants	-2.361*** (0.146)	-2.151*** (0.659)		-2.631*** (0.982)			
Observation	1024	1024	1024	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.20: Impact of FHE on child growth for one additional month of exposure

	Stunted			Severely Stunted			Underweight		
	Coefficient		Marginal effect	Coefficient		Marginal effect	Coefficient		Marginal effect
Treatment (FHE)	-0.078	-0.054	-0.013	-0.021	-0.123	-0.002	0.267	0.274	0.054
	(0.302)	(0.311)	(0.074)	(0.401)	(0.467)	(0.007)	(0.346)	(0.308)	(0.059)
Time	-0.126	-0.123	-0.029	-0.165	-0.168	-0.003	-0.128	-0.123	-0.024
	(0.192)	(0.191)	(0.046)	(0.279)	(0.273)	(0.005)	(0.235)	(0.234)	(0.047)
Treatment* Time (Impact)	-0.053	-0.060	-0.014	0.032	0.032	0.001	-0.346	-0.354	-0.07
	(0.268)	(0.268)	(0.063)	(0.421)	(0.414)	(0.007)	(0.284)	(0.283)	(0.054)
BMDA operated area	-0.067	0.003	0.001	-0.426	-0.448	-0.007	-0.340	-0.335	-0.066
	(0.316)	(0.257)	(0.061)	(0.342)	(0.358)	(0.008)	(0.287)	(0.264)	(0.053)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Constants	-0.807***	-0.239		-3.020***	-2.139**		-1.064***	-0.133	
	(0.276)	(0.750)		(0.584)	(0.992)		(0.358)	(0.841)	
Observation	1095	1095	1095	1095	1095	1095	1095	1095	1095

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.21: Impact of FHE on child growth for one additional month of exposure

	Severely Underweight			Wasted			Severely wasted		
	Coefficient		Marginal effect	Coefficient		Marginal effect	Coefficient		Marginal effect
Treatment (FHE)	0.100	0.026	0.000	0.429**	0.395**	0.034	-0.559	-0.567	-0.003
	(0.435)	(0.543)	(0.000)	(0.173)	(0.193)	(0.02)	(0.438)	(0.453)	(0.003)
Time	-0.135	-0.141	-0.000	0.292	0.298*	0.026	0.099	0.088	0.001
	(0.348)	(0.355)	(0.000)	(0.180)	(0.181)	(0.018)	(0.341)	(0.332)	(0.002)
Treatment* Time (Impact)	-0.520	-0.551	-0.000	-0.525**	-0.536**	-0.047**	0.321	0.338	0.002
	(0.468)	(0.483)	(0.001)	(0.233)	(0.234)	(0.024)	(0.463)	(0.454)	(0.003)
BMDA operated area	0.171	0.034	0.000	0.019	-0.101	-0.009	-0.084	-0.101	-0.001
	(0.419)	(0.429)	(0.000)	(0.167)	(0.187)	(0.016)	(0.288)	(0.249)	(0.002)
Household characteristics	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Constants	-4.133***	-1.278		-2.051***	-2.127***		-2.865***	-2.373***	
	(0.620)	(1.245)		(0.224)	(0.638)		(0.462)	(0.799)	
Observation	1095	1095	1095	1095	1095	1095	1095	1095	1095

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.22: Impact of FHE on number of household diarrhoea for any member in last one month (with household characteristics shown in details)

	Short term		Medium term	
	Coefficient	Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	0.760***	0.123***	0.700***	0.097***
	(0.238)	(0.038)	(0.166)	(0.024)
Time	0.738***	0.119***	0.492***	0.068***
	(0.193)	(0.030)	(0.155)	(0.022)
Treatment*Time	-0.574*	-0.093*	-0.662***	-0.091**
(Impact)	(0.333)	(0.053)	(0.252)	(0.036)
BMDA operated area	-0.276***	-0.045***	-0.129	-0.018
	(0.081)	(0.013)	(0.112)	(0.015)
Per capita expenditure	-0.044	-0.007	0.035	0.005
(in BDT 5000)	(0.053)	(0.009)	(0.042)	(0.006)
Household size	-0.003	0.000	0.096	0.013
	(0.155)	(0.025)	(0.139)	(0.019)
Distance from road (km)	-0.089	-0.014	-0.123	-0.017
	(0.112)	(0.018)	(0.161)	(0.022)
Distance from small	-0.074	-0.012	-0.021	-0.003
market (km)	(0.080)	(0.013)	(0.065)	(0.009)
Distance from big market	-0.010	-0.002	-0.559***	-0.077***
(in 10 km)	(0.345)	(0.056)	(0.190)	(0.027)
Distance from health	0.186	0.03	0.491	0.068
center (in 10 km)	(0.454)	(0.074)	(0.541)	(0.076)
Distance from nearest	-0.010	-0.002	-0.010	-0.001
town (km)	(0.014)	(0.002)	(0.017)	(0.002)
Grid Electricity (1=Yes)	0.129	0.021	-0.196	-0.027
	(0.296)	(0.048)	(0.293)	(0.041)
Age of household head	0.010	0.002	0.005	0.001
(years)	(0.012)	(0.002)	(0.017)	(0.002)
Years of schooling of	0.002	0.000	-0.020	-0.003
household head	(0.029)	(0.005)	(0.041)	(0.006)
Wage earning household	-0.119	-0.019	0.063	0.009
(1=Yes)	(0.334)	(0.054)	(0.360)	(0.05)
Agricultural household	-0.354	-0.057	-0.214	-0.029
(1=Yes)	(0.381)	(0.062)	(0.296)	(0.041)
Total Land (acres)	-0.046	-0.007	-0.023	-0.003
	(0.155)	(0.025)	(0.095)	(0.013)
_cons	-2.151***		-2.631***	
	(0.659)		(0.982)	
Observation	1024	1024	1024	1024

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.23: Impact of FHE on child nutritional status with all covariates (with household characteristics shown in details)

Variables	Stunted		Underweight		wasted	
	Coefficient	Marginal effect	Coefficient	Marginal effect	Coefficient	Marginal effect
Treatment (FHE)	-0.054 (0.311)	-0.013 (0.074)	0.274 (0.308)	0.054 (0.059)	0.395** (0.193)	0.034* (0.02)
Time	-0.123 (0.191)	-0.029 (0.046)	-0.123 (0.234)	-0.024 (0.047)	0.298* (0.181)	0.026 (0.018)
Treatment*Time (Impact)	-0.060 (0.268)	-0.014 (0.063)	-0.354 (0.283)	-0.07 (0.054)	-0.536** (0.234)	-0.047** (0.024)
BMDA operated area	0.003 (0.257)	0.001 (0.061)	-0.335 (0.264)	-0.066 (0.053)	-0.101 (0.187)	-0.009 (0.016)
Per capita expenditure (in BDT 5000)	-0.205*** (0.078)	-0.049*** (0.018)	-0.237*** (0.081)	-0.047*** (0.016)	-0.051 (0.037)	-0.004 (0.003)
Household size	-0.171* (0.095)	-0.041* (0.021)	-0.095 (0.103)	-0.019 (0.02)	0.056 (0.041)	0.005 (0.004)
Distance from road (km)	-0.004 (0.045)	-0.001 (0.011)	-0.176** (0.072)	-0.035** (0.015)	-0.179* (0.095)	-0.016** (0.008)
Distance from small market (km)	-0.044 (0.079)	-0.01 (0.019)	0.016 (0.053)	0.003 (0.01)	0.019 (0.048)	0.002 (0.004)
Distance from big market (in 10 km)	1.185*** (0.414)	0.281*** (0.090)	1.169*** (0.357)	0.231*** (0.064)	0.382* (0.223)	0.033 (0.022)
Distance from health center (in 10 km)	-0.284 (0.550)	-0.068 (0.132)	-0.089 (0.470)	-0.018 (0.094)	0.078 (0.305)	0.007 (0.027)
Distance from nearest town (km)	-0.001 (0.013)	-0.000 (0.003)	-0.025* (0.014)	-0.005* (0.003)	-0.012 (0.009)	-0.001 (0.001)
Grid Electricity (1=Yes)	-0.212 (0.228)	-0.05 (0.054)	0.021 (0.228)	0.004 (0.045)	0.315 (0.195)	0.027 (0.019)
Age of household head (years)	0.003 (0.011)	0.001 (0.003)	-0.004 (0.011)	-0.001 (0.002)	-0.011 (0.008)	-0.001 (0.001)
Years of schooling of household head	0.061** (0.027)	0.014** (0.007)	0.036 (0.030)	0.007 (0.006)	0.034 (0.026)	0.003 (0.002)
Wage earning household (1=Yes)	0.502* (0.265)	0.119* (0.062)	0.414 (0.295)	0.082 (0.06)	0.181 (0.226)	0.016 (0.019)
Agricultural household (1=Yes)	0.241 (0.325)	0.057 (0.075)	0.005 (0.295)	0.001 (0.058)	-0.003 (0.161)	0.000 (0.014)
Total Land (acres)	0.016 (0.089)	0.004 (0.021)	0.022 (0.078)	0.004 (0.016)	-0.024 (0.071)	-0.002 (0.006)
_cons	-0.239 (0.750)		-0.133 (0.841)		-2.127*** (0.638)	
Observation	1095	1095	1095	1095	1095	1095

Source: Authors calculation based on primary survey data. The number in the parentheses shows the robust standard error clustered in the village level. This table shows the impact of one additional month of exposure to treatment as both are treated in the endline. note: *** p<0.01, ** p<0.05, * p<0.1

Table A. 7.24: Present Discounted Value of DALY at different discount rate for CBA analysis.

Year	PDV DALY averted	Cumulative	
0 [End of intervention year]	€10,305	€10,305	Discount rate=3%,
1 [End of 2^{nd} year from intervention]	€10,005	€20,310	PDV= $\sum_{t=0}^{n} \frac{D_t}{(1+r)^t}$
2 [End of 3^{rd} year from intervention]	€9,713	€30,023	

Source: Author's calculation, For the calculation the first two years including the intervention year is considered only. 3^{rd} year from intervention is not used in CBA calculation.

Table A. 7.25: Summary of Cost Benefit Analysis

Cost	Description	Estimated values	References
Microbiological testing of drinking water and food utensils	*E. coli* testing of drinking water and food preparing utensils of 512 households in 3 times	€5300	estimated value from project
Poster of Food Hygiene Education (FHE) messages	One poster for all participating households	€600	estimated value from project
Training personnel cost	Two experienced trainers conducted the training session in the villages	€1000	estimated value from project
Microbiologist cost	Two Microbiologist worked for collecting and testing the samples in the laboratory	€3000	estimated value from project
Opportunity cost	Shadow wage for time spent for training participation	€650	estimated value from project
Total PDV costs		**€10550**	

Benefits	Descriptions	Estimated values	References
Value of Nutritional gain for food hygiene practices	PDV of nutritional outcome to children	€196897	calculated based on Hoddinott, Alderman, Behrman, Haddad, & Horton (2013)
Adjustment for societal objective	PDV of DALY averted	€20310	Calculated based on Mahmud (2006), Miller (2000) and (Cameron et al. 2011; Prüss et al. 2002a)
Total PDV Benefits		**€217207**	

NPV (Total PDV benefit – total PDV costs)	**€**206657	
Benefit/Cost ratio (discount rate 3%)	**20.59**	

Source: Author’s calculation.

Figure A. 7.3: Photos of training, *E. coli* counts, water sample collection and child anthropometrics.

Source: Author’s photoshoot

Food Hygiene Education (FHE) for rural households in Bangladesh

Mohammad Monirul Hasan
Center for Development Research (ZEF), University of Bonn, Germany. Email: mhasan@uni-bonn.de

Zentrum für Entwicklungsforschung
Center for Development Research
Universität Bonn

রাজশাহী বিশ্ববিদ্যালয়

Foundation fiat panis

DAAD

Bill & Melinda Gates foundation

Figure A. 7.4: Poster of Food Hygiene Education experiment

Source: Author’s poster for the experiment (Hasan 2015).