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

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Abstract

We investigated the impacts of piped water on water quality, sanitation, hygiene and health outcomes in marginalized rural households of north-western Bangladesh using a quasi-experimental analysis. A government organization – the Barindra Multipurpose Development Authority (BMDA) – established a piped water network to provide these rural households with improved water as they have poor access to potable water. Using propensity score matching, the study compares a treatment and a control group of households to identify gains in water-sanitation, hygiene and health outcomes. We found that the BMDA piped water infrastructure had a positive impact on access to improved water and significantly reduced the distance traveled for and time spent on collecting drinking water. However, we found no improvement in the drinking water quality, which was measured by the extent of fecal contamination (*E. coli* count per 100 ml of water) at the point of use. The hygiene status of food utensils also did not show any improvement; food utensils were tested positive for *E. coli* in both the control and treatment group. Although access to BMDA piped water in the premises involves cost, it didn't improve hygiene behavior: handwashing with soap after defecation and before feeding children. The treated households own larger water containers which implies that the intervention has had a clear impact on the quantity of water used for household purposes. However, we did not find evidence of health benefits, such as decreased diarrhea incidence of in under-five children, improved child anthropometrics stunting, underweight and wasting of children due to piped water use.

JEL classification: D12, I12, I31, O12, O18, Q15, Q25, P46

Keywords: Child diarrhea, Child growth, Piped water supply, Water-Sanitation, Hygiene, Irrigation agriculture, Propensity Score Matching, water quality, food utensil hygiene.

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1. Introduction

The world is still suffering from a lack of proper sanitation and safe drinking water in the twenty-first century. 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). The number of people with access to piped water increased from 2.3 billion in 1990 to 4.2 billion in 2015 (United Nations, 2015). 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 diarrhea incidence) and child development (Jyotsna Jalan & 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, 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 et al. (2011) found that 58% of the surveyed households reported having insufficient water for their daily use. Having insufficient water has negative consequences on hygiene behavior, height-for-age and diarrhea incidence in under-five children (van der Hoek, Feenstra, & Konradsen, 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 diarrhea morbidity and diarrhea mortality, including the probability of hookworm infection. In comparison, better water quality plays a smaller role in reducing diarrhea than sanitation and hygiene (S A Esrey, Potash, Roberts, & Shiff, 1991a). The importance of water quality and sanitation in reducing health risk has been well-documented (S A Esrey et al., 1991a; Fewtrell et al., 2005a; Waddington, Snilstveit, White, & Fewtrell, 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. (Steven A Esrey, 1996). A study conducted in 145 low- and middle-income countries showed that in 2012, about 502 thousand diarrhea 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 diarrhea 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 (Steven A Esrey, 1996). Installing water filters and building high-quality piped water systems with sewer connections are better at reducing diarrhea cases than other kinds of intervention (Wolf et al., 2014). A study showed that diarrhea 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 (Guiteras, Levinsohn, & 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 diarrhea (van der Hoek et al., 2002). Diarrhea 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 diarrhea and malnutrition than those receiving nutritional supplementation (Javaid et al., 1991). One way of breaking the vicious cycle of diarrhea and malnutrition is to increase the use of safe water and improved sanitation. This reduces the transmission of pathogens, thereby lowering diarrhea incidence and child mortality and improving nutritional status (Steven A Esrey, 1996). Van der Hoek et al. (2002) found that larger water storage is associated with higher diarrhea risk and child stunting prevalence.

There are a handful of studies that investigated the relationship between improved water and health gains (S A Esrey, Potash, Roberts, & Shiff, 1991b; Fewtrell et al., 2005b; Hoque, Juncker, Sack, Ali, & Aziz, 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 intercorrelations 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 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 bacteria *E. coli* in drinking water and on kitchen utensils, water, sanitation and hygiene infrastructure and behavior, and various health outcomes (such as diarrhea incidence and child anthropometrics).

2. Sample and Data

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 Programme 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).

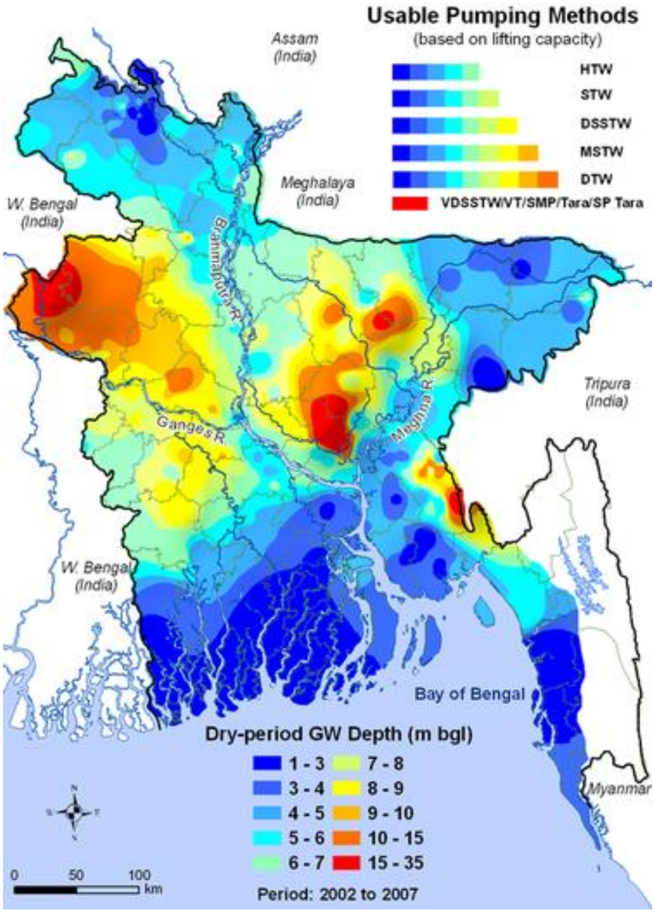


Figure 1: Map of Bangladesh based on usable pumping method.

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 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[1] in term of access to fresh groundwater. Therefore, the BMDA, a public body,

[1] 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).

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.

2.2 Conceptual framework

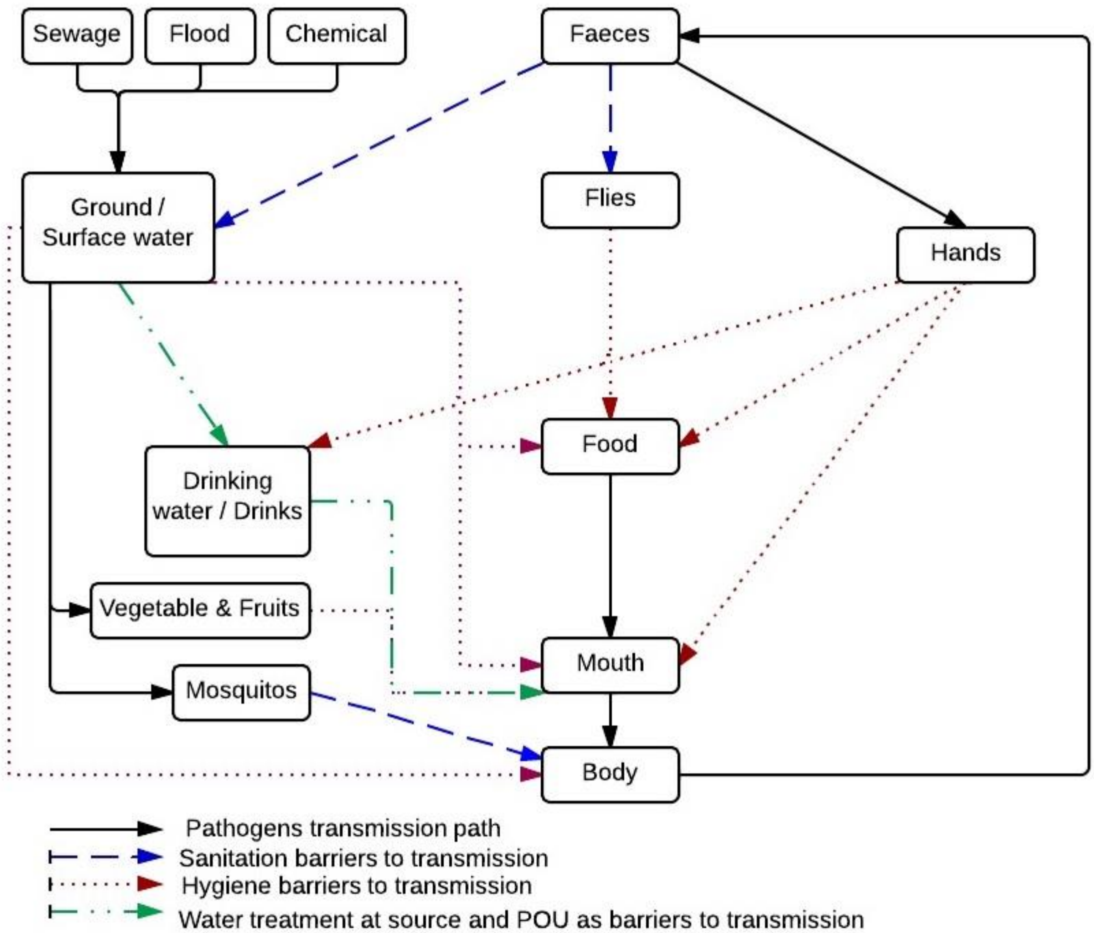


Figure 2: Water treatment, sanitation and hygiene barriers to transmission of pathogens.

Source: Author's calibration; adopted from Prüss, Kay, Fewtrell, and Bartram, (2002), and Waddington et al. (2009).

Human health is affected by the transmission of pathogens from feces and waste water to humans. Pathogens is transmitted through various agents such as improper sanitation and hygiene, and unsafe drinking water sources (Figure 2). The transmission of pathogens from feces 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). In Figure 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 color 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.

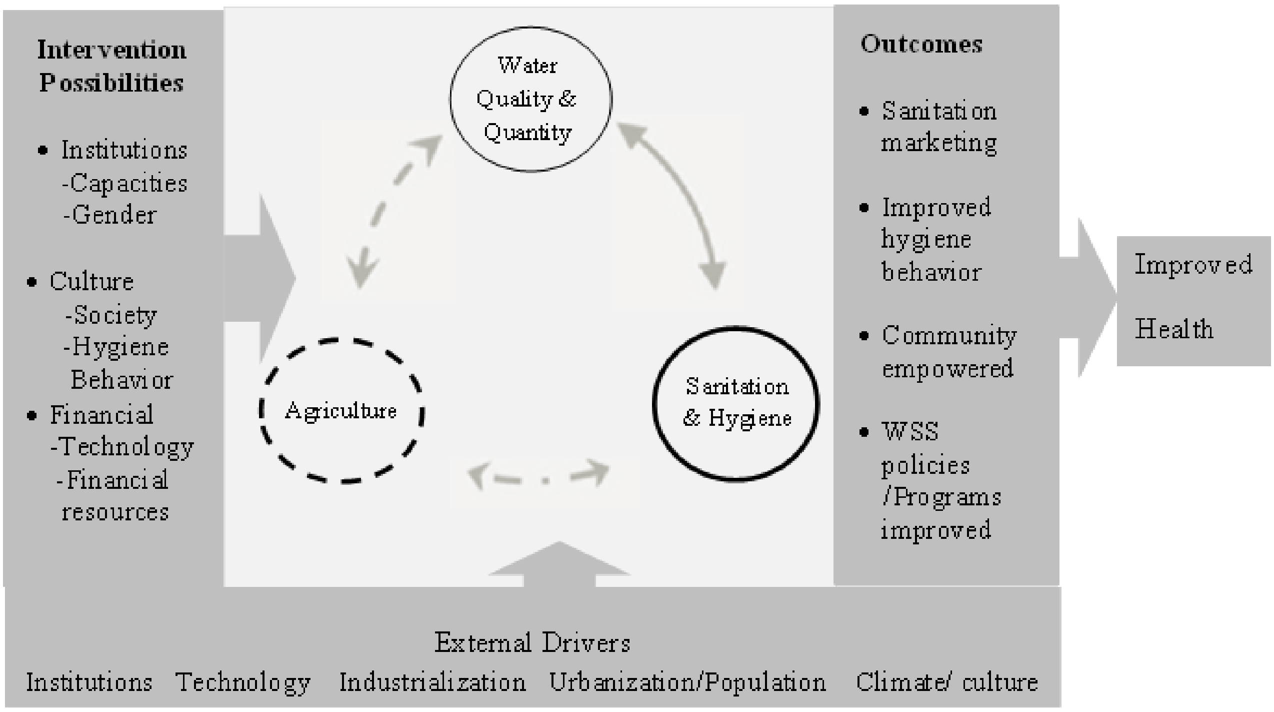


Figure 3: Conceptual framework of Agriculture-water-sanitation nexus on human health

Source: (Tsegai, Mcbain, and Tischbein, 2013)

Agriculture plays an important role in maintaining water quality. The relationship between agriculture, water and sanitation can be analyzed as shown in Figure 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 behavior; (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.

2.3 Data

The selected study areas are located in the Rajshahi and Naogaon district (Figure 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.

Source: Banglapedia. www.bpedia.org/R_0079.php, Accessed on October 5, 2015.

Source: www.bpedia.org/N_0048.php Accessed on October 5, 2015.

Figure 4: Map of Rajshahi district (left) and Naogaon district (right)- the study area

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%.

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.

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.

2.5 Data collection

Household survey:

Household survey (baseline) was conducted in October 2014 in the rural villages in Rajshahi and Naogaon district, located in north-western Bangladesh (Figure 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 fecal 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 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 5).

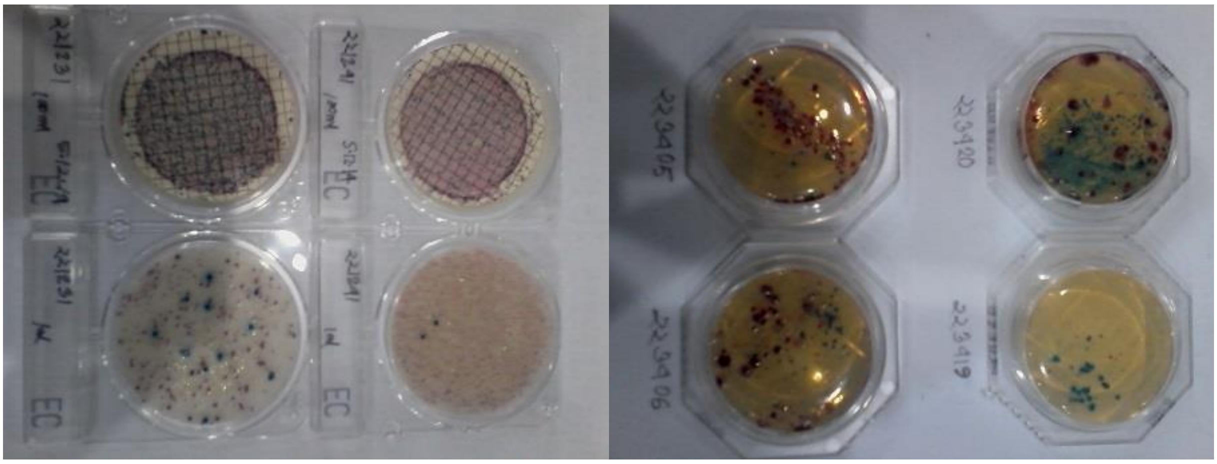


Figure 5: *E. coli* colony forming units (cfus) in 100 ml water (left) and *E. coli* cfu in food preparing utensils (right).

Source: Microbiological survey data, 2014.

3. Descriptive statistics

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). 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). 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). 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.

3.2 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 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 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 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 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

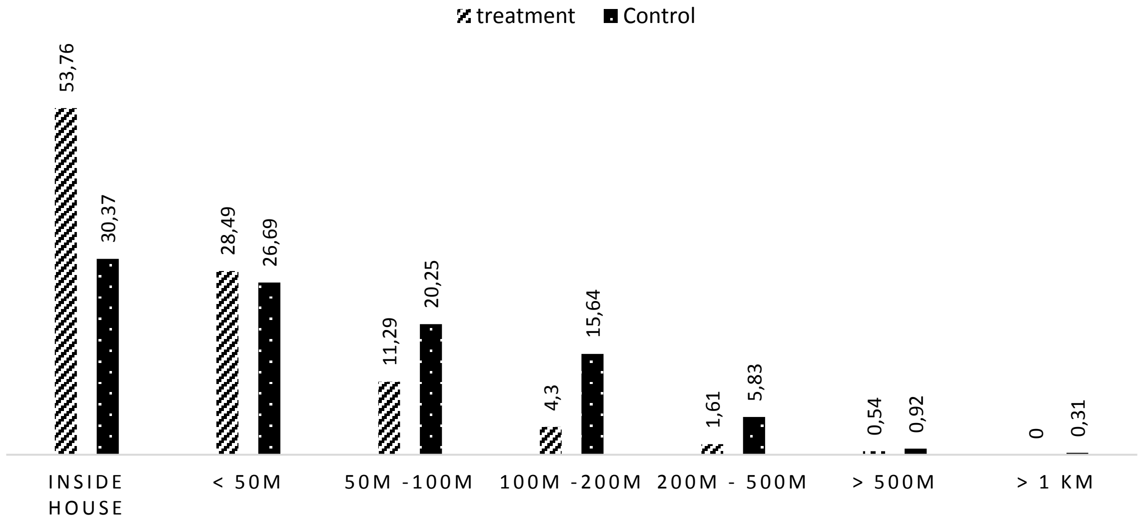


Figure 6: Percentage of households by traveling distance to collect drinking water. Fisher's exact= 0.000

Source: Baseline survey, 2014.

3.3 Microbiological quality of water and food utensils

Figure 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.

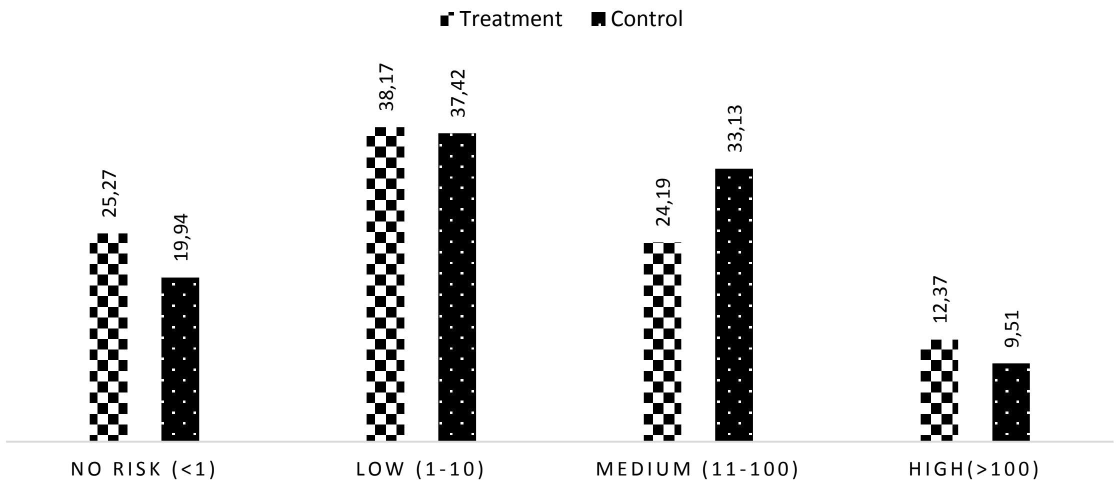


Figure 7: Percentage of households under different risk level for drinking water faecal contamination based on *E. coli* cfu counts. Fisher's exact = 0.126.

Source: Microbiological survey data, 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 8 shows the percentage of households with and without *E. coil* contamination on their food utensils. It is observed that the *E. coli* counts on the kitchen utensils of the control households were higher than those in the treated households. The mean difference between the treatment and the control households is statistically significant at the 0.074 level.

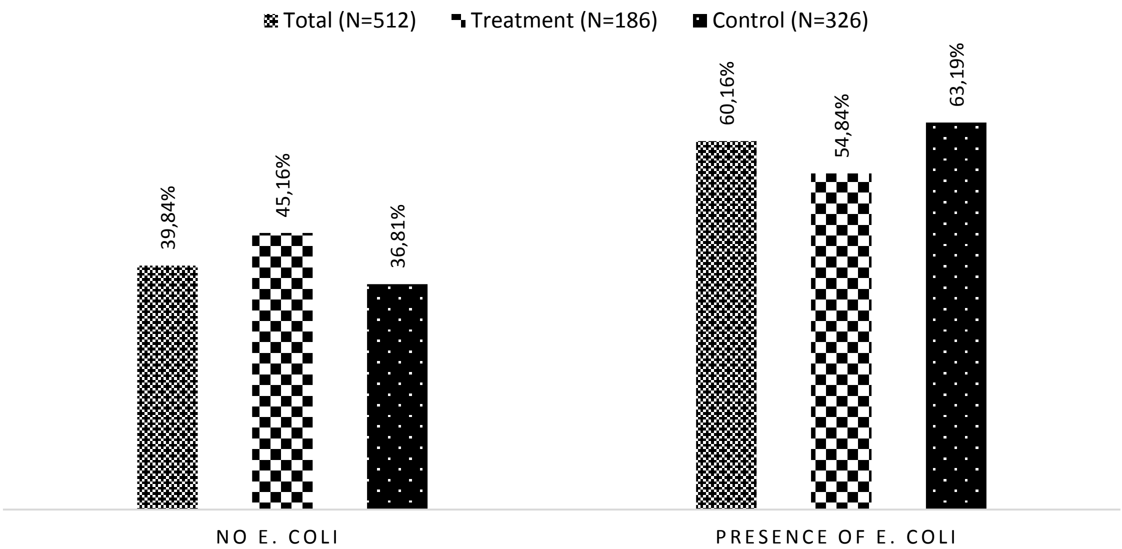


Figure 8: Presence of *E. coli* in the food preparing utensils. Fisher's exact = 0.074

Source: Microbiological survey data, 2014.

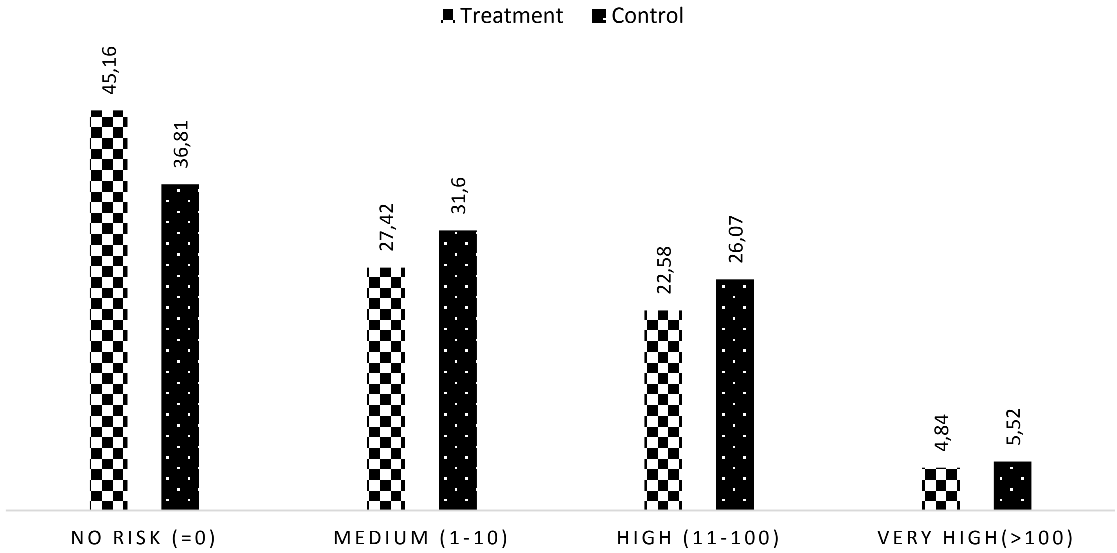


Figure 9: Percentage of households under different risk level for food preparing utensils fecal contamination based on *E. coli* cfu counts. Fisher's exact = 0.338.

Source: 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 9).

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). 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 2).

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

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). 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.

3.6 Child diarrhea and medical expenditure

Child diarrhea could result from unimproved water, unimproved sanitation and poor hygiene practices and may have long-term consequences on child's development. Diarrhea cases in under-five children living in the study areas were recorded for a month, and it was observed that child diarrhea was not highly prevalent in the areas. Only 13% of the households reported diarrhea cases in their under-five children, which comprised 11% of the treated households and 14% of the control households (Table 3). There was no significant differences between the treated and control households in terms of diarrhea 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 were not statistically significant.

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 spent 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: 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 program (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 diarrhea 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: Baseline survey, 2014.

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 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: Baseline survey, 2014.

In the study areas, 36% of the children exhibited stunted growth and 10% were severely stunted (Table 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.

4. Theory and Methods

4.1 Theory and Assumptions

This paper is developed based on "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 piped water improves health and productivity (Figure 10). This causal link works through investment in the water, sanitation and hygiene infrastructures which, in the short term, results in lower child diarrhea 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.

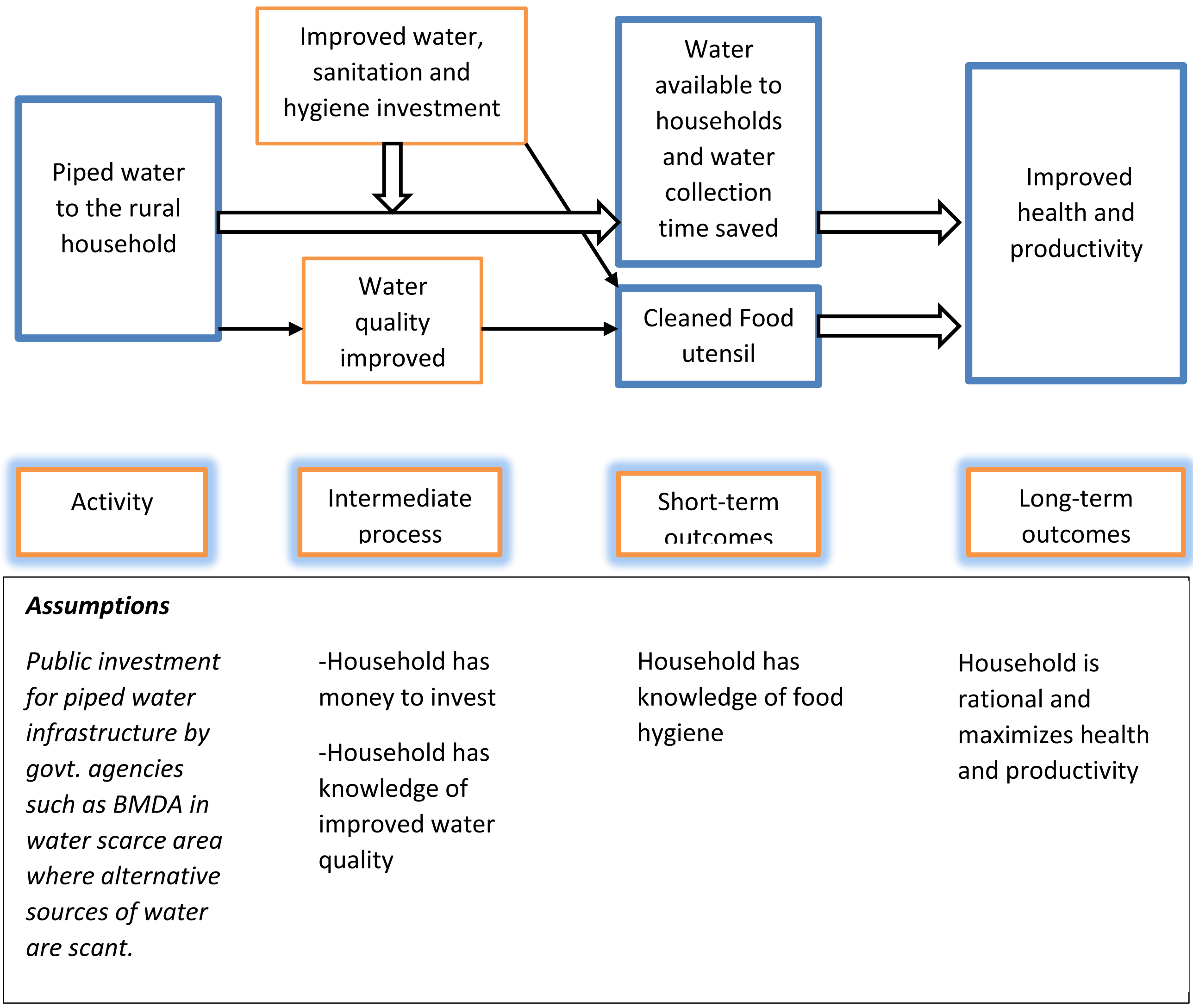


Figure 10: Theory of Change- impact pathways.

Source: Authors' calibration

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

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

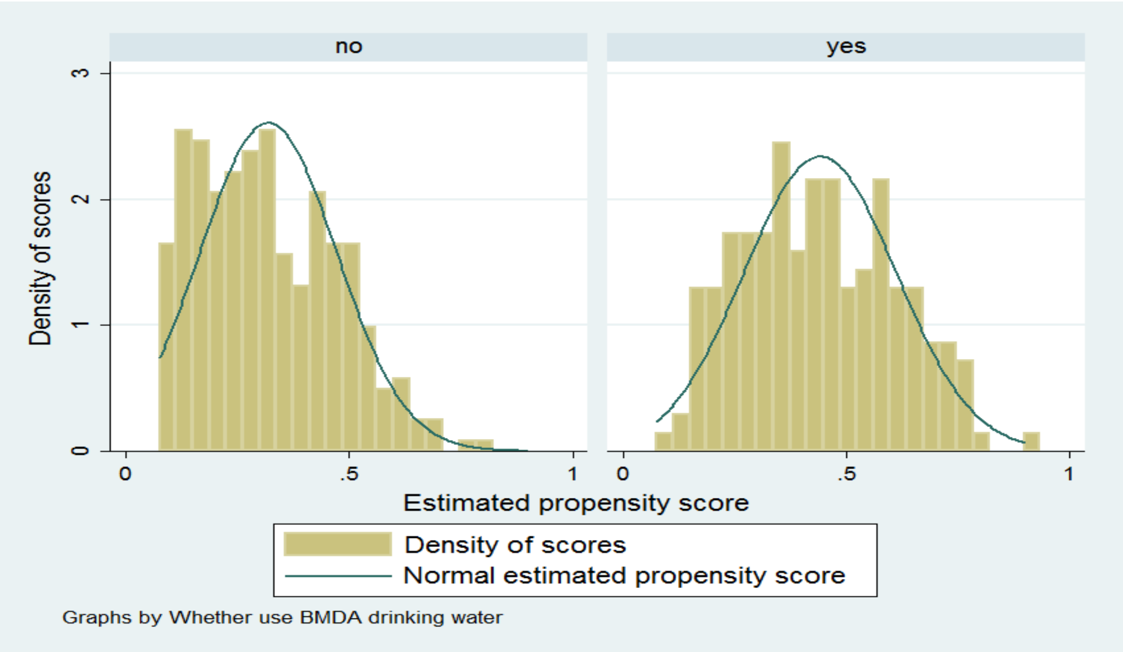
Here, the outcome of using piped water is denoted by y_1 and the outcome of not using of piped water $(bmdause=0)$ by y_0. The impact can be observed in the average treatment effect on the treated (ATT), which is defined as

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

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 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 11).



Control group *Treatment group*

Figure 11: Estimated propensity score for treatment and control groups

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 & 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" (P. R. 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).

5. Impact estimates

The impact of piped water access on the rural households were 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 5) and an individual-level analysis (Table 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 behavior and health outcomes) in the ATT and coefficient columns in Table 5 and Table 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.

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. 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 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 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 5). 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 5). The regression-based model showed a similar result (BDT 633); the result is statistically significant at the 0.01 level (Table 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.

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 behavior. 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 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.

5.3 Impact on health

In this study, impact on health was measured in terms of child diarrhea 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 diarrhea incidence; that is, the t-statistics and the p-value were not statistically significant (Table 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.

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. 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).

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 7. 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 program 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 9), the result 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 8 and Table 10. 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 8). For the variable “percentage of underweight children” (Table 10), 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.

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 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 diarrhea 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 diarrhea 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.

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. Diarrhea 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 adhere 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.

Table 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 (liter)	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. [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 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. [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 7: 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

* gamma is the log odds of differential assignment due to unobserved factors

Table 8: 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

* Odds of differential assignment due to unobserved factors

Table 9: 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

* gamma is the log odds of differential assignment due to unobserved factors

Table 10: 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

* Odds of differential assignment due to unobserved factors

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