Economic Valuation of Safe Water from New Boreholes in Rural Zambia: A Coping Cost Approach with Estimates of Internal Rate of Return

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Abstract

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Abstract

Access to safe water sources remains scarce in sub-Saharan African countries. We estimate the economic value of safe water from newly constructed boreholes in rural Zambia. Our quasi-experimental setting allows us to estimate the revealed preference measure of new safe water sources in a causal way, empowered by precise information on water collection and distance to new facilities. We show that the share of time value for water collection in total expenditures was about 5 percent at the baseline survey, which was reduced to 1.6 percent at the end-line survey, but the difference-in-differences analysis reveals that the project did not reduce the time burden for collecting water due to the greater demand for safe water. Moreover, we estimate the economic benefits of the project stemming from the significant reduction of diarrhea incidence. By estimating the economic value of a reduction in days lost due to diarrhea and a decrease in age-standardized disability-adjusted life years (DALYs), the internal rate of return (IRR) is estimated to be 14.2 percent, which is highly likely to be the lowest boundary of the actual IRR.

Keywords: Nonmarket valuation, revealed preference, time use, borehole, groundwater development, Zambia.

JEL Classification Codes: I38, J22, O18.

1. Introduction

Ensuring access to safe water is a basic need for all people and indispensable to improving their living standards, as stated in the United Nations (UN) Sustainable Development Goals (SDGs) (Goal 6.1).[1] In 2017, however, 579 million people globally did not have access to water from improved sources, with access to safe water most limited in sub-Saharan African (SSA) countries (UNICEF and WHO, 2019). Only 61% of people enjoyed basic drinking water or above in sub-Saharan Africa, which is far below the worldwide average of 90%, and 135 million people used water sources that required more than 30 minutes to complete water collection.

Limited access to safe water is attributed to the absolute shortage of a safe water supply. Moreover, a lack of general market mechanisms exacerbates efficient allocation of safe water. Thus, a large volume of literature, predominantly by environment economists, has been devoted to providing quantitative estimates of the economic valuation of safe water since it is a nonmarket resource whose economic value is rarely observed (Orgill-Meyer et al., 2018). One major strategy to assess the economic valuation of safe water is the revealed preference (RP) approach used to measure the demand for nonmarket environmental improvements. RP works by examining existing choices of households to make inferences about marginal benefits, which is indispensable to developing a better understanding of the efficient working of market mechanisms.[2]

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[1] Goal 6.1 calls for securing universal and equitable access to safe and affordable drinking water for all to achieve Goal 6 to “ensure access to water and sanitation for all” by 2030 (United Nations, n.d.).

[2] The revealed preference approach includes the travel cost method and averting expenditure method as well as the hedonic valuation method. Another popular strategy is the stated preference (SP) approach using survey responses on the willingness to pay for specific changes and includes contingent valuation (Orgill-Meyer et al., 2018).

One popular variant of the RP approach is the coping cost approach (averting expenditures) that is frequently used to gauge the economic benefits of water supply improvements. The typical procedure of the approach is to decompose the coping cost to obtain a monetary valuation of non-health benefits such as reduction of time on water collection and water treatment, market purchase of water, as well as the health benefits from avoiding any adverse effects on health and employment caused by waterborne diseases.

When we constrain our scope to limited water access in developing countries, the estimated total coping costs relative to income vary widely between studies: 1% of current income in Kathmandu, Nepal (Pattanayak et al., 2005), 7.5% of income in Parral, Mexico (Vasquez et al., 2009), 0.8% in Leon, Nicaragua (Vasquez, 2012), 12% of reported monthly cash income in Kianjai, Kenya (Cook et al., 2016), 4% of monthly expenditure in Zarqa and the eastern part of Amman, Jordan (Orgill-Meyer et al., 2018) and 15% of income in low-income households in Chennai, India (Amit and Sasidharan, 2019).[3] Most of those studies focused on measuring the values of water treatment costs and water storage investments for urban consumers who suffer from intermittent supply (Cook et al., 2016).

In contrast to many studies using stated preference (SP) methods to measure willingness to pay for improved water supply directly, there have been several empirical studies on coping strategies in rural areas in developing countries. Kremer et al. (2011) use both revealed and stated preference methods to estimate the value of water source protection in rural Kenya, focusing on coping strategies in water treatment and water

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[3] There are a number of studies on the coping cost of water in developed countries focusing on treatment behavior of tap water with a short collection time (e.g., McConnell and Rosado, 2000; Um et al., 2002).

collection times without showing detailed estimates of coping cost. Pattanayak et al. (2010) measured the time costs of water collection, storage and treatment as well as poor sanitation and illness in a community demand-driven water supply program in India and showed that half of the total coping cost stems from time cost. Jessoe (2013) reported that improved water sources reduce household spending on water treatment, which offsets 4% of the gains from water quality improvement in rural India. Cook et al. (2016) estimated the non-health benefits from water by measuring the coping cost on water collection time as well as the capital cost for storage and rainwater collection, money paid to obtain water, treating diarrhea cases, and water treatment. The results showed that the median total coping cost is US$20 per month or 12% of monthly cash income in rural Kenya.

This paper provides new estimates of the economic value of safe water by calculating the coping cost of safe water using a revealed preference approach in rural Zambia. We attempt to add the existing literature on estimates of economic valuation of safe water in several new aspects.

First, we estimate the revealed preference measure of new safe water sources in a causal way. Most of the previous literature has relied on cross-sectional data, in which it is difficult to disentangle the effects of new water facilities and other confounding factors from the unobservable characteristics of households. We utilize a unique dataset collected under a quasi-experimental setting in the dry season at sites with new access to safe water sources and without. We employ difference-in-difference (DID) estimates to gauge the causal impact of new boreholes made exogenously available, which captures the impact of safe water sources in a more precise way.

Second, we examine the impact of access to safe water without contamination at source. A variety of tests were used to confirm that the boreholes were free from potential contamination at source, including the amount of Escherichia coli (E. coli) before the boreholes were handed over to villagers.

Third, we employ a detailed time use survey on a variety of activities including water collection. We utilize an exhaustive timetable for the whole day from 5 am to 10 pm at both project and control sites. The merit of a time-use survey should be emphasized since there are only a small number of empirical estimates of time spent on traveling and waiting for water collection (Whittington et al., 1990; Pattanayak et al., 2005; Cool et al., 2016).[4] We also incorporate the distance to water sources using location information to capture the difference of the impact of improved access to safe water across locations.

This paper proceeds as follows. The next section describes the theoretical framework. Section 3 illustrates the target project, our research design and the data set. Section 4 estimates each component of the coping costs and discusses our estimates of the economic valuation of safe water and calculates the internal rate of return. The conclusion in Section 5 discusses the implication of our main findings and possibilities for future research.

2. Theoretical framework

We consider the following unitary household utility maximization problem to examine the revealed preference for the value of safe water made available by the

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[4] Several studies reported the time burden in fetching water. Rosen and Vincent (1999) show that women spend 2–3 hours per day on water collection on average in rural sub-Saharan Africa and women and girls are mainly responsible for water collection (Ray, 2007; Sorenson et al., 2011; Koolwal and Van de Walle, 2013; Graham et al., 2016).

groundwater development project.

$$\max U(G, K, X, L_l, S(G, K, C)\,)$$

$$\text{s.t.} \qquad p_1 G + p_2 K + p_3 C + X \leq Y \ \ \text{(budget constraint)}$$

$$L_e + L_l + L_G + L_K \leq T(S) \ \ \text{(time endowment)}$$

$$L_G = c_G \cdot t_G \ \text{ and } \ L_K = c_K \cdot t_K$$

$$wL_e = Y \ \ \text{(income)}$$

$$G \leq G_{max}$$

where the notations are as follows; G: volume of water from the new borehole; K: volume of water from the pre-existing water sources; $p_1$and p_2: unit costs of obtaining G and K respectively; X: composite goods; S: sickness; C: water treatment; p_3: unit cost of water treatment; L_e: time of work; L_l: time of leisure; $L_G \, and \, L_K$: time of water collection for G and K, respectively; $T(S)$: time endowment adversely affected by sickness ($\frac{\partial T}{\partial S} < 0$); $c_G \, and \, c_K$: number of trips for water collection; $c_G = \mathrm{G/g}$ and $c_K = \mathrm{K/k}$ where g and k are water volume per trip; $t_G \, and \, t_K$: time of water collection per trip; w: market wage rate.

The equation of the method of Lagrange multiplier is shown below:

$$L = U - \lambda(w(T(S) - L_l - L_G - L_K) - p_1 G - p_2 K - p_3 C - X)$$

By applying the duality, the equation for the cost minimization problem can be expressed as follows:

$$\psi = w(L_l + L_G + L_K - T(S)) + p_1 G + p_2 K + p_3 C + X - \mu(U^* - U)$$

By taking a derivative with respect to G_{max}, we can use the following equation to consider the amount of willingness to pay for water use from the new borehole (Pattanayak et al., 2010):

$$\frac{\partial\psi}{\partial G_{max}} = w\left(\frac{\partial L_l}{\partial G_{max}} + \frac{\partial L_G}{\partial G_{max}} + \frac{\partial L_K}{\partial G_{max}} - \frac{\partial T}{\partial G_{max}}\right) + p_1 + p_2\frac{\partial K}{\partial G_{max}} + p_3\frac{\partial C}{\partial G_{max}} + \frac{\partial X}{\partial G_{max}} - \mu\frac{\partial U}{\partial G_{max}}$$

At the time of the baseline survey, water supply from the new boreholes was zero; $G_{max} = 0$, and thus the constraint was binding. After the new boreholes were built by the end-line survey, households began fetching water *G* from the boreholes by paying p_1. The cost of obtaining water *G* from the newly built boreholes was not based on a volumetric method but fixed-amount payment p_1 as maintenance and administration fees. The variable cost can be measured by time spent on water collection from the boreholes evaluated by the opportunity cost, i.e., market wage rate w; $w\frac{\partial L_G}{\partial G_{max}}$ (>0). By utilizing more water from the new boreholes, households are expected to reduce the volume of water use from other water sources and thus lead to a decrease in the purchase of *K* and also the time cost of collecting water from other water sources; $p_2\frac{\partial K}{\partial G_{max}}$ (<0) and $w\frac{\partial L_K}{\partial G_{max}}$ (<0).

Before starting to use safe water from newly built boreholes, households utilize some water treatment methods by paying p_3C. The availability of safe water may influence C and thus the cost of utilizing a water treatment method is measured by $p_3\frac{\partial C}{\partial G_{max}}$ (<0). Moreover, under the liquidity constraint, the consumption of composite goods is also affected, $\frac{\partial X}{\partial G_{max}}$. In addition to the time cost for water collection, the value of leisure time is measured by the opportunity cost $w\frac{\partial L_l}{\partial G_{max}}$. Other gains are realized through a change in utility caused by the change in resource allocation. Furthermore, improvement of health status affects utility level $\mu\frac{\partial U}{\partial S}\cdot\frac{\partial S}{\partial G_{max}}$.

3. The project site, research design and dataset

(1) Zambia and Luapula Province

Zambia is a landlocked sub-Saharan African country with 17 million people in 2019. It suffers from limited access to safe water. In 2015, only 67.7% of households had access to improved sources of drinking water (Central Statistical Office, 2016), a slight improvement on 62% in 2010, with a wide regional variation between urban and rural areas (Central Statistical Office, 2011).

We focus on Luapula Province as a case study of rural Zambia, which is located in the northern territory with a population of one million living in an area of 30 thousand square kilometers. The province had the highest poverty rate among the provinces in the country in 2010, which worsened to 81.1% in 2015 (Central Statistical Office 2016). While the province is endowed with rich water sources, with more than 40% taken up by lakes and wetland areas (Figure 1), the province suffers from lower access to safe drinking water; the proportion of people with access to safe water in the province was among the lowest, at only 28% in 2010, but improving to 52.9% in 2015 (Central Statistical Office 2016).

A lack of access to safe water is detrimental to the daily lives of people since they cannot enjoy the health or non-health benefits from water facilities. For health benefits from safe water, there is a growing concern that a lack of access to safe water is a major cause of waterborne diseases including diarrhea, which is ranked among the top ten major causes of morbidity in Zambia and, in more recent years, a higher incidence of diarrhea has been observed (Ministry of Health, Republic of Zambia, 2014). The national average of diarrhea incidence per 1,000 population in Zambia was 8.6 % and the hospital case fatality rates for diarrhea were 65 deaths per 1,000 admissions in 2012. In the Luapula province, the incidence of diarrhea registered at 8.3% and the hospital case fatality rates were 69 deaths per 1,000 admissions in the same period (Ministry of Health, Republic of Zambia 2014).

The non-health benefits of access to safe water stem from a reduction in the time burden required for water collection, treatment and storage, and the decreased need to purchase water. Most studies of sub-Saharan African countries use cross-sectional data showing that the estimated time saving by improving access to water sources has ranged widely from 30 to 300 minutes (Cairncross and Cliff, 1987; Bevan et al., 1989; Blum et al., 1990). Recently, Devoto et al. (2012) reported that 27 minutes were saved per day by switching from a public to a private connection in Morocco's urban area, and Gross et al. (2018) found that 41 minutes were saved per day from water collection activities due to the provision of new public water points in rural Benin. We echo the method of those two papers by using longitudinal data to examine the time-saving effect of new water sources rigorously.

(2) The groundwater development project

The target project of this study is "Project for Groundwater Development in Luapula Province Phase 2," conducted by the Japan International Cooperation Agency (JICA). This is a grant aid project to provide both hardware and software components with the aim of reducing water-related diseases by assuring improved access to safe and stable water sources. In the project, new borehole water supply facilities were constructed with hand pumps at 216 sites between February 2012 and May 2013. Each facility was designed to provide 30 liters of water for 250 people per day (JICA, 2014).

Those boreholes have a designed average depth of 63 meters below ground level, which ensures that water is free from ground contaminants at the source. The quality of water at each borehole was tested to satisfy the national standards of Zambia before being handed over to the residents.[5]

The target sites in the project were selected as follows: 320 sites in four districts (Milenge, Mwense, Mansa and Nchelenge) were specified by the Government of Zambia in its request for grant aid. Then, each specified site was screened using a preparatory survey of seven criteria[6] and 291 sites were identified as candidate sites; 216 sites were selected as target sites and the remaining 75 sites served as alternatives when drilling was unsuccessful at target sites. Since there was still a risk of failing to find underground water, a maximum of two drillings were attempted at each site, and if both were unsuccessful, the site was abandoned and replaced with an alternative (JICA, 2014). In the end, the project constructed 216 facilities at 214 sites, but 31 target sites were replaced because it was impossible to obtain groundwater.[7] The construction of new boreholes was accompanied with (re-)organization of the Village Water, Sanitation and Health Education (V-WASHE) Committee, which is responsible for general and daily operations and maintenance at the village level, along with a variety of training programs provided to stakeholders (JICA, 2014).

(3) Data description

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[5] The tests included electrical conductivity, pH, iron, manganese, fluorine content and Escherichia coli (E. coli)

[6] The seven criteria are: demand for safe and stable water supply; accessibility to the site; hydrogeological conditions; availability of existing water supply facilities; overlap with other related projects; possibility of forming a V-WASHE Committee; and residents' willingness to pay the operation and maintenance costs of the facilities (JICA, 2014).

[7] In Milenge district, two additional facilities were constructed at two sites since the number of unsuccessful sites exceeded the number of alternative sites (JICA, 2014).

The data used in this study consists of the first-round (baseline) survey conducted from June to July 2012 with no facilities available at the timing, and the second-round (end-line) survey from June to August 2013 with the completion of new boreholes. Both surveys were implemented in the dry season within the almost-no-rain period. The survey was conducted in three districts (Milenge, Mwense, and Nchelenge).[8] At the baseline survey, 94 sites were randomly selected in each district (50 sites from the list of the target sites and 44 from the control sites).

However, the project was not able to obtain water from new boreholes at some target sites because it was difficult to predict the possibility of obtaining water successfully when blind-boring. Those sites without water could be regarded as control sites in the end-line survey, and new sites converted from control sites into target sites where it was possible to get water from new boreholes.

After these conversions, we ended up with 63 "project sites" with the new boreholes and 31 "control sites" without them in total. The conversions eventually created an ideal situation for the causal impact analysis as if the construction of the new borehole had been randomly assigned to the project sites. Then, 8 households were randomly selected from each of the 94 sites, and thus 752 households in total were interviewed. 117 households (15.6% of the total) could not be revisited in the end-line survey. The total number of households surveyed at both baseline and end-line was 635 (434 in the treatment group and 201 in the control group).[9]

We make two remarks on the dataset. First, the interval between baseline and end-

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[8] Mansa was excluded from the survey since some facilities were handed over to the villagers before the baseline survey was undertaken.

[9] Households with fewer family members were more likely to move away but this attrition pattern did not significantly differ between project and control sites (JICA, 2014).

line is short (only one year), which enables us to examine the short-term impact of safe water access. Second, villagers living around different sites started to use them at different times, with the period for using the new facilities in the project sites averaging six months (varying from two months to ten months).

Both rounds of the survey employed household and community questionnaires, and these contained a wide variety of socio-economic variables related to individuals, households, and communities. The same questionnaire was used in both surveys with minor revisions after another pre-test for the end-line survey. In the survey, access to existing water sources outside houses was confirmed by both community and household questionnaires and the practice of fetching water per day from each water source for the day before the interview. Moreover, rich information on health status was collected, including episodes of illness/injury for each individual family member over the last two weeks and any diarrhea-related symptoms over the same period together. This was accompanied by a simple test of the quality of drinking water stored at each household by the enumerators. Furthermore, the survey collected detailed time-use information by asking respondents to fill in a timetable for a whole day according to 18 types of activities.[10] The time-use survey allowed us to comprehensively measure the time spent on a variety of activities, including time spent on water collection and water-related chores.

4. Estimates of coping costs and benefits

(1) Use rate of water sources

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[10] The most knowledgeable person was made responsible for providing information on use of time.

Table 1 summarizes the use rate of water sources from which rural households collect water. At the baseline survey, hand-dug wells were the most common water sources in both project (45.2 percent) and control sites (29.1 percent). Only about 15 percent of the households had access to boreholes, which were shallower ones compared to the new boreholes constructed by the project, and about 10 percent used shallow wells. Other water sources were natural resources such as springs, streams, rivers, and lakes.

After construction of the new water facilities, the end-line survey reveals that the average distance to the new boreholes was 255 meters and 77.9 percent of the sampled households used the new boreholes. Figure 2 shows a histogram of the households in the project sites and examines the relationship between distance to and the use rate of the new boreholes by employing a kernel-weighted local polynomial regression. The use rate was over 80 percent near the new boreholes and declined as the distance became greater. After constructing the new boreholes, the use rate of the other water sources declined significantly. In the control sites, the use rate of the boreholes fell to 35 percent because some shallower boreholes were newly constructed. Nonetheless, the use rate of the other water sources remained unchanged, suggesting that new borehole construction had limited influence on the control sites. The average distance to the nearest water source was 454 meters in the project sites and 547 meters in the control sites at the baseline survey, both of which were reduced to 163 meters and 395 meters, respectively.

(2) Outcome variables and control covariates

Table 2 provides a sneak preview of outcome variables used to estimate the coping costs of water and benefits of the groundwater development project. We conducted balance tests of the outcome variables and can confirm that there is no statically significant difference between the project sites and control sites at the baseline survey. In contrast, we find some significant differences at the end-line survey. By employing the difference-in-differences estimation, we examine if these differences can be attributed to the project effect. For the difference-in-differences estimation to reveal the causal effect of the project, the central assumption is a "common trend" between the project sites and the control sites. Balance tests of the initial conditions of the sites are conducted to confirm that both project and control sites had similar demographic and socio-economic characteristics at the baseline survey (Appendix).[11] Because the common trend assumption is likely to be violated when changes in covariates confound the trend, we include control covariates in the estimation. The summary statistics of covariates controlled for in multivariate regression analysis are shown in Table 3.

(3) Coping costs for water collection

To cope with the scarcity of water resources, local people spend a lot of time collecting water from various water sources. Our time-use survey reveals that households on average were spending 3.53 hours per day collecting water in the project sites and 3.60 hours per day in the control sites at the baseline survey (Table 2 Column (A) and (B))).[12] The average household size was 5.22 (2.70 females and 2.52 males) in the project sites and 5.17 (2.58 females and 2.59 males).[13] Working-age females aged

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[11] More detailed explanations about the estimation strategy to identify the causal effect of the project can be found in Shimamura et al. (2020a, 2020b).

[12] At the baseline survey, $L_G = 0$ and the numbers represent L_K. At the end-line survey, the numbers represent $L_G + L_K$. In the project sites, an increase in L_G was accompanied by a decrease in L_K. This study examines the net effect of the project on the total time for water collection ($\frac{\partial L_G}{\partial G_{max}} + \frac{\partial L_K}{\partial G_{max}}$).

[13] In the project sites, 2.70 females (2.52 males) consist of 0.62 (0.57) pre-school-age children aged 0 to 6, 0.91 (0.87) school-age children aged 7 to 18, and 1.07 (0.98) working-age adults aged 19 to 59, and 0.11 (0.09) elderly aged 60 and above. In the control sites, 2.58 females (2.59 males) consist of

19 to 59 were the main collectors and on average spent 1.68 hours per day in the project sites and 1.73 hours per day in the control sites collecting water. On average, school-age girls aged 7 to 18 spent 0.78 hours per day in the project sites and 0.88 hours per day in the control sites, whereas school-age boys spent 0.58 hours per day in the project sites and 0.60 hours per day in the control sites.

Then, we evaluate the economic value of time spent on water collection by referring to the market wage rate, one thousand ZMK per hour equivalent to 1.54 USD per 8-hour workday. By putting 25 percent as a weight, the economic value of 3.53 hours per day or 161 workdays per year is equivalent to 62.0 USD per year in the project sites, while 3.60 hours per day or 164 workdays per year is equivalent to 63.2 USD per year in the control sites. These numbers indicate that the estimated coping cost spent on water collection is evaluated as 5.1 percent of total expenditures in the project sites and 5.5 percent in the control sites.

At the end-line survey, time spent on water collection in both project and control sites significantly decreased because of the construction of the new water facilities and the shorter distance to the nearest water source. On average, the households spent 1.43 hours per day on water collection in the project sites and 1.46 hours per day in the control sites (Table 2 Column (C) and (D)), which is equivalent to 65 workdays or 23.5 USD per year in the project sites and 67 workdays or 24.0 USD per year in the control sites. These numbers suggest that the coping cost for water collection was reduced to 1.6 percent of total expenditures in the project sites and 1.5 percent in the control sites.

We now employ the difference-in-differences estimation to investigate the causal

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0.65 (0.67) pre-school-age children, 0.78 (0.82) school-age children, and 1.05 (1.03) working-age adults, and 0.10 (0.08) elderly.

effects of new borehole construction on time spent for water collection. Table 4 reports the estimation results and shows that the project does not cause any change in time spent on water collection (Column (A)), while we saw a reduction in time for water collection was a common trend over the survey period in both project and control sites. Even when we consider the effect of the use of the new boreholes (Column (B)) as well as the interaction terms between the use of and distance to the new boreholes measured in kilometers in Column (C) and in minutes in Column (D), no significant causal effect is detected.

(4) Behavioral changes in water collection

To explore the reasons for no causal effect of the project on time for water collection, we further examine how the project changed behaviors of fetching water. First, we examine the effect of the project on water volume carried. At the baseline survey, the households on average fetched 64.1 liters of water per day in the project sites and 63.7 liters per day in the control sites, which reduced to 52.6 liters and 49.3 liters after the intervention, respectively (Table 2). Table 5 presents the difference-in-difference estimation results to show that we could not find any significant effect on the volume of water carried, yet the point estimates suggest that the households in the project sites carried more water volume per day (Columns (A)-(D))

Second, we examine the effect of the project on the number of trips made to fetch water. On average, the households made 3.8 rounds for fetching water per day (23.0 rounds per week) in the project sites and 3.6 rounds per day (22.5 rounds per week) in the control sites at the baseline survey (Table 2). The number of trips per day in the project sites was unchanged but decreased to 21.0 rounds per week, whereas the number of trips in the control sites decreased to 3.2 rounds per day and 17.9 rounds per week.[14] We do not find any significant effect on the number of trips per day (Columns (E)-(H)), yet the point estimates suggest that the households in the project sites made more trips per day. Looking at the number of trips per week (Columns (I)-(L)), the increase in the number of trips per week among the households living close to the new boreholes is statistically significant, suggesting that they made 3.3 more trips for fetching water per week.

These results suggest that the demand for safe water increased, particularly in the project sites, because water from the new boreholes was E. coli free. Hence, the number of trips increased to obtain a greater volume of water and the total time spent on water collection did not decline. This tendency is more pronounced among the borehole users living near the newly constructed boreholes, confirming that these behavioral changes in fetching water were caused by new borehole construction.

(5) Other coping costs

Another component of coping cost is the fixed-amount payment for maintenance and administration fees to use the new boreholes. The majority of the users paid 1 ZMK per month at the end-line survey after the denomination in 2013, which is equivalent to 2.16 USD per year. Other coping costs were comprised of fees for water storage and for utilizing water treatment methods. We collected information on household behaviors of storing water at home. The households used plastic containers and clay pots for storing water, and more than 90 percent stored water for drinking purposes separately, of which

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[14] We can estimate the volume of water carried per round. At the baseline survey, the households carried 16.9 liters per trip in the project sites and 17.6 liters per trip in the control sites, which was reduced to 13.8 and 15.3 liters per trip at the end-line survey, respectively. The households in the project sites carried a slightly smaller volume of water each time.

more than 90 percent comprised covered containers with a lid. We examined behavioral changes in storing water due to the project, but we did not find any significant change in the behaviors of storing water at home (not shown).

We also collected information about the utilization of water treatment methods such as boiling water, chlorination, and filtration. Among various water treatment methods, chlorination was the most popular. At the baseline survey, 22.9 percent of the households utilized chlorine in the project sites and 23.3 percent did in the control sites, which decreased to 9.9 percent and 19.3 percent, respectively (Table 2). Table 6 shows the estimation results from the difference-in-differences estimations to explore the causal effect of the project on the utilization of chlorine and reports a 10 percentage-point decrease, which is statically significant (Columns (A)-(D)). Because people believed that the water supply from the new boreholes was perfectly safe, they tended to cease using chlorine. This is understandable because chlorination makes the taste of water unpleasant, particularly for drinking purposes. In addition, the households in the project sites tended to stop boiling and filtering (Columns (E)-(L)), although the application rates of these water treatment methods were low (less than 10 percent of the households boiled water and less than 1 percent filtered water). By reducing the utilization of these water treatment methods, the households in the project sites reduced some coping costs, which is approximately 2 to 3 USD per year.[15]

(6) Estimates of the benefits of the project

Now, we turn to the benefits of the project. Because the project provided safe water, we expected a reduction in the incidence of waterborne diseases, particularly

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[15] The market price of one bottle of chlorine to disinfect the maximum of 1,000 liters of water that satisfied demand for a family with six members for one month in Lusaka, the capital city of Zambia, was estimated 0.2 to 0.3 USD (Ashraf et al. 2010; 2013).

diarrhea. Our surveys collected information about diarrheal episodes over the previous two weeks and the number of days during which each household member could not perform regular activities due to diarrhea. On average, the households reported 0.128 diarrhea cases in the project sites and 0.121 cases in the control site at the baseline, which decreased to 0.091 cases in the project sites and increased to 0.146 cases in the control sites at the end-line survey (Table 2). Table 7 shows the difference-in-difference estimation results to demonstrate that the project reduced diarrhea incidence by 0.073 cases per household over the last two weeks, equivalent to a 57 percent decrease in the incidence of diarrhea. The magnitude of the impact is larger and statistically significant among the borehole users living close to the new boreholes (Columns (B)).

To estimate the economic values of the health benefits, we consider the following age cohorts separately: working-age adults aged 19 to 59, school-age children aged 7 to 18, and pre-school-age children aged 0 to 6. Among working-age adults, the household reported 0.033 diarrhea cases in the project sites and 0.024 cases in the control site, which decreased to 0.026 cases in the project sites and increased to 0.044 cases in the control sites at the end-line survey (Table 2). Table 7 reports that the project reduced diarrhea incidence by 0.030 cases (Column (E)) and days lost by 0.128 days per two weeks (or 3.328 days per year) (Column (I)) among working-age adults. We evaluate the health benefit of the project for working-age adults by using 25 percent of the market wage rate, which is the same as the valuation of time for water collection. The economic value of the reduction in diarrhea incidence among working-age adults is estimated as 1.28 USD per year.

For the school-age cohort, the households reported 0.026 diarrhea cases over the last two weeks in the project sites and 0.024 cases in the control site at the baseline survey, which decreased to 0.019 cases and 0.015 cases at the end-line survey, respectively (Table 2). Table 8 provides the difference-in-difference estimation results to show that no significant causal effect of the project was observed (Columns (A)-(D)). For the pre-school age cohort, the households reported 0.068 diarrhea cases over the last two weeks in the project sites and 0.063 cases in the control site at the baseline survey, which decreased to 0.035 cases and 0.078 cases at the end-line survey, respectively (Table 2). Table 8 shows the difference-in-difference estimation to reveal that the project reduced diarrhea incidence by 0.054 cases per household over the last two weeks, which is statistically significant (Columns (E)) and indicates about an 80 percent decrease in the incidence of diarrhea. The magnitude of the health impact is larger among the borehole users (Columns (F)-(H)).

To measure the economic values of the improvement of health status from a more general perspective, we further employ the concept of DALYs: disability-adjusted life years. DALYs comprise the number of years of life lost due to premature death and the number of years of life lived with a disability arising from new cases of disease or injury. There have been some variants of the DALY estimates depending on diseases and countries as well as methodologies. Our estimation relies on age-standardized DALYs (1015.5 per 100,000) caused by diarrheal diseases in 2013 (GBD 2013 DALYs and HALE Collaborators 2013), which is multiplied by the ratio of 1.19 for Zambia (GBD 2015 DALYs and HALE Collaborators 2015). Among all age groups, a 57 percent decrease in diarrhea incidence is associated with a reduction of age-standardized DALYs of 688.1 per 100,000. The average household size of our sample is 5.26 and thus the decrease in DALYs corresponds to 13.2 days for a family, which can be evaluated as 5.08 USD.

The total economic value of health benefits is 6.36 USD, including those caused by a reduction in days lost among working-age adults and a decrease in DALYs among all age cohorts. The average population in a target village was 480 households and the average construction costs for a new borehole were approximately 20,000 USD. By assuming that the health benefits from the newly constructed borehole materialize every year and continue for 20 years, the internal rate of return (IRR) can be calculated as 14.2 percent. As we have found a larger reduction in diarrhea incidence among pre-school-age children, this estimate is highly likely to provide the lowest boundary for the actual IRR. For diarrheal diseases among children under 5 years old, Troeger et al. (2018) estimate the total DALYs comprising the acute DALYs that are the burden associated with immediate health loss and the long-term sequelae DALYs that are burden associated with growth impairment. They find a 70 percent increase in the total DALYs compared to the acute DALYs in Zambia. By incorporating the long-term sequelae DALYs for pre-school-age children, the estimate of the IRR is likely to be much higher than the one we estimate.

5. Conclusion

This study attempts to evaluate the economic value of a groundwater development project, which provided safe water by constructing new boreholes free from potential contamination. We show that the share of time value for water collection in total expenditures was estimated to be about 5 percent at the baseline survey, which was reduced to 1.6 percent at the end-line survey, but the project did not reduce the time burden to collect water because of the greater demand for saving water.

We also perform estimates of the economic benefits of the project, focusing on a reduction in days lost due to diarrhea and a decrease in age-standardized DALYs. We estimate the IRR of the new boreholes to be 14.2 percent, which is highly likely to provide the lowest boundary of the actual IRR because we have found that the health benefits for pre-school-age children are much larger than that for working-age adults. The economic value of the health benefits for pre-school-age children is likely to be much higher once we incorporate the long-term sequelae DALYs, which are the burden associated with growth impairment.

We add the existing literature by providing new evidence on measuring the economic value of safe water at a quasi-experimental setting with new estimates of IRR. Further research should refine economic valuations of safe water from a variety of sources in more rigorous ways in developing countries, which is indispensable to improving the living standards of people suffering from scarcity of water supply, through a better understanding of efficient mechanisms for nonmarket goods supply.

References

Ashraf, N., Berry, J., Shapiro, J.M., 2010. Can higher prices stimulate product use? Evidence from a field experiment in Zambia. American Economic Review 100, 2383-2413.

Ashraf. N., Jack, B.K., Kamenica, E., 2013. Information and subsidies: complements or substitutes? Journal of Economic Behaviour & Organization 88, 133–139.

Amit, R.K., Sasidharan, S., 2019. Measuring affordability of access to clean water: A Coping cost approach. Resources, Conservation & Recycling 141, 410–417.

Bevan, D., Collier, P., Gunning, J.W., 1989. Peasants and governments: An economic analysis. Clarendon, Oxford.

Blum, D., Robert, N., Emeh, S., Huttly, R.A., Dosunmu-Ogunbi, O., Okeke, N., Ajala, M., Okoro, J.I., Akujobi, C., Kirkwood, B.R., Feachem, R. G., 1990. The Imo State (Nigeria) Drinking Water Supply and Sanitation Project: Description of the project, evaluation methods, and impact on intervening variables. Transactions of the Royal Society of Tropical Medicine and Hygiene 84 (2), 309–15.

Cairncross, S., Cliff, J.L., 1987. Water use and health in Mueda, Mozambique. Transactions of the Royal Society of Tropical Medicine and Hygiene 81 (1), 51–54.

Central Statistical Office, Republic of Zambia., 2011. Living conditions monitoring survey report 2010. Lusaka: CSO.

Central Statistical Office, Republic of Zambia., 2016. Living conditions monitoring survey report 2015. Lusaka, CSO.

Cook, J., Kimuyu P., Whittington, D. 2016. The costs of coping with poor water supply in rural Kenya. Water Resource Research 52, 841–859.

Devoto, F., Duflo, E., Dupas, P., Parienté, W., Pons, V. 2012. Happiness on tap: Piped water adoption in urban Morocco. American Economic Journal: Economic Policy 4 (4), 68–99.

GBD 2013 DALYs and HALE Collaborators, 2015. Global, regional, and national disability-adjusted life years (DALYs) for 306 diseases and injuries and healthy life expectancy (HALE) for 188 countries, 1990–2013: Quantifying the epidemiological transition. Lancet 386, 2145–2191.

GBD 2015 DALYs and HALE Collaborators, 2017. Global, regional, and national disability-adjusted life years (DALYs) for 306 diseases and injuries and healthy life expectancy (HALE) for 188 countries, 1990–2015: Quantifying the epidemiological transition. Lancet 388, 1603–1658.

Graham, J., Hirai, M., Kim, S., 2016. An analysis of water collection labor among women and children in 24 sub-Saharan African Countries. PLoS ONE 11 (6), e0155981. https://doi.org/10.1371/journal.pone.0155981

Gross, E., Günther, I., Schipper, Y. 2018. Women are walking and waiting for water: The time value of public water supply." Economic Development and Cultural Change 66 (3), 489-517.

Japan International Cooperation Agency (JICA), 2014. Basic research for impact evaluation trial on grant aid: A case from Rural Groundwater Development Project in Zambia. JICA, Tokyo.

Jessoe, K., 2013. Improved source, improved quality? Demand for drinking water quality in rural India. Journal of Environment Economics and Management 66 (3), 460–475.

Koolwal, G., Van de Walle, D., 2013. Access to water, women's work and child outcomes. Economic Development and Cultural Change 61 (2), 369-405.

Kremer, M., Leino, J., Miguel, E., Zwane, A.P., 2011. Spring cleaning: Rural water impacts, valuation, and property rights institutions. Quarterly Journal of Economics 126, 145–205.

McConnell, K. E., Rosado, M.A., 2000. Valuing discrete improvements in drinking water quality through revealed preferences. Water Resource Research 36 (6), 1575–1582.

Ministry of Health, Republic of Zambia., 2014. Annual health statistical bulletin 2012. MOH, Lusaka.

Orgill-Meyer, J., Jeuland, M., Albert, J., Cutler, N., 2018. Comparing contingent valuation and averting expenditure estimates of the costs of irregular water supply. Ecological Economics 146, 250–264.

Pattanayak, S., Poulos, C., Yang, J.-C., Patil, S.R., 2010. How valuable are environmental health interventions? Evidence from a quasi-experimental evaluation of community water projects. Bulletin of World Health Organization 88, 535–542.

Pattanayak, S., Yang, J.-C., Whittington, D.. Bal Kumar, K., 2005. Coping with unreliable public water supplies: averting expenditures by households in Kathmandu, Nepal. Water Resources Research 41 (2), W02012.

Ray, I., 2007. Women, water and development. Annual Review of Environment and Resources 32, 421–49.

Rosen, S., Vincent, J. R., 1999. Household water resources and rural productivity in sub-Saharan Africa: A review of the evidence. Unpublished manuscript. Cambridge, MA, Harvard Institute for International Development.

Sorenson, S., Morssink, C., Campos P., 2011. Safe access to safe water in low income countries: Water fetching in current times. Social Science and Medicine 72 (9), 1522–26.

Shimamura, Y., Shimizutani, S., Taguchi, S., Yamada, H., 2020a. The impact of improved access to safe water on childhood health, schooling and Time Allocation in Rural Zambia." *KEIO IES Discussion Paper* DP2020-022.

Shimamura, Y., S. Shimizutani, S. Taguchi, and H. Yamada (2020b). "Improved Access to Safe Water: Effects on Adult Health and Time Reallocation in Rural Zambia." *KEIO IES Discussion Paper* DP2020-024.

Troeger, C., D. V. Colombara, D.V., Rao, P.C., Khalil, I.A., Brown, A., Brewer, T.G., Guerrant, R.L., Houpt, E.R.,. Kotloff, K.L., Misra, K., Petri Jr, W.A., Platts-Mills, J., Riddle, M.S., Swartz, S.J., Forouzanfar, M.H., Reiner Jr, R.C., Hay, S.I., Mokdad, A.H., 2018. Global disability-adjusted life-year estimates of long-term health burden and undernutrition attributable to diarrhoeal diseases in children younger than 5 years. Lancet Global Health 6, e255–269.

Um, M. J., Kwak, S.J., Kim, T. 2002. Estimating willingness to pay for improved drinking water quality using averting behavior method with perception measure, Environmental Resource Economics 21, 285–300.

United Nations, (n.d.). *Sustainable Development Goals, Goal 6 Water and Sanitization*. https://www.un.org/sustainabledevelopment/water-and-sanitation/

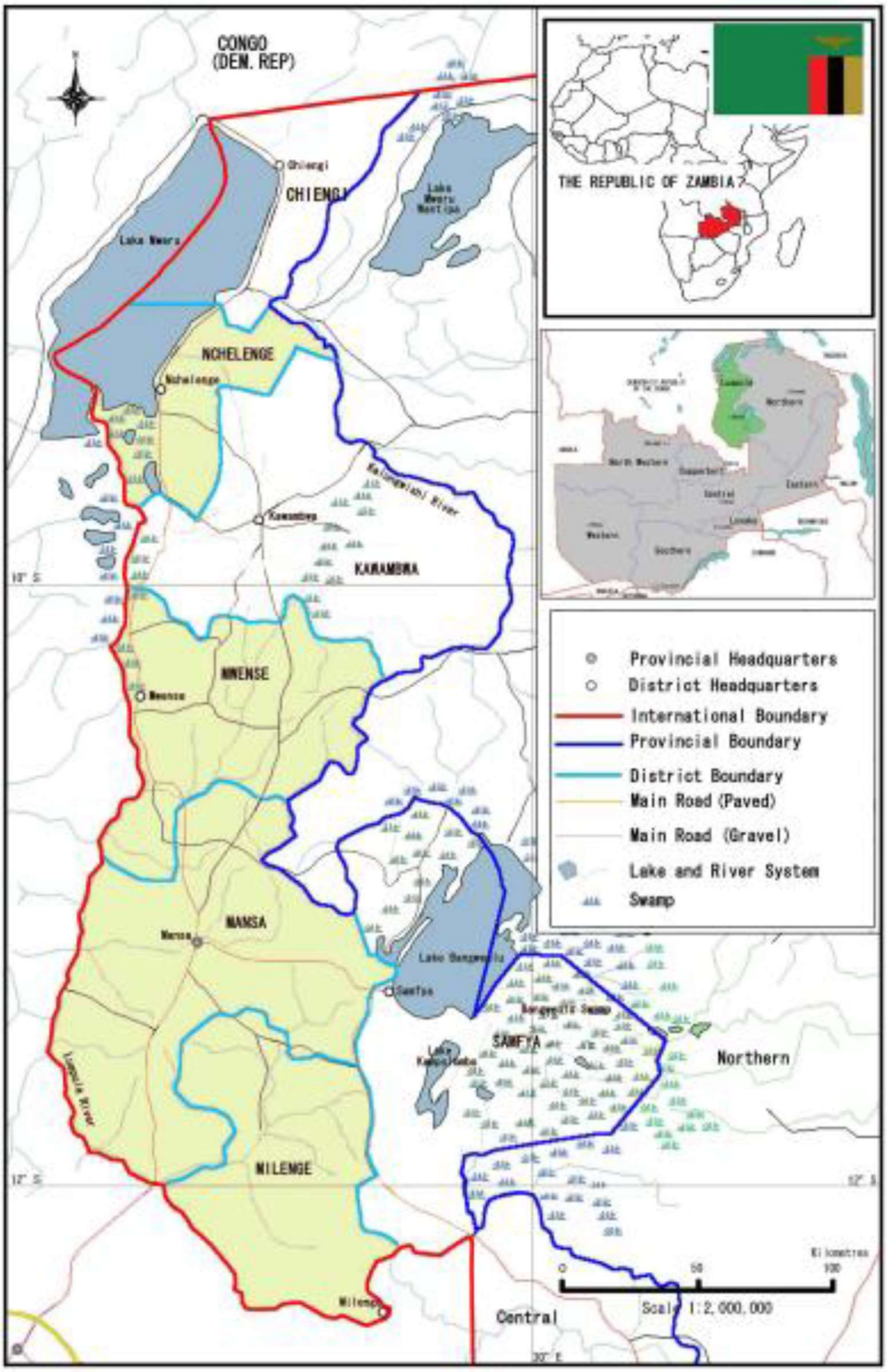
United Nations Children's Fund (UNICEF) and World Health Organization (WHO), 2019. Progress on household drinking water, sanitation and hygiene 2000-2017. Special focus on inequalities. UNICEF & WHO, New York.

Vasquez, W. F., Mozumder, P. J. Hernandez-Arce, J., Berrens, R.P., 2009. Willingness to pay for safe drinking water: Evidence from Parral, Mexico. Journal of Environment Management 90, 3391–3400.

Vasquez, W.F., 2012. Reliability perceptions and water storage expenditures: Evidence from Nicaragua. Water Resource Research 48, W10547.

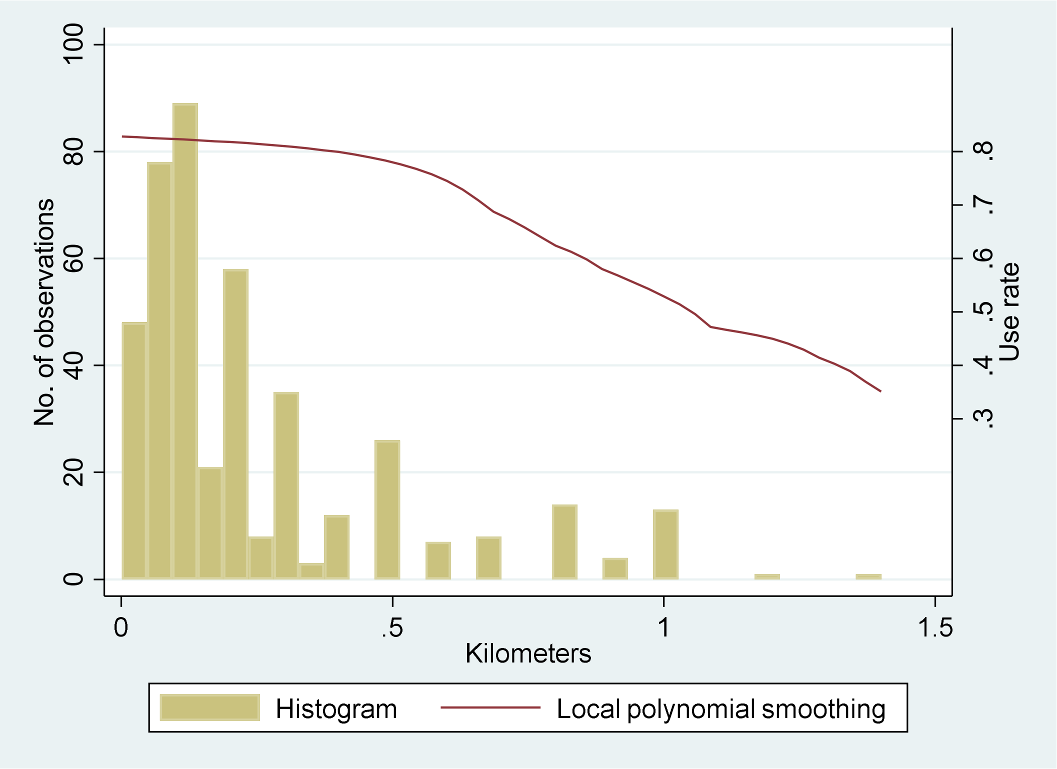
Whittington, D., Mu, X., Roche, R., 1990. Calculating the value of time spent collecting water: Some estimates for Ukunda, Kenya. World Development 18 (2), 269–280.

Figure 1 Map of Luapula Province



Source: JICA (2014).

Figure 2 Distance to and use rate of new boreholes in the project sites



Note: The total number of sampled households in the project sites is 429.

Table 1 Use rate of water sources

Water source	***Project sites***				***Control sites***			
	Baseline		***End-line***		***Baseline***		***End-line***	
	Obs.	%	Obs.	%	Obs.	%	Obs.	%
JICA borehole			334	77.9				
Other boreholes	60	14.0	30	7.0	31	15.0	73	35.4
Shallow well	44	10.3	19	4.4	25	12.1	27	13.1
Hand-dug well	194	45.2	126	29.4	60	29.1	64	31.1
Spring	18	4.2	9	2.1	25	12.1	22	10.7
Stream	101	23.5	60	14.0	38	18.4	30	14.6
River	70	16.3	42	9.8	52	25.2	46	22.3
Lake	26	6.1	12	2.8	11	5.3	5	2.4
Sampled households	429		429		206		206	

Note: Comparison between project sites and control sites in more detail is shown in Appendix.

Table 2 Outcome variables used for the estimation of coping costs and benefits

	Baseline			***End-line***		
	Project sites	***Control sites***	***Diff. (A)-(C)***	***Project sites***	***Control sites***	***Diff. (D)-(E)***
	(A)	(B)	(C)	(D)	(E)	(F)
Coping costs of water						
Time for water collection (hours per day)						
All family members	3.53	3.60	-0.07	1.43	1.46	-0.03
All females	2.60	2.70	-0.11	0.99	1.12	-0.13
School-age female children (7-18)	0.78	0.88	-0.10	0.36	0.31	0.05
Working-age female adults (19-59)	1.68	1.73	-0.06	0.59	0.74	-0.15
All males	0.93	0.90	0.03	0.44	0.34	0.09
School-age male children (7-18)	0.58	0.60	-0.03	0.28	0.21	0.06
Working-age male adults (19-59)	0.33	0.24	0.09	0.13	0.13	0.00
Volume and trips of water collection by the household						
Water volume carried yesterday (liters)	64.1	63.7	0.42	52.6	49.3	3.31
Number of trips yesterday	3.8	3.6	0.18	3.8	3.2	0.60**
Number of trips over the last 1 week	23.0	22.5	0.48	20.9	17.9	3.00***
Use of water treatment methods of the household (=1)						
Chlorination	0.226	0.233	-0.007	0.098	0.194	-0.096***
Boiling	0.061	0.024	0.036*	0.026	0.058	-0.033*
Filtration	0.014	0.000	0.014	0.000	0.005	-0.005
Benefits of the project						
Diarrhea incidence over the last 2 weeks						
All family members	0.128	0.121	0.007	0.091	0.146	-0.055*
Pre-school children (0-6)	0.068	0.063	0.004	0.035	0.078	-0.043**
School-age children (7-18)	0.026	0.024	0.001	0.019	0.015	0.004
Working-age adults (19-59)	0.033	0.024	0.008	0.026	0.044	-0.018
Days lost due to diarrhea incidence over the last 2 weeks						
Working-age adults (19-59)	0.159	0.107	0.052	0.068	0.121	-0.054
Sampled households	429	206		429	206	

Note: Outcome variables are aggregated to the household level. t-test or Fisher's exact test results are shown:
* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Table 3 Summary statics of explanatory variables

2012	Mean	s.d.	Min.	Max.
	(A)	(B)	(C)	(D)
Household characteristics	n=635			
Female headed household (=1)	0.200	(0.400)	0	1
Age of the head	43.1	(13.62)	18	84
Highest education (years) among females	5.114	(2.929)	0	12
Highest education (years) among males	6.825	(2.823)	0	12
Household size	5.203	(2.365)	1	15
Ratio of dependents to household size	0.452	(0.246)	0	1
Monthly consumption per capita (thousand ZMK)	156.2	(193.0)	16.01	2780
Value of durable assets (million ZMK)	1.385	(1.915)	0.005	29.40
Surveyed in June (=1)	0.647	(0.478)	0	1
Surveyed in July (=1)	0.353	(0.478)	0	1
Village characteristics	n=94			
Population	467.3	(524.9)	48	3360
Average assets per household (million ZMK)	6.313	(5.214)	1.448	29.30
2013	**Mean**	**s.d.**	**Min.**	**Max.**
	(A)	(B)	(C)	(D)
Household characteristics	n=635			
Project site (=1)	0.676	(0.469)	0	1
Project site * Borehole user (=1)	0.526	(0.500)	0	1
Distance to the new borehole (km) a)	0.203	(0.211)	0	1
Walking time to the new borehole (min)	3.916	(5.505)	0	60
Female headed household (=1)	0.195	(0.397)	0	1
Age of the head	43.9	(13.68)	17	85
Highest education (years) among females	4.973	(2.956)	0	12
Highest education (years) among males	6.715	(2.884)	0	12
Household size	5.409	(2.349)	1	15
Ratio of dependents to household size	0.452	(0.234)	0	1
Monthly consumption per capita (thousand ZMK)	173.1	(309.4)	4.021	3826
Value of durable assets (million ZMK)	1.651	(2.813)	0.005	44.30
Surveyed in June (=1)	0.824	(0.381)	0	1
Surveyed in August (=1)	0.176	(0.381)	0	1
Village characteristics	n=94			
Population	482.5	(488.0)	80	3360
Average assets per household (million ZMK)	7.547	(6.400)	1.566	51.47

Note: The sample is confined to children in the households that were surveyed in both rounds.

Monthly consumption per capita is adjusted by using adult equivalence scales and measured in the real terms at the price level of 2012. Assets per household include the value of residence, residential and agricultural land, and durable assets. 1USD was worth approximately 5200ZMK as of June 2012.

a) The figures are calculated based on the information about only borehole users (n=334).

Table 4 Difference-in-differences analysis on time for water collection

Dependent variable: Time allocation (hours)	**All family members**				**All females**				**All males**			
	Project	**Borehole use**			**Project**	**Borehole use**			**Project**	**Borehole use**		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
Project and year dummy variables												
Project site/Borehole use	-0.002	0.006	-0.106	-0.062	-0.062	-0.106	-0.192	-0.150	0.059	0.112	0.086	0.087
* Year 2013 (=1)	(0.351)	(0.359)	(0.378)	(0.364)	(0.289)	(0.295)	(0.318)	(0.304)	(0.150)	(0.158)	(0.153)	(0.153)
Project site * Borehole use			0.558	0.017			0.427	0.011			0.131	0.006
* Year 2013 * Distance (km/min.)			(0.542)	(0.016)			(0.427)	(0.014)			(0.270)	(0.008)
Project site/Borehole use (=1)	-0.109	-0.034	-0.035	-0.033	-0.072	-0.006	-0.007	-0.005	-0.037	-0.028	-0.029	-0.028
	(0.330)	(0.332)	(0.332)	(0.333)	(0.284)	(0.287)	(0.287)	(0.287)	(0.123)	(0.128)	(0.128)	(0.128)
Project site * Borehole non-use		-0.034	-0.032	-0.039		0.091	0.093	0.088		-0.126	-0.125	-0.127
* Year 2013 (=1)		(0.474)	(0.474)	(0.473)		(0.355)	(0.355)	(0.355)		(0.226)	(0.226)	(0.226)
Project site * Borehole non-use (=1)		-0.376	-0.375	-0.375		-0.306	-0.305	-0.305		-0.070	-0.070	-0.070
		(0.442)	(0.442)	(0.442)		(0.338)	(0.338)	(0.338)		(0.212)	(0.212)	(0.212)
Year 2013 (=1)	-2.189***	-2.191***	-2.196***	-2.192***	-1.615***	-1.614***	-1.618***	-1.615***	-0.576***	-0.577***	-0.578***	-0.577***
	(0.309)	(0.310)	(0.310)	(0.310)	(0.262)	(0.262)	(0.262)	(0.262)	(0.131)	(0.131)	(0.131)	(0.131)
Individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R sq.	0.256	0.258	0.258	0.258	0.209	0.210	0.211	0.210	0.151	0.153	0.153	0.154
No. of observations	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270

Note: Village-level cluster-adjusted standard errors are in parentheses: * Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Distance is measured in kilometers in Columns (C) (G) and (K) and measured in minutes in Columns (D) (H) and (L).

Table 5 Difference-in-differences analysis on volume and number of trips for water collection

Dependent variable: Water volume (liters) and number of trips	**Water volume carried yesterday**				**Number of trips yesterday**				**Number of trips last 1 week**			
	Project	**Borehole use**			**Project**	**Borehole use**			**Project**	**Borehole use**		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
Project and year dummy variables												
Project site/Borehole use	3.874	5.612	6.142	7.281	0.402	0.502	0.516	0.548	2.509	2.571	3.276*	3.279*
* Year 2013 (=1)	(5.598)	(5.482)	(5.675)	(5.610)	(0.313)	(0.336)	(0.355)	(0.351)	(1.660)	(1.750)	(1.916)	(1.794)
Project site * Borehole use			-2.598	-0.412*			-0.070	-0.011			-3.454	-0.175*
* Year 2013 * Distance (km/min.)			(7.871)	(0.212)			(0.746)	(0.020)			(2.935)	(0.091)
Project site/Borehole use (=1)	-0.977	-1.281	-1.277	-1.300	0.060	0.016	0.016	0.016	-0.061	0.213	0.218	0.205
	(5.570)	(5.646)	(5.649)	(5.651)	(0.201)	(0.211)	(0.211)	(0.211)	(1.441)	(1.467)	(1.466)	(1.467)
Project site * Borehole non-use		-2.204	-2.212	-2.225		0.052	0.052	0.051		2.283	2.272	2.274
* Year 2013 (=1)		(8.817)	(8.822)	(8.818)		(0.394)	(0.394)	(0.394)		(2.125)	(2.125)	(2.126)
Project site * Borehole non-use (=1)		0.056	0.053	0.037		0.213	0.212	0.212		-1.022	-1.026	-1.030
		(7.190)	(7.192)	(7.195)		(0.269)	(0.269)	(0.269)		(1.675)	(1.674)	(1.675)
Year 2013 (=1)	-14.880***	-14.874***	-14.851***	-14.850***	-0.345	-0.346	-0.345	-0.345	-4.101***	-4.110***	-4.080***	-4.100***
	(4.603)	(4.608)	(4.607)	(4.611)	(0.261)	(0.261)	(0.261)	(0.261)	(1.297)	(1.299)	(1.299)	(1.300)
Individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R sq.	0.086	0.079	0.079	0.081	0.051	0.049	0.049	0.049	0.077	0.078	0.079	0.080
No. of observations	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270

Note: Village-level cluster-adjusted standard errors are in parentheses: * Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Distance is measured in kilometers in Columns (C) (G) and (K) and measured in minutes in Columns (D) (H) and (L).

Table 6 Difference-in-differences analysis of water treatment methods

Dependent variable: Use of water treatment methods (=1)	**Chlorination**				**Boiling**				**Filtration**			
	Project	**Borehole use**			**Project**	**Borehole use**			**Project**	**Borehole use**		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
Project and year dummy variables												
Project site/Borehole use	-0.093*	-0.099*	-0.104*	-0.105*	-0.075***	-0.073***	-0.084***	-0.078***	-0.019**	-0.023**	-0.023**	-0.023**
* Year 2013 (=1)	(0.052)	(0.053)	(0.055)	(0.054)	(0.024)	(0.025)	(0.026)	(0.025)	(0.009)	(0.011)	(0.010)	(0.010)
Project site * Borehole use			0.025	0.002			0.053	0.001			-0.003	-0.000
* Year 2013 * Distance (km/min.)			(0.095)	(0.002)			(0.058)	(0.002)			(0.003)	(0.000)
Project site/Borehole use (=1)	-0.019	-0.019	-0.019	-0.019	0.033*	0.032*	0.032*	0.032*	0.013**	0.017**	0.017**	0.017**
	(0.048)	(0.048)	(0.048)	(0.048)	(0.018)	(0.019)	(0.019)	(0.019)	(0.006)	(0.008)	(0.008)	(0.008)
Project site * Borehole non-use		-0.072	-0.072	-0.072		-0.081**	-0.081**	-0.081**		-0.005	-0.005	-0.005
* Year 2013 (=1)		(0.071)	(0.071)	(0.071)		(0.034)	(0.034)	(0.034)		(0.005)	(0.005)	(0.005)
Project site * Borehole non-use (=1)		-0.016	-0.016	-0.016		0.033	0.033	0.033		-0.002	-0.002	-0.002
		(0.061)	(0.061)	(0.061)		(0.024)	(0.024)	(0.024)		(0.004)	(0.004)	(0.004)
Year 2013 (=1)	-0.029	-0.028	-0.029	-0.029	0.035	0.035	0.035	0.035	0.006	0.006	0.006	0.006
	(0.041)	(0.041)	(0.041)	(0.041)	(0.021)	(0.021)	(0.021)	(0.021)	(0.006)	(0.006)	(0.006)	(0.006)
Individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R sq.	0.069	0.069	0.069	0.069	0.029	0.029	0.030	0.030	0.025	0.029	0.029	0.029
No. of observations	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250

Note: Village-level cluster-adjusted standard errors are in parentheses: * Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Distance is measured in kilometers in Columns (C) (G) and (K) and measured in minutes in Columns (D) (H) and (L).

Table 7 Difference-in-differences analysis on diarrheal incidence and days lost for adults

Dependent variable: Diarrhea incidence and days lost	**Diarrhea incidence (all)**				**Diarrhea incidence (adults (19-59))**				**Days lost (adults (19-59))**			
	Project	**Borehole use**			**Project**	**Borehole use**			**Project**	**Borehole use**		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)
Project and year dummy variables												
Project site/Borehole use * Year 2013 (=1)	-0.073	-0.095*	-0.098**	-0.090*	-0.030	-0.038*	-0.036*	-0.035*	-0.128	-0.162	-0.175*	-0.156
	(0.048)	(0.048)	(0.049)	(0.049)	(0.019)	(0.020)	(0.021)	(0.020)	(0.089)	(0.099)	(0.098)	(0.100)
Project site * Borehole use * Year 2013 * Distance (km/min.)			0.015	-0.001			-0.011	-0.001*			0.069	-0.001
			(0.066)	(0.001)			(0.046)	(0.000)			(0.179)	(0.001)
Project site/Borehole use (=1)	0.018	0.021	0.021	0.021	0.012	0.017	0.017	0.017	0.075	0.110	0.110	0.110
	(0.033)	(0.035)	(0.035)	(0.035)	(0.013)	(0.015)	(0.015)	(0.015)	(0.078)	(0.090)	(0.090)	(0.090)
Project site * Borehole non-use * Year 2013 (=1)		0.006	0.006	0.006		-0.004	-0.004	-0.004		-0.011	-0.011	-0.011
		(0.080)	(0.081)	(0.080)		(0.026)	(0.026)	(0.026)		(0.086)	(0.086)	(0.086)
Project site * Borehole non-use (=1)		0.011	0.011	0.011		-0.007	-0.007	-0.007		-0.048	-0.048	-0.048
		(0.045)	(0.045)	(0.045)		(0.016)	(0.016)	(0.016)		(0.058)	(0.058)	(0.059)
Year 2013 (=1)	0.017	0.017	0.017	0.017	0.023	0.023	0.023	0.023	0.005	0.004	0.004	0.004
	(0.041)	(0.041)	(0.041)	(0.041)	(0.016)	(0.016)	(0.016)	(0.016)	(0.065)	(0.065)	(0.065)	(0.065)
Individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R sq.	0.046	0.050	0.050	0.050	0.038	0.039	0.039	0.040	0.024	0.026	0.026	0.026
No. of observations	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270	1270

Note: Village-level cluster-adjusted standard errors are in parentheses: * Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Distance is measured in kilometers in Columns (C) (G) and (K) and measured in minutes in Columns (D) (H) and (L).

Table 8 Difference-in-differences analysis on diarrheal incidence for children

Dependent variable: Diarrhea incidence	**School-age children (7-18)**				**Preschool-age children (0-6)**			
	Project	**Borehole use**			**Project**	**Borehole use**		
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
Project and year dummy variables								
Project site/Borehole use	0.001	-0.010	-0.008	-0.009	-0.054*	-0.060*	-0.071**	-0.061*
* Year 2013 (=1)	(0.019)	(0.018)	(0.019)	(0.018)	(0.032)	(0.032)	(0.033)	(0.033)
Project site * Borehole use			-0.012	-0.000			0.053	0.000
* Year 2013 * Distance (km/min.)			(0.015)	(0.000)			(0.050)	(0.001)
Project site/Borehole use (=1)	0.001	0.003	0.003	0.003	0.015	0.011	0.010	0.011
	(0.015)	(0.015)	(0.015)	(0.015)	(0.021)	(0.023)	(0.023)	(0.023)
Project site * Borehole non-use		0.041	0.041	0.041		-0.030	-0.030	-0.030
* Year 2013 (=1)		(0.042)	(0.042)	(0.042)		(0.051)	(0.051)	(0.051)
Project site * Borehole non-use (=1)		-0.005	-0.005	-0.005		0.032	0.033	0.032
		(0.019)	(0.019)	(0.019)		(0.031)	(0.031)	(0.031)
Year 2013 (=1)	-0.015	-0.015	-0.015	-0.015	0.011	0.011	0.011	0.011
	(0.015)	(0.015)	(0.015)	(0.015)	(0.027)	(0.027)	(0.027)	(0.027)
Individual characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R sq.	0.027	0.027	0.027	0.027	0.049	0.052	0.053	0.052
No. of observations	1270	1270	1270	1270	1270	1270	1270	1270

Note: Village-level cluster-adjusted standard errors are in parentheses: * Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Distance is measured in kilometers in Columns (C) and (G) and measured in minutes in Columns (D) and (H).

Appendix: Balance test

	Project sites	Control sites	Difference
	(A)	(B)	(C)
Individual characteristics	**n=2239**	**n=1065**	
Female (%)	51.8	50.0	1.9
Age	20.9	20.7	0.2
Aged 0 to 6 (%)	22.8	25.4	-2.7*
Aged 7 to 18 (%)	34.1	30.9	3.2**
Aged 19 to 59 (%)	39.3	40.3	-0.9
Aged 60 and above (%)	3.8	3.4	0.4
Working age females aged 19 to 59	**n=459**	**n=217**	
Education (years of schooling) completed	5.483	4.764	0.719***
Crop farmers (%)	79.5	77.4	2.1
Fishery workers (%)	0.0	0.5	-0.5
Traders/retail shopkeepers (%)	4.8	6.9	-2.1
Working age males aged 19 to 59	**n=422**	**n=212**	
Education (years of schooling) completed	6.895	6.700	0.196
Crop farmers (%)	72.5	71.7	0.8
Fishery workers (%)	4.7	3.3	1.4
Traders/retail shopkeepers (%)	3.1	3.8	-0.7
Household characteristics	**n=429**	**n=206**	
Female headed household (%)	20.0	19.9	0.14
Age of the head	43.4	42.3	1.18
Household size	5.219	5.170	0.049
Ratio of dependents to household size	0.452	0.453	-0.002
Monthly consumption per capita (thousand ZMK)	162.4	143.2	19.2
Value of durable assets (million ZMK)	1.394	1.366	0.029
Agricultural land value (million ZMK)	3.362	5.138	-1.776*
Village characteristics	**n=63**	**n=31**	
Population (households)	98.2	97.6	0.61
Population (individuals)	480.6	439.8	40.7
Land area (ha)	141.4	98.4	42.9
Flat villages (%)	31.7	38.7	-7.0
Slightly sloping villages (%)	38.1	35.5	2.6
Moderately sloping villages (%)	28.6	22.6	6.0
Steeply sloping/hilly villages (%)	1.6	3.2	-1.6
Average assets per household (million ZMK)	5.940	7.071	-1.131
Distance to district center (km)	45.4	36.4	8.9
Distance to town center (km)	26.5	15.8	10.7
Distance to market (km)	12.3	13.2	-0.9
Distance to government primary school (km)	2.0	2.7	-0.7
Distance to government secondary school (km)	29.2	30.8	-1.6
Distance to rural health center (km)	7.3	9.5	-2.2

Note: t-test or Fisher's exact test results are shown:
* Significant at 10%, ** Significant at 5%, *** Significant at 1%.

Monthly consumption per capita is adjusted by using adult equivalence scales and measured in the real term at the price level of 2012. Assets per household includes the value of residence, residential and agricultural land, and durable assets. 1USD was approximately 5200ZMK as of June 2012.