GSICS Working Paper Series

Effect of Groundwater Development Project on Diarrhea Incidence in Rural Zambia

Yasuharu SHIMAMURA*

Hiroshi NISHINO**

Hirofumi TSURUTA***

and

Keitaro AOYAGI****

No. 31

May 2017

Graduate School of International

Cooperation Studies

Kobe University

Effect of Groundwater Development Project on Diarrhea Incidence in Rural Zambia

Yasuharu SHIMAMURA*

Hiroshi NISHINO**

Hirofumi TSURUTA***

and

Keitaro AOYAGI****

Abstract

This study evaluates the effect of a groundwater development project in rural Zambia. Our empirical analysis using a difference-in-differences methodology under an experimental setting reveals that the project reduced the incidence of diarrhea over the past two weeks by 1.6 percentage points among individuals of all age groups and by 5.9 percentage points among children under five. This study, however, simultaneously finds that the impact of the newly constructed water supply facilities is highly likely to be impaired by recontamination of improved source water during transport and storage, which appears further deteriorated by a reduction in the use of water treatment methods at home.

***Keywords*:** waterborne disease; groundwater development; Zambia; impact evaluation; Japan International Cooperation Agency; development project

---

*Graduate School of International Cooperation Studies, Kobe University, 2-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan, Tel: +81-78-803-7158, Email: yshima@harbor.kobe-u.ac.jp

**Metrics Work Consultants Inc., 4-9-15-1308 Shirakawa, Koto-ku, Tokyo 135-0021, Japan, Tel: +81-3-6260-9926, Email: nishino@metricswork.co.jp

***Namidabashi Lab. Co., Ltd., 1-1-10 Nihonzutsumi, Taito-ku, Tokyo 111-0021, Japan, Tel: +81-3-6240-6120, Email: hirofumi.t@namida-lab.com

**** Metrics Work Consultants Inc., 4-9-15-1308 Shirakawa, Koto-ku, Tokyo 135-0021, Japan, Tel: +81-3-6260-9926, Email: aoyagi@metricswork.co.jp

Acknowledgements: We thank the Ministry of Local Government and Housing of Zambia and the Japan International Cooperation Agency for conducting the impact evaluation study. Any errors or omissions are the responsibility of the authors.

Effect of Groundwater Development Project on Diarrhea Incidence in Rural Zambia

1. Introduction

Access to safe water is a crucial issue that affects human life, yet 663 million people still have no access to improved drinking water sources as of 2015 (UNICEF/WHO, 2015).[1] People without access to safe water are forced to use contaminated water sources such as unprotected wells and springs and surface water, which causes high prevalence of diarrhea. Diarrhea is one of the leading causes of death among children, and every year nearly 1.5 million children under the age of five die from diarrhea caused by a lack of access to safe water and basic sanitation facilities (UNICEF/WHO, 2009). In particular, the lack of access to safe water in rural areas in sub-Saharan Africa remains as one of the most serious concerns in the international society (UNIECF/WHO, 2015).

Responding to these concerns, governments, international organizations, and academic researchers have been tackling this issue, and evidence on the impact of water, sanitation, and hygiene interventions on waterborne diseases such as diarrhea has been accumulated (Arnold and Colford, 2007; Cairncross et al., 2010; Clasen et al., 2006; Esrey et al., 1991; Fewtrell et al., 2005; Gundry et al., 2004; Waddington et al., 2009). The evidence indicates that point of use (POU) water quality improvement has the highest effectiveness to reduce diarrhea incidence, while other types of interventions tend to have smaller impacts, and particularly interventions at water sources appear to have less impact on reducing the incidence of diarrhea because, as depicted in Figure 1, POU interventions are expected to have direct impact on the health status while the effect of source treatment interventions can be hampered by (re-) contamination between water sources and POU.

Indeed, evidence from recent individual studies suggests that improvement of water sources does not

[1] According to UNICEF/WHO, "improved drinking water sources" is one that, adequately protects the source from outside contamination, particularly faecal matter, including piped water into dwelling, piped water to yard/plot, public tap or standpipe or tube well or borehole, protected dug well, protected spring and rainwater. The improved drinking water source can supply safe water.

always have a desirable impact on the health status of water users (Devoto, 2012; Galiani et al., 2005; Gamper-Rabindran, 2010; Kremer et al., 2011; Mangyo, 2008; Zhang, 2011). Recontamination of the improved source water during transportation and storage is a major concern as it undermines the potential benefits from the improved water source. Recontamination may be caused by mishandling the improved source water (Fewtrell et al., 2005). Mixed use of other water sources of unknown quality may also explain (re-)contamination detected at home (Kremer et al., 2011). It can also be the case that source water treatment does not have a significant impact on the incidence of diarrhea without appropriate sanitation and hygiene practices (Esrey, 1996). Considering the possibility of recontamination, whether water source improvement has the positive effects on POU water quality and health status of water users is still an empirical question, and therefore, further accumulation of empirical evidence on the effectiveness of water source interventions is demanded.

This study examines the impact of a water source improvement project in which both "hardware," i.e. construction of borehole water supply facilities, and "software" components, i.e. capacity building for proper operation and maintenance of the facility and hygiene promotion, were provided in rural Zambia by utilizing a difference-in-differences methodology under a natural experimental setting yielded by unpredictable failures in the drilling of boreholes. We evaluate the impacts of the project on water quality improvement in terms of fecal contamination measured at home and the incidence of diarrhea over the past two weeks with a particular focus on children under five. Additionally, since there has been a particular interest in how interventions affect people's health behaviors and whether a change in health behavior can be sustained (Aboud and Singla, 2012; Fiebelkorn et al., 2012), this study also examines one critical aspect of health behavior related to hygiene, i.e., utilization of water treatment method Throughout these analyses, we also investigate the impact heterogeneity in household income.

The next section provides a brief description of key features of the health status in rural Zambia, particularly in Luapula Province where the groundwater development project was implemented. Section 3 then gives detailed information about the intervention that we evaluate. In Section 4, we explain our empirical strategy. Section 5 shows estimation results, while Section 6 summarizes the major findings and concludes our discussions.

2. Water access and waterborne diseases in Zambia

2.1 Access to safe water

Zambia, one of the sub-Saharan African countries, has been struggling to expand its water supply coverage. The overall proportion of people with access to improved water was only 60 per cent (Central Statistical Office, 2011), and significant efforts are needed to achieve the target under the Millennium Development Goals, which is 74.5 per cent (UNDP, 2013). The problem is particularly serious in rural areas, with more than half living without access to safe water, while 86 per cent of the urban population has access (UNICEF/WHO, 2015). Rural residents particularly from poor and marginalized families tend to have no access to safe water and basic sanitation. Ensuring access to safe water and basic sanitation remains as a particular focus in the Sustainable Development Goals, which was agreed by the international society in 2015.

Luapula Province, where the project was implemented, is situated in the northern part of Zambia, with a population of nearly one million in 2010 in an area of 30,600 km^2, approximately 8 per cent and 25 per cent of the national totals, respectively (Central Statistical Office, 2011). As shown in Figure 2, since 43.5 per cent of its surface area is covered by lakes and wetland areas (JICA, 2011), there is access to relatively abundant water resources. The major bodies of water are Lake Bangweulu in the southeastern corner of the province, Lake Mweru in the northwestern corner, and the Luapula River, which flows between them. Provincial administration is divided into seven districts, including the four districts targeted by the project: Mansa, Nchelenge, Mwense, and Milenge.

Nevertheless, Luapula is a province with limited water supply coverage. Although there was a significant increase in water coverage from 2006 to 2010, as of 2010 only 28.0 per cent of the people had access to safe water, which forced many people to rely on unprotected shallow wells, hand-dug wells, streams, rivers, and lakes, for their livelihood (Central Statistical Office, 2011). The preparatory survey conducted in 2010 also showed that more than 90 per cent of the households use water from unsafe sources for drinking and daily use, and most of the people expressed their dissatisfaction with these water sources (JICA, 2011).

2.2 Waterborne diseases

In Zambia, there are growing concerns that a lack of safe water, together with poor hygiene, can be a contributing factor to the high prevalence of diarrhea and other waterborne diseases. Indeed, water-related health status has not improved or even deteriorated for the period 2010 to 2012. According to the Ministry of Health (2014), the national incidence rate of diarrhea increased from 79 per 1,000 population in 2010 to 86 per 1,000 population in 2012, while hospital case fatality rates for diarrhea decreased from 74 deaths per 1,000 admissions in 2008 to 65 deaths per 1,000 admissions in 2010. The causes of the currently observed incidence of diarrhea may be diverse. According to key-informant interviews targeting program officers at the provincial, district, and facility levels conducted by the authors in 2012, there were several possibilities, such as poor access to protected water sources, underutilization of chlorine for water treatment, and poor hygiene especially in rural areas.

Luapula Province is historically recognized as a high-risk area for water-related diseases because it is a remote province with the large number of rivers, streams, and lakes, which are untreated and easily contaminated. Poor hygiene, particularly around fish markets along the Luapula River, has long been regarded as a problem. The incidence of diarrhea in Luapula increased from 6.0 per cent to 8.2 per cent between 2010 and 2012, and hospital case fatality rates in the same period also worsened from 54 deaths per 1,000 admissions in

2010 to 69 deaths per 1,000 admissions. (Ministry of Health, 2014). In addition, the preparatory survey conducted at the project area revealed that diarrhea was recognized as a major health issue in about 50 per cent of the sites (JICA, 2011).

3. Groundwater development project in Luapula Province

To improve access to safe water, JICA and other donors have implemented several projects in this province. Between 2008 and 2010, JICA provided the Government of Zambia with grant aid assistance for the construction of 200 water facilities with hand pumps in all seven districts in Luapula Province, which provided nearly 50,000 people (approximately 5% of population in the province) with the access to safe water (Project for Groundwater Development in Luapula Province Phase 1). Technical cooperation projects have also been conducted to strengthen local capacity for the operation and maintenance of existing water facilities. Similar interventions, such as the construction of water facilities and training for personnel in charge of the operation and maintenance of facilities, are also conducted by the United Nations Children's Fund (UNICEF), African Development Bank, Water Aid, and Plan International. As a result of these interventions, the proportion of the population with access to safe water doubled between 2006 and 2010 (11.1% to 28.0%), although the figure is still very low (Central Statistical Office, 2011).

The target project for which we conduct an impact evaluation is the second phase of the project for groundwater development in Luapula Province financed by JICA. The project was conducted in four districts of the province—Nchelenge, Mwense, Mansa, and Milenge. The project (intervention) is a package of "hardware," i.e. construction of borehole water supply facilities, and "software" components, i.e. capacity building for proper operation and maintenance of the facility and hygiene promotion, with the objective of improving the living standard of the rural population by providing safe drinking water. More specifically, this project aimed at reducing water-related diseases, especially diarrhea, by assuring reasonable access to safe and stable water sources.

3.1 Facility construction

Facility construction included the construction of borehole water facilities with hand pumps at 216 sites. Each facility was designed to provide 30 liters of water for each of 250 people (i.e., 7500 liters of water) per day. In total, the project was expected to benefit more than 54,000 people in the four districts. As shown in Figure 3, the construction started in February 2012 and was completed in April 2013. The first facilities were handed over and started being used by residents in October 2012. One of the characteristics of this project is the depth of the boreholes. The average depth of boreholes is designed to be 63 m, which secures that water is free from ground contaminants. In addition, before each facility was handed over to the residents, tests were conducted to check if the water quality satisfied the standards of Zambia. This means that the water was uncontaminated at the source, at least at the time of completion.[2]

3.2 Software component

The software component consisted of several activities aiming at encouraging the community-based operation and maintenance and maximizing the project impact.[3] First, prior to the hardware component, project orientation was conducted to explain the contents of the project and gain consent from villagers to the participation in the project. In this activity, residents also participated in village meetings to determine drilling

[2] The water quality testing conducted before handing over the facilities examines electrical conductivity, pH, and content of iron, manganese, fluorine, and *E. coli*. The testing was conducted on-site, and when further examination was needed, samples were reexamined at the laboratory of the University of Zambia in Lusaka. At three sites where the iron content exceeded the reference value, iron remover was installed to reduce the iron content. (By chance, these three sites were not included in our sample.)

[3] Software component activities were conducted at all target sites (including the site where the facility was not constructed due to drilling failure) and alternative sites that actually replaced target sites.

points where the facilities were constructed. While the drilling points at each site were selected in accordance with the hydrogeological conditions through careful field reconnaissance and geophysical sounding, priority was given to the local residents' demands with careful consideration of the possibility of groundwater contamination.

Second, the software component included (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, including minor repairs, collection of maintenance fees, and communication with the administration or Area Pump Menders (APMs).[4] Capacity-building workshops was conducted for V-WASHE members to acquire knowledge and techniques for the operation and maintenance of the facilities and for organization management. In addition, training was also conducted at the district level so that district officers, WASHE facilitators, and APMs can provide the V-WASHE with the necessary administrative and technical support.[5]

The software components also included activities to promote hygiene and sanitation practices at the target sites. These activities involved the provision of knowledge on health, hygiene and sanitation, including promotion of safer disposal of faeces (the use of latrine), hand-washing, and keeping drinking water free from contamination in the home and source. Proper understanding of health and sanitation was expected to maximize the project impact by enhancing proper hygiene behaviors and also to facilitate resident ownership of the facilities and their commitment to maintenance activities including the payment of maintenance fees.

3.3 Project site selection

---

[4] One or two people are assigned as APMs in each ward, and are responsible for maintenance and repairs of the facilities that communities cannot handle for a fee. The fees for APMs were fixed in 2013 in range of ZMK 50,000 to 100,000 per village, which is reasonable compared with the average household monthly consumption in our sample (ZMK 199,940) considering that the fee is shared by all villagers. APMs are also provided with repair kits (one kit per ward) by the preceding project.

[5] The Rural Water Supply and Sanitation (RWSS) Unit takes administrative responsibility in the planning and implementation of rural water supply and sanitation projects within a district, and the District Water, Sanitation and Health Education (D-WASHE) Committee provides the RWSS Unit with technical advice.

Figure 1 shows the selection process of the sites that the project targeted. First, 320 sites in the four districts were specified by the Zambian Government in its request for grant aid. Each site was then examined using seven criteria to consider the feasibility and relevance of the project implementation.[6] As a result of the examination, 291 sites that satisfied the above criteria were identified as candidate sites. Then, 216 sites were selected as the target sites for this project based on their population size, considering the project capacity within the specified period (two years).

The remaining 75 sites were reserved as alternative sites that would replace target sites where drilling was unsuccessful. Although the drilling point was determined through careful examination, there was still a risk of failure to find underground water because it was technically impossible to accurately identify the points where groundwater was available, and consequently whether drilling was successful or not depended on chance, even with careful examination. In this project, a maximum of two drillings were attempted, and if both the first and second drilling was unsuccessful, the site was cancelled and replaced with one of the alternative sites.[7]

In the end, the project constructed 216 facilities at 214 sites; 31 target sites were replaced because it was impossible to obtain water even after two drillings. In Milenge district, since the number of unsuccessful sites exceeded the number of alternative sites, two facilities were constructed at two sites.

4. Methods

4.1 Estimation strategy

In conventional program evaluations for infrastructure development projects, simple before/after or

---

[6] The 320 sites were screened in the preparatory survey using the following seven criteria: (1) demand for safe and stable water supply; (2) accessibility to the site; (3) hydrogeological conditions; (4) availability of existing water supply facilities; (5) overlap with other related projects; (6) possibility of forming a V-WASHE Committee; and (7) residents' willingness to pay the operation and maintenance costs of the facilities.

[7] The software components were implemented as planned in all target sites and alternative sites which actually replaced unsuccessful sites as well.

with/without comparisons are usually employed for the assessment of a project's effectiveness. However, these approaches cannot lead to accurate assessment of the real project effects, because a change before/after the intervention might be explained by factors other than the project, and with/without comparison might suffer from placement bias (e.g., only worse-off communities might be targeted as a project beneficiary community) (Ravallion, 2001). In recognition of the potential bias problem, this study employs a difference-in-differences (DID) approach to control for the potential bias and estimate the causal effects (impacts) of the project.

The DID methodology combines before/after and with/without comparisons, and is popularly used for project impact evaluations. The central assumption for the DID methodology to be valid is the "parallel trend," which assumes that a change (without the intervention) caused by unobserved characteristics during the baseline and end-line survey period is common between the treatment and control sites. Unpredictable failures in finding groundwater and the replacement of target sites help assure the validity of this assumption because they created circumstances identical to the situation where the construction sites had been determined randomly. Under the "parallel trend" assumption, the DID methodology, by subtracting the common trend from the change in the treatment sites, can identify the causal effects of the project.

Since we analyze the impacts on binary outcome variables in this study, a logistic specification is employed. Let y_{ijt} be an outcome variable of a household (or an individual) i residing at the site j surveyed at time t (t = 0 for baseline and t = 1 for end-line). Using these settings, the simplest version of our empirical model can be expressed as follows:

$$y_{ijt}^{*} = \gamma_0 + \gamma_1 \cdot S_j + \gamma_2 \cdot t + \gamma_3 \cdot S_j \times t + u_{ijt}, \quad (1)$$

$y_{ijt} = 1$ if $y_{ijt}^{*} > 0$, and 0 otherwise.

where S_j takes the value of 1 when the site j has a successful borehole facility, and 0 otherwise. γ_0, γ_1, γ_2, and γ_3 are the parameters to be estimated, and γ_3 is the parameter of interest that measures the causal effect of the project.

u_{ijt} is an error term.

In addition to the simplest version of the DID model, we also employed an empirical model with some covariates. The parallel trend assumption can be violated if changes in covariates are not common between project and control sites, and thus we need to examine if this is the case by explicitly controlling some observable covariates. Let X_{ijt} be a set of observed household (or individual) i's characteristics and X_{jt} be a set of observed site j's characteristics other than the results of facility construction. With these observable covariates, another version of our empirical model can be written as follows:

$$y^*_{ijt} = \gamma_0 + \gamma_1 \cdot S_j + \gamma_2 \cdot t + \gamma_3 \cdot S_j \times t + X_{ijt}\beta_1 + X_{jt}\beta_2 + u_{ijt}\,, \tag{2}$$

$y_{ijt} = 1$ if $y^*_{ijt} > 0$, and 0 otherwise.

Thus far, our empirical models aim at estimating the so-called intention-to-treat (ITT) impact of the project at the village level (in other words, the impact of constructing water facilities in the village). However, because some households at the project sites did not report that they used the new facility constructed by the project, we try to distinguish the impact of the usage of the new facility from that of the construction of the facility in the same village. The former can used to measure direct impact of the project and the latter may involve a spillover effect.

4.2 Data

Data used for this study were collected through two rounds of original surveys. The first round (baseline) was implemented during July–August 2012, and the second round (end-line) during July–August in 2013.[8] The surveys were conducted by an independent local consulting firm hired by the JICA Zambia Office. Each round of the survey used both household and community questionnaires and the collection of an array of

[8] This period falls in the dry season (from April to October) with almost no rain at all in June, July, and August. Since it is practically impossible to travel in the project area in the rainy season due to poor road conditions, the survey was conducted in the dry season.

socioeconomic variables of individuals, households, and communities.[9] With respect to access to water outside the home, the community questionnaire confirmed the presence of various types of water sources in the community and also their accessibility from the community, whereas the household questionnaire asked the respondents to provide information about the access to each water source and also its use as drinking water. The household questionnaire also asked about the utilization of various water treatment methods at home. [10]

Regarding water-related diseases, the household questionnaire focused on diarrhea symptoms over the past two weeks.[11] In addition to these general health conditions of individuals, the enumerator conducted a simple test on the quality of drinking water stored at each household by drawing a cup of water from a storage container and utilizing a test sheet. The test sheet examined whether or not the drinking water contained a certain amount of *Escherichia coli* (*E. coli*, one of the indicators of water quality).[12] The appearance of spots on the test sheet indicated that the household drinking water was contaminated.[13]

4.3 Sample

Table 1 summarizes the number of sample sites for the impact study of the project. The sample size was determined considering the results of power calculation and budget constraints. Project sites were selected in three districts (Milenge, Mwense, and Nchelenge) in Luapula Province. Although the project was implemented in four districts, Mansa district was excluded from this study because facility construction had already started

[9] Household questionnaire was administered to a spouse of household head (or female household head) who was confirmed by the pilot test to be the most knowledgeable about health status of family members. Community questionnaire was answered by several respondents, such as village leaders and V-WASHE members.
[10] The measurement is based on self-report of "usual" utilization of each treatment method (no specific time period) following the question used in the Demographic Health Survey (DHS).
[11] The precise wording for the question on diarrhea incidence is "Write down the name of all household members who had diarrhea in the last two weeks." It is a standard practice to look at diarrhea incidence as a binary variable and to ask the incidence in the past two weeks as used in other survey such as the (DHS).
[12] *E. coli* is used as a maker of bacterial contamination of disease-causing pathogen from animal/human waste or sewage because E. coli is a type of fecal coliform bacteria commonly found in the intestines of animals and humans. The contamination of *E. coli* implies the possibility of presence of any type of disease-causing pathogens because waste and sewages may contain many type of such pathogens. But *E. coli* cannot be used as a maker of chemical contamination.
[13] The test results were independently judged by an enumerator and a supervisor, and when there was discordance between them, the project manager made a final judgment. According to the manufacturer, the test tools can detect 1−300 CFU (colony-forming unit)/g.

before the baseline survey began. In the three districts, at the time of the baseline survey, 50 target sites[14] were randomly selected from the list of villages where the project was to be implemented, and 44 alternative sites were then selected from the list of villages where the project was not to be implemented by carefully examining a number of fundamental characteristics of the village to ensure appropriate comparison groups.[15] The sampled sites totaled 94.[16]

The procedure described above does not indicate that we had the intended number of projec sites and control sites at the time of the end-line survey. At some target sites, the groundwater project could not obtain water from the new boreholes, and they were regarded as control sites at the time of the end-line survey. In contrast, as a result of failures at some target sites, some alternative sites were converted to project sites and water was successfully obtained from the new boreholes constructed by the project. It was in fact technically very difficult to predict the possibility of success in obtaining water from deep boreholes by examining observable characteristics on the ground, and thus some failures were inevitable. For this reason, we ended up with 64 project sites and 30 control sites.

Table 1 also shows the number of sampled households used for this study. At the time of the baseline survey, the list of all households residing in each village was made prior to interviews. Then, eight households to be interviewed were chosen from the list by a simple random sampling method. The total number of sampled households at the baseline survey was 752 in 94 villages, which 117 households (15.6% of the total households)

---

[14] "Target sites" are defined as sites where the construction of facilities was initially planned (including those where water was not available and facilities were not actually constructed). "Project sites" are defined as sites where facilities were actually constructed (including those that replaced target sites).

[15] To be a candidate for the JICA groundwater project, a higher priority was placed on villages with a greater demand for water, which was primarily determined by population.

[16] At the time of the end-line survey, we discovered that other donors had unexpectedly constructed water facilities (boreholes) at our control sites. These interventions have the potential to cause bias in our estimates of the project's impact using the DID methodology. Because we expect that these interventions would reduce the incidence of diarrhea by providing better access to safe water in our control sites, the DID methodology could underestimate the JICA project's impact. Thus, the empirical findings presented in this report should be interpreted as a conservative estimate of the project's impact.

moved away after the baseline survey and could not be visited at the end-line survey.[17] As a result, the total number of sampled households used for the study became 635 (434 at the project sites and 201 at the control site). Among the sampled households at the project sites, 86.6 per cent answered that they utilized water from the newly constructed facilities for cooking and drinking during the dry season in 2013.

4.4 Comparison between project and control sites

Before we apply the DID methodology to our data for impact evaluation, Table 2 compares socioeconomic characteristics between the project and control sites before the implementation of the project. The situation in which people at the project and control sites lived under similar conditions before the project, which is a desirable requirement for the parallel trend assumption to hold, although the DID methodology allows for level differences in the outcome variables at the time of the baseline survey. Thus, we conclude that these differences do not significantly affect the validity of applying the DID methodology to our data.

Another concern is that the project sites might have larger populations than the control sites because one of the most important criteria for a village to be a project target site is its population, which determines the demand for water. Due to unpredictable failures of the project at some target sites, however, we do not find a significant difference in population between the project sites and control sites. Furthermore, based on the information collected by the community questionnaire, we can confirm that residents in the project and control sites had similar access to natural resources such as water and firewood. We can also confirm that their communities had similar infrastructure conditions such as roads, irrigation, and electricity. They also had similar access to shops/markets, schools, and health facilities at the time of the baseline survey.

[17] Given the relatively high attrition rate, we conducted an analysis of factors associated with attrition. The estimation results show that households with fewer family members were more likely to move away, although this attrition pattern did not significantly differ between project and control sites. This fact must be kept in mind and caution is required whenever we interpret the estimation results based on the DID methodology. Causal effects of the project on smaller households are less likely to be taken into account.

5. Results

5.1 Contamination with *E. coli* in water stored at home

Our impact study begins with an investigation into the effect on water quality measured by the test sheet for *E. coli*. Table 3 presents descriptive statistics and the analytical results from the simple DID estimation. Drinking water contained *E. coli* at 95.2 per cent of households at the project sites and 94.0 per cent of households at the control sites in 2012. The difference between the project sites and the control sites was 1.1 percentage points, which was not statistically significant at any conventional levels. After implementation of the project in 2013, *E. coli* was found at 93.2 per cent of the households at the project sites and 95.4 per cent of the households at the control sites. While there was a decrease in 1.9 percentage points in the rate of *E. coli* content in the project sites, the rate increased by 1.4 percentage points in the control sites. These figures lead to a 3.3 percentage points decline as a DID estimate for the casual effect of the project, although this is not statistically significant at any conventional levels. As mentioned in Section 3, the water test conducted at the time of handing over the facilities confirmed that *E. coli* was not detected at any facilities constructed by the project. Since the water test examines water stored at home at the time of the interview, the water might have been contaminated during transport and/or storage.

We conduct the same analysis for two different groups divided by the level of consumption per capita utilized as a proxy of income.[18] The analytical results in Table 4 show that the magnitude of reduction in contamination with *E. coli* is slightly larger among upper-half households (7.3% percentage point decline), even though this is not statistically significant at any conventional levels.

We then utilized multivariate logit regression models. Table 5 shows the summary statistics of

[18] For the division, the median of consumption per capita in 2012 was used. Upper-half households do not necessarily mean wealthier families. By applying an estimated poverty line of 1.25USD per day (not considering purchasing power parity), approximately 85% of the sample households are classified as poor. 1USD was equivalent to about 6000ZMK in 2012.

explanatory variables and Table 6 presents the estimation results. The estimation results indicate in general that the estimated impacts of the project are similar to the results from the descriptive analysis of the difference in means even after controlling some observed characteristics and utilizing discrete choice models. The most important finding is that an 8.8 percentage point reduction is associated with the use of the new facility among upper-half households, which is statistically significant at the 10 per cent level (Column D). Given the fact that 86.6 per cent of households in the project sites fetch water from the facilities, the treatment effect is almost identical to the ITT effect, whereas spillover effects on the non-users of the facilities in the project sites are not evident.

5.2 Diarrhea among individuals in all age groups

We next examine the impact of the project on the incidence of diarrhea symptoms during the past two weeks. In 2012, 2.5 per cent of individuals at the project sites self-reported having a symptom of diarrhea and 2.2 per cent of individuals at the control sites reported such symptoms (Table 3). The difference between the project and control sites was 0.3 percentage points and was not statistically significant. After the project, in contrast, while 1.8 per cent of individuals at the project sites self-reported diarrhea, 3.0 per cent of individuals at the control sites reported diarrhea symptoms. The difference became 1.2 percentage points and was statistically significant at the 10 per cent level. These figures indicate that, while the rate of diarrhea incidence declined by 0.8 percentage points in the control sites, the rate was improved by 0.7 percentage points in the project sites. Thus, the simple DID estimation suggests that the causal project impact is a 1.5 percentage-point decline.

Table 4 shows the analytical results for the two different groups depending on the level of consumption per capita. The analytical results indicate that the magnitude of the estimated impact of the project was larger among the upper-half households, even though it is not statistically significant. Table 7 presents the estimation results using the multivariate logit models. The estimation results of the models with both individual and household covariates reveal that the project, on average, decreased the rate of diarrhea incidence by 1.6 percentage points, which is statistically significant at the 10 per cent level (Column A). The largest decrease (a 2.7%-point decline, which is statistically significant at the 5% level) is found among the facility users of the upper-half households (Column D), whereas no significant reduction can be found among the lower-half households.

5.3 Diarrhea among children under 5 years old

Since diarrheal diseases pose a more serious health problem among children under five, we placed a particular focus on the impact of the project on such children. When we restrict our sample to children under five, the incidence of diarrhea over the past two weeks was more prevalent: in 2012, it was reported that 6.0 per cent of children under five at the project sites had diarrhea symptoms and 5.1 per cent did so at the control sites (Table 3). The difference was 0.9 percentage points and not statistically significant at any conventional levels. After the project, 4.4 per cent of children under five at the project sites had diarrhea symptoms, whereas 9.4 per cent did so at the control sites. The difference became 5.0 percentage points and was statistically significant at the 10 per cent level. These figures indicate that, while the rate of diarrhea incidence worsened by 4.3 percentage points at the control sites, the rate was improved by 1.6 percentage points at the project sites. The simple DID estimation therefore indicates that the impact of the project was a 5.9 percentage-point reduction.

We divide children under five into two groups by the level of consumption per capita: The analytical results indicate that the magnitude of the estimated impact of the project on diarrhea incidence is very similar (around 5.5%-point decrease, although not statistically significant at any conventional levels) regardless of the level of consumption per capita. Table 8 summarizes the estimation results of the regression models with control covariates. The estimation results of the model with both individual and household covariates reveal that the project, on average, reduced the rate of diarrhea incidence by 5.9 percentage points (Column A), which is statistically significant at the 10 per cent level. No significant effect is detected when we divide the sample by the level of consumption per capita. Small sample size may explain these insignificant results, but the fact that even improved home water quality found among the facility user households does not lead to a significant reduction in diarrhea may indicate that other private inputs such as breastfeeding and washing dishes are more influential factors affecting diarrhea for infants and young children.

5.4 Utilization of water treatment methods

Finally, we examine the effect of the project on the utilization of water treatment methods. The outcome variable is defined as a binary variable that takes the value of 1 if the household utilized at least one of the following water treatment methods: boiling water, chlorination, filter use, solar disinfection, and sedimentation. We expect that "software" components of the project enhance the use of water treatment methods. Table 3 provides a descriptive analysis. We find that before the project, 30.4 per cent of the households at the project sites utilized water treatment and 28.4 per cent did at the control sites. The difference was 2.1 percentage points and was not statistically significant. After implementation of the project, surprisingly, the utilization of water treatment methods decreased by 18.4 percentage points at the project sites, whereas only a 5.0 percentage-point decrease can be seen at the control sites. Thus, the simple DID estimation reveals that the project reduced the utilization of water treatment methods by 13.5 percentage points, which is statistically significant at the 10 per cent level.

This reduction in the use of water treatment methods is more profound among upper-half households, while the reduction among the lower-half households is not significant (Table 4). Table 9 shows the estimation results of the regression models with control covariates, which indicate that the project, on average, reduced the use of water treatment methods by 15.8 percentage points (statistically significant at the 5% level) and reduced it by 23.1 percentage points (statistically significant at the 5% level) among the upper-half households. These findings are unexpected. Yet, Günther and Schipper (2011) found that households receiving an improved water source tend to stop using other household-level water treatment technologies. Günther and Schipper (2013) also argue that households receiving an improved water source are less likely to maintain the utilization of water treatment methods. Our findings echo the results of these studies.

6. Concluding remarks

Our empirical analysis reveals that the groundwater development project, on average, reduced diarrhea incidence over the past two weeks by 1.6 percentage points among individuals in all age groups and by 5.9 percentage points among children under five. In addition, we find that the use of the new water supply facility is associated with a significant improvement of water quality measured at home and a significant reduction in diarrhea incidence among upper-half households. However, the improvement of home water quality is not clear among lower-half households, even though the effect of the project on the reduction of diarrhea incidence is evident. The most plausible explanation for this inconsistency is that bacterial contamination is in fact reduced to some extent by the project but this cannot be detected by the simple water test. Since the outcome of the water test is binary (whether *E. coli* is detected or not), our water test cannot capture the degree of contamination.[19]

Even though we find that the project did reduce diarrhea incidence, the detection of *E. coli* at more than 90 per cent households even after the project indicates that improved source water is exposed to various risks of recontamination during transport and storage (note that no contamination is detected at the water sources at least when boreholes were handed over to the communities). The recontamination of improved source water in turn is highly likely to impair the potential health benefit of constructing new water supply facilities, i.e.,

[19] Kremer et al. (2011) examine the number of *E. coli* fecal coliform units per 100 ml and find a slight improvement of home water quality, but a significant reduction in diarrhea incidence. They argue that a slight improvement is sufficient to reduce diarrhea in Kenya.

"hardware" investment. The "software" components of the project emphasize the facilitation of personnel and organizational capabilities for the maintenance of the water supply facilities. However, additional attention should be paid to the handling of the improved source water during transport and storage. We also find that the project did reduce the utilization of water treatment methods at home among upper-half households, which appears to further deteriorate the water quality. Infrastructure investments tend to be very costly. Devising more sound "software" components that prevent recontamination would improve the effectiveness of the "hardware" investment of the project, which is very costly.

Another important finding of this study is that the effects of the project on water quality and the reduction in diarrhea among lower-half households are not significant. This may reflect the fact that the incidence of diarrhea was slightly more prevalent among upper-half households,[20] and thus the effect of the project was more evident among them. We can also seek for other possibilities. In terms of use of and access to the water supply facilities, we find no significant difference between the two groups.[21] They use similar types of containers for transport (most households use plastic containers). Likewise, we do not find a significant difference in hygienic behaviors with the exception of soap use for hand washing (mothers in lower-half households are more likely to wash their hands without soap). In contrast, family characteristics differ significantly. Lower-half households consist of more family members, particularly more children under 12 years old. Therefore, a possible explanation for our finding is that the involvement of more children in handling the water would result in more recontamination of improved source water.

Finally, because this study is apparently the first to evaluate the impact of groundwater development projects in sub-Saharan Africa, while we emphasize significant health benefits of the project thus far, we point

---

[20] World Bank (2012) also provides a similar finding.
[21] At the project sites, 88% of upper-half households use the borehole and the average distance to the borehole is 236 m, and 85% of lower-half households use the borehole and the average distance is 276 m.

to two more weaknesses of this approach to the water-related problems in the region. First, this approach cannot technically provide access to safe water when the construction of a facility fails. For such communities, an alternative approach must be taken; otherwise, such communities would remain without access to safe water. Second, even within the one-year period of this study (October 2012 – October 2013), one village reported that the new facility had already broken. Although the “software” components of the project facilitated personnel and organizational capabilities for the maintenance of the water supply facilities, it is still very difficult to keep the new water facilities working for a longer period. Thus, in addition to the one-time intervention of the project, it is important to monitor the project from the long-term perspective for its sustainability.

References

Aboud, E.F., and R.D. Singla. 2012. “Challenges to Changing Health Behaviors in Developing Countries: A Critical Overview.” *Social Science & Medicine* 75: 589–594.

Arnold, B., J. Colford Jr. 2007. “Treating Water with Chlorine at Point-of-use to Improve Water Quality and Reduce Child Diarrhea in Developing Countries: A Systemic Review and Meta-analysis.” *American Journal of Tropical Medicine and Hygiene* 76(2): 35–364.

Cairncross, S., C. Hunt, S. Boisson, K. Bostoen, V. Curtis, I.C. Fung, and W.P. Schmidt. 2010. “Water, Sanitation and Hygiene for the Prevention of Diarrhea.” *International Journal of Epidemiology* 2010(39): i193–i205.

Central Statistical Office, Republic of Zambia. 2011. Living Conditions Monitoring Survey Report 2006 and 2010.

Clasen, T.F., I.G. Roberts, T. Rabie, W.P. Schmidt. And S. Cairncross, S. 2006. “Interventions to Improve Water Quality for Preventing Diarrhoea.” *Cochrane Database of Systematic Reviews,* Issue 3.

Devoto, F., E. Duflo, P. Dupas, W. Pariente, V. Pons. 2012. “Happiness on Tap: The Demand for and Impact of Piped Water in Urban Morocco.” *American Economic Journal: Economic Policy* 4(4): 68–99.

Esrey, S.A. 1996. “Water, Waste and Well-being: A Multicountry Study.” *American Journal of Epidemiology* 143: 608–622.

Esrey, S.A., J.B. Potash, L. Roberts, and C. Shiff. 1991. “Effects of Improved Water Supply and Sanitation on Ascariasis, Diarrhoea, Dracunculiasis, Hookworm Infection, Schistosomiasis, and Trachoma.” *Bulletin of the World Health Organization* 69(5): 609–621.

Fewtrell, L., R.B. Kaufmann, D. Kay, W. Enanoria, L. Haller, and J.M. Colford Jr. 2005. “Water, Sanitation, and Hygiene Interventions to Reduce Diarrhoea in Less Developed Countries: A Systematic Review and Meta-analysis.” *Lancet Infect. Dis.* 5: 42–52.

Fiebelkorn, A.P., B. Person, R.E. Quick, S.M. Vindigni, M. Jhung, A. Bowen, and P.L. Riley. 2012. “Systematic Review of Behavior Change Research on Point-of-use Water Treatment Interventions in Countries Categorized as Low- to Medium-development on The Human Development Index.” *Social Science & Medicine* 75: 622–633.

Gamper-Rabindran, S., S. Khan, and C. Timmins. 2010. “The Impact of Piped Water Provision on Infant Mortality in Brazil: A Quantile Panel Data Approach.” *Journal of Development Economics* 92: 188–200.

Galiani, S., P. Gertler, and E. Schargrodsky. 2005. “Water for Life: The Impact of the Privatization of Water Services on Child Mortality.” *Journal of Political Economy* 113(1): 83–120.

Gundry, S., J. Wright, and R, Conroy. 2004. “A Systematic Review of The Health Outcomes Related to Household Water Quality in Developing Countries.” *Journal of Water and Health* 02.1: 1–13.

Günther, I., and Y. Schipper. 2011. Chapter 3: Quantitative Impact Analysis. In: Impact Evaluation of Drinking Water Supply and Sanitation Programmes, BMZ/ KfW/ IOB (eds). IOB: The Hague.

Günther, I., and Y. Schipper. 2013. “Pumps, Germs and Storage: The Impact of Improved Water Containers on Water Quality and Health.” *Health Economics* 22: 757–774.

Jalan, J., and M. Ravallion. 2003. “Does Piped Water Reduce Diarrhea for Children in Rural India?” *Journal of Econometrics* 112(1): 153–173.

Japan International Cooperation Agency (JICA). 2011. Preparatory Survey Report on the Project for Groundwater Development in Luapula Province Phase 2 in the Republic of Zambia.

Kremer, M., J. Leino, E. Miguel, and A.P. Zwane. 2011. “Spring Cleaning: Rural Water Impacts, Valuation, and Property Rights Institutions.” *Quarterly Journal of Economics* 126: 145–205.

Mangyo, E. 2008. “The Effect of Water Accessibility on Child Health in China.” *Journal of Health Economics* 27: 369–405.

Ministry of Health, Republic of Zambia. 2014. Annual Health Statistical Bulletin 2012: Luapula Province. Lusaka: Ministry of Health.

Ravallion, M. 2001. “The Mystery of the Vanishing Benefits: An Introduction to Impact Evaluation.” *World Bank Economic Review* 15(2): 115–140.

United Nations Children Fund (UNICEF)/World Health Organization (WHO). 2009. *Diarrhoea: Why Children Are Still Dying and What Can Be Done*. New York: UNICEF; Geneva: WHO.

———. 2015. *Progress on Drinking Water and Sanitation: 2015 Update*. New York: UNICEF; Geneva: WHO.

United Nations Development Programme (UNDP). 2013. Millennium Development Goals Progress Report: Zambia 2013. New York: UNDP.

Waddington, H., and B. Snilstveit. 2009. “Effectiveness and Sustainability of Water, Sanitation, and Hygiene Interventions in Combating Diarrhoea.” *Journal of Development Effectiveness* 1(3): 295–335.

World Bank. 2012. Health Equity and Financial Protection Report – Zambia. Washington, D.C., The World Bank.

Zhang, J. 2011. “The Impact of Water Quality on Health: Evidence from Drinking Water Infrastructure Program in Rural China.” *Journal of Health Economics* 31(1): 122–134.

Table 1. Sample sites and sample households

District	Number of Sample Sites			Number of Sample Households		
	All	Project	Control	All	Project	Control
Milenge	26	21	5	185	150	35
Mwense	36	25	11	236	156	80
Nchelenge	32	18	14	214	128	86
Total	94	64	30	635	434	201

Table 2. Comparison of socioeconomic characteristics at baseline (2012)

	Project	Control	Diff.
	(A)	(B)	(A) − (B)
Individual characteristics (number of observations)	2268	1036	
Female (=1)	0.513	0.500	0.013
Age	20.92	20.68	0.24
Education level (highest grade completed)	3.967	3.668	0.299
Household characteristics (number of observations)	434	201	
Female head of household (=1)	0.207	0.199	0.008
Age of household head	43.43	42.25	1.18
Highest education among female members older than 18	5.163	4.477	0.686*
Highest education among male members older than 18	6.015	5.674	0.340
Household size	5.226	5.154	0.072
Number of children under 12	1.961	2.060	−0.099
Monthly consumption per capita [1,000ZMK]	163	200	−366
Village characteristics (number of observations)	64	30	
Population	446	346	100

Note: Statistical tests are performed by linear regressions with consideration of village-level clusters;
*Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 3. Comparison of water-related outcomes

Year	All Households				
	Project		Control		Diff.
	(A)	(B)	(C)	(D)	(B) − (D)
	Obs.	**Mean**	**Obs.**	**Mean**	
Panel A: Home water contamination with* E. Coli *(=1)					
2012	434	0.952	201	0.940	0.011
2013	428	0.932	197	0.954	−0.022
Change		−0.019		0.014	−0.033
Panel B: Incidence of diarrhea over the past 2 weeks among all individuals (=1)					
2012	2268	0.025	1036	0.022	0.003
2013	2155	0.018	988	0.030	−0.012*
Change		−0.007		0.008	−0.015
Panel C: Incidence of diarrhea over the past 2 weeks among children under five (=1)					
2012	385	0.060	197	0.051	0.009
2013	317	0.044	160	0.094	−0.050*
Change		−0.016		0.043	−0.059
Panel D: Utilization of water treatment methods (=1)					
2012	434	0.304	201	0.284	0.021
2013	434	0.120	201	0.234	−0.114**
Change		−0.184		−0.050	−0.135*

Note: Statistical tests are performed by linear regressions. Village-level cluster-robust standard errors are shown in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 4. Comparison of water-related outcomes by wealth level

Year	Upper-half households					Lower-half households				
	Project		Control		Diff.	Project		Control		Diff.
	(A)	(B)	(C)	(D)	(B) − (D)	(E)	(F)	(G)	(H)	(F) − (H)
	Obs.	**Mean**	**Obs.**	**Mean**		**Obs.**	**Mean**	**Obs.**	**Mean**	
Panel A: Home water contamination with* E. Coli *(=1)										
2012	218	0.959	99	0.919	0.040	216	0.944	102	0.961	−0.016
2013	214	0.916	98	0.949	−0.033	214	0.949	99	0.960	−0.011
Change		−0.043		0.030	−0.073		0.004		−0.001	0.005
Panel B: Incidence of diarrhea over the past 2 weeks among all individuals (=1)										
2012	969	0.029	442	0.025	0.004	1299	0.022	594	0.020	0.002
2013	943	0.022	451	0.042	−0.020*	1212	0.012	537	0.020	−0.008
Change		−0.007		0.017	−0.024		−0.010		0.000	−0.010
Panel C: Incidence of diarrhea over the past 2 weeks among children under five (=1)										
2012	175	0.046	94	0.064	−0.018	210	0.071	103	0.039	0.033
2013	156	0.058	84	0.131	−0.073*	161	0.031	76	0.053	−0.022
Change		0.012		0.067	−0.055		−0.040		0.014	−0.054
Panel D: Utilization of water treatment methods (=1)										
2012	218	0.381	99	0.333	0.047	216	0.227	102	0.235	−0.008
2013	218	0.133	99	0.293	−0.160**	216	0.106	102	0.176	−0.070
Change		−0.248		−0.040	−0.207**		−0.120		−0.059	−0.062

Note: Statistical tests are performed by linear regressions. Village-level cluster-robust standard errors are shown in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 5. Summary statistics of explanatory variables

	Baseline (2012)				End-line (2013)			
	Mean	**S.D.**	**Min.**	**Max.**	**Mean**	**S.D.**	**Min.**	**Max.**
Individual characteristics	n = 3304				n = 3143			
Female (=1)	0.509	(0.500)	0	1	0.508	(0.500)	0	1
Age	20.8	(17.6)	0	88	21.8	(17.9)	0	89
Household characteristics	n = 635				n = 635			
Project site/Facility user (=1)	0.683	(0.465)	0	1	0.592	(0.492)	0	1
Project site *Facility non-user (=1)					0.091	(0.288)	0	1
Female head of household (=1)	0.205	(0.404)	0	1	0.198	(0.399)	0	1
Age of the household head	43.1	(13.6)	18	84	43.9	(13.7)	17	85
Female education: None or absent (=1)	0.142	(0.349)	0	1	0.135	(0.342)	0	1
Primary [1–7] (=1)	0.658	(0.475)	0	1	0.677	(0.468)	0	1
Secondary or higher [7+] (=1)	0.200	(0.400)	0	1	0.187	(0.391)	0	1
Male education: None or absent (=1)	0.176	(0.381)	0	1	0.169	(0.375)	0	1
Primary [1–7] (=1)	0.460	(0.499)	0	1	0.488	(0.500)	0	1
Secondary or higher [7+] (=1)	0.364	(0.481)	0	1	0.343	(0.475)	0	1
log (household size)	1.529	(0.526)	0	2.708	1.475	(0.534)	0	2.708
Ratio of children under 12 to household size	0.339	(0.234)	0	0.833	0.325	(0.237)	0	0.800
log (monthly consumption per capita)	11.66	(0.742)	9.681	16.23	11.65	(1.001)	8.367	15.38

Note: Monthly consumption per capita is measured at constant prices in 2012.

Table 6. Impact of the project on water quality

Dependent variable: Home water contamination with *E. Coli* (=1)	All households		Upper-half households		Lower-half households	
	Project	Facility	Project	Facility	Project	Facility
	(A)	(B)	(C)	(D)	(E)	(F)
Project and year dummy variables						
Project site/Facility user	−0.0317	−0.0397	−0.0762	−0.0879*	0.0102	0.0065
*Year 2013 (=1)	(0.0451)	(0.0459)	(0.0510)	(0.0525)	(0.0548)	(0.0555)
Project site *Facility non-user		0.0285		0.0151		0.0350
*Year 2013 (=1)		(0.0578)		(0.0651)		(0.0823)
Year 2013 (=1)	0.0155	0.0156	0.0354	0.0351	−0.0043	−0.0041
	(0.0415)	(0.0414)	(0.0420)	(0.0418)	(0.0503)	(0.0504)
Project site/Facility user (=1)	0.0193	0.0262	0.0493	0.0578	0.0007	0.0066
	(0.0356)	(0.0361)	(0.0411)	(0.0408)	(0.0427)	(0.0439)
Project site *Facility non-user (=1)		−0.0202		−0.0034		−0.0290
		(0.0416)		(0.0524)		(0.0522)
Household characteristics						
Female head of household (=1)	0.0265	0.0272	0.0423	0.0452	0.0268	0.0260
	(0.0240)	(0.0246)	(0.0349)	(0.0357)	(0.0407)	(0.0412)
Head age dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Female education:	−0.0018	−0.0031	0.0205	0.0198	−0.0272	−0.0298
Primary [1–7] (=1)	(0.0194)	(0.0194)	(0.0219)	(0.0220)	(0.0278)	(0.0285)
Female education:	0.0213	0.0207	0.0544	0.0555	−0.0156	−0.0174
Secondary or higher [7+] (=1)	(0.0298)	(0.0293)	(0.0402)	(0.0400)	(0.0367)	(0.0373)
Male education:	0.0096	0.0097	0.0092	0.0083	0.0189	0.0202
Primary [1–7] (=1)	(0.0243)	(0.0248)	(0.0310)	(0.0311)	(0.0395)	(0.0402)
Male education:	−0.0174	−0.0169	0.0110	0.0104	−0.0358	−0.0341
Secondary or higher [7+] (=1)	(0.0288)	(0.0291)	(0.0390)	(0.0392)	(0.0404)	(0.0412)
log (household size)	−0.0044	−0.0044	−0.0068	−0.0076	−0.0100	−0.0099
	(0.0178)	(0.0177)	(0.0283)	(0.0280)	(0.0243)	(0.0238)
Ratio of children under 12 to	−0.0249	−0.0220	−0.0495	−0.0437	−0.0158	−0.0140
household size	(0.0382)	(0.0390)	(0.0537)	(0.0578)	(0.0496)	(0.0500)
log (consumption per capita)	−0.0010	−0.0015	0.0052	0.0045	−0.0038	−0.0040
	(0.0085)	(0.0086)	(0.0122)	(0.0126)	(0.0130)	(0.0132)
District dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.0672	0.0714	0.0922	0.0984	0.0997	0.1028
Number of observations	1250	1250	624	624	626	626

Note: Average marginal effects are shown. Coefficients indicate changes in the probability of existing *E. Coli* in the water stored at home when the value of the dummy variable changes from zero to one.
Village-level cluster-robust standard errors in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 7. Impact on incidence of diarrhea symptoms (all individuals)

Dependent variable: Incidence of diarrhea over the past 2 weeks (=1)	All households		Upper-half households		Lower-half households	
	Project	Facility	Project	Facility	Project	Facility
	(A)	(B)	(C)	(D)	(E)	(F)
Project and year dummy variables						
Project site/Facility user	−0.0159*	−0.0203**	−0.0227	−0.0271*	−0.0097	−0.0154
*Year 2013 (=1)	(0.0094)	(0.0094)	(0.0147)	(0.0151)	(0.0105)	(0.0111)
Project site *Facility non-user		0.0157		0.0202		0.0210
*Year 2013 (=1)		(0.0166)		(0.0255)		(0.0190)
Year 2013 (=1)	0.0080	0.0081	0.0185	0.0184	−0.0076	−0.0081
	(0.0068)	(0.0068)	(0.0115)	(0.0115)	(0.0089)	(0.0089)
Project site/Facility user (=1)	0.0034	0.0057	0.0077	0.0101	−0.0001	0.0023
	(0.0063)	(0.0065)	(0.0090)	(0.0092)	(0.0070)	(0.0072)
Project site *Facility non-user (=1)		−0.0172		−0.0226		−0.0170
		(0.0124)		(0.0255)		(0.0128)
Individual characteristics						
Female (=1)	0.0034	0.0035	0.0013	0.0017	0.0055	0.0053
	(0.0036)	(0.0036)	(0.0062)	(0.0061)	(0.0047)	(0.0047)
Age cohort dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics						
Female head of household (=1)	−0.0107	−0.0108	0.0006	−0.0006	−0.0196*	−0.0188*
	(0.0100)	(0.0099)	(0.0161)	(0.0160)	(0.0113)	(0.0112)
Head age dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Female education:	−0.0062	−0.0069	0.0189	0.0186	−0.0182***	−0.0196***
Primary [1–7] (=1)	(0.0071)	(0.0072)	(0.0149)	(0.0149)	(0.0058)	(0.0061)
Female education:	−0.0056	−0.0064	0.0156	0.0152	−0.0103	−0.0119
Secondary or higher [7+] (=1)	(0.0078)	(0.0080)	(0.0182)	(0.0183)	(0.0071)	(0.0073)
Male education:	0.0028	0.0026	−0.0186	−0.0195	0.0145	0.0149
Primary [1–7] (=1)	(0.0107)	(0.0106)	(0.0206)	(0.0205)	(0.0099)	(0.0099)
Male education:	0.0042	0.0044	−0.0073	−0.0075	0.0028	0.0031
Secondary or higher [7+] (=1)	(0.0108)	(0.0108)	(0.0216)	(0.0216)	(0.0102)	(0.0104)
log (household size)	−0.0027	−0.0026	−0.0131	−0.0135	0.0036	0.0042
	(0.0061)	(0.0061)	(0.0098)	(0.0096)	(0.0085)	(0.0087)
Ratio of children under 12 to household size	−0.0327***	−0.0324***	−0.0246	−0.0245	−0.0355**	−0.0356**
	(0.0123)	(0.0122)	(0.0230)	(0.0225)	(0.0147)	(0.0147)
log (consumption per capita)	0.0101***	0.0097***	0.0108***	0.0103***	0.0144***	0.0149***
	(0.0020)	(0.0019)	(0.0031)	(0.0032)	(0.0036)	(0.0037)
District dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.0986	0.1030	0.1180	0.1221	0.1540	0.1616
Number of observations	6447	6447	2805	2805	3642	3642

Note: Average marginal effects are shown. Coefficients indicate changes in the probability of having a diarrhea symptom over the past 2 weeks when the value of the dummy variable changes from zero to one.
Village-level cluster-robust standard errors in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Table 8. Impact on incidence of diarrhea symptoms (children under 5)

Dependent variable: Incidence of diarrhea over the past 2 weeks (=1)	All households		Upper-half households		Lower-half households	
	Project	Facility	Project	Facility	Project	Facility
	(A)	(B)	(C)	(D)	(E)	(F)
Project and year dummy variables						
Project site/Facility user	−0.0586*	−0.0637*	−0.0365	−0.0331	−0.0616	−0.0820
*Year 2013 (=1)	(0.0355)	(0.0368)	(0.0501)	(0.0512)	(0.0511)	(0.0540)
Project site *Facility non-user		−0.0319		−0.0572		0.0120
*Year 2013 (=1)		(0.0526)		(0.0987)		(0.0652)
Year 2013 (=1)	0.0381	0.0381	0.0529	0.0529	(0.0007)	(0.0013)
	(0.0257)	(0.0257)	(0.0365)	(0.0365)	(0.0483)	(0.0484)
Project site/Facility user (=1)	0.0041	0.0037	−0.0153	−0.0141	0.0153	0.0198
	(0.0213)	(0.0223)	(0.0310)	(0.0323)	(0.0312)	(0.0322)
Project site *Facility non-user (=1)		0.0060		−0.0182		−0.0082
		(0.0338)		(0.0631)		(0.0371)
Individual characteristics						
Female (=1)	0.0139	0.0151	0.0066	0.0057	0.0172	0.0162
	(0.0135)	(0.0136)	(0.0210)	(0.0211)	(0.0180)	(0.0177)
Age dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics						
Female head of household (=1)	−0.0482	−0.0477	−0.130**	−0.134**	−0.0415	−0.0367
	(0.0471)	(0.0474)	(0.0651)	(0.0659)	(0.0373)	(0.0368)
Head age dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Female education:	0.0252	0.0241	0.0771	0.0780	−0.0130	−0.0166
Primary [1–7] (=1)	(0.0341)	(0.0342)	(0.0697)	(0.0686)	(0.0389)	(0.0419)
Female education:	0.0310	0.0302	0.0494	0.0486	0.0164	0.0110
Secondary or higher [7+] (=1)	(0.0364)	(0.0366)	(0.0777)	(0.0771)	(0.0393)	(0.0432)
Male education:	0.0014	0.0014	−0.121**	−0.122**	0.0629	0.0647
Primary [1–7] (=1)	(0.0425)	(0.0428)	(0.0512)	(0.0503)	(0.0557)	(0.0553)
Male education:	0.0106	0.0105	−0.0701	−0.0703	0.0423	0.0422
Secondary or higher [7+] (=1)	(0.0426)	(0.0429)	(0.0639)	(0.0630)	(0.0553)	(0.0562)
log (household size)	0.0156	0.0153	−0.0690*	−0.0706*	0.0763	0.0729
	(0.0307)	(0.0306)	(0.0404)	(0.0410)	(0.0515)	(0.0526)
Ratio of children under 12 to household size	−0.0799	−0.0852	−0.0461	−0.0368	−0.1030	−0.1090
	(0.0554)	(0.0557)	(0.0769)	(0.0824)	(0.0818)	(0.0828)
log (consumption per capita)	0.0203***	0.0196***	0.0201**	0.0208**	0.0397***	0.0391***
	(0.0065)	(0.0067)	(0.0090)	(0.0098)	(0.0145)	(0.0145)
District dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.1041	0.1057	0.1376	0.1383	0.2655	0.2776
Number of observations	1059	1059	509	509	550	550

Note: Average marginal effects are shown. Coefficients indicate changes in the probability of having a diarrhea symptom over the past 2 weeks when the value of the dummy variable changes from zero to one.
Village-level cluster-robust standard errors in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

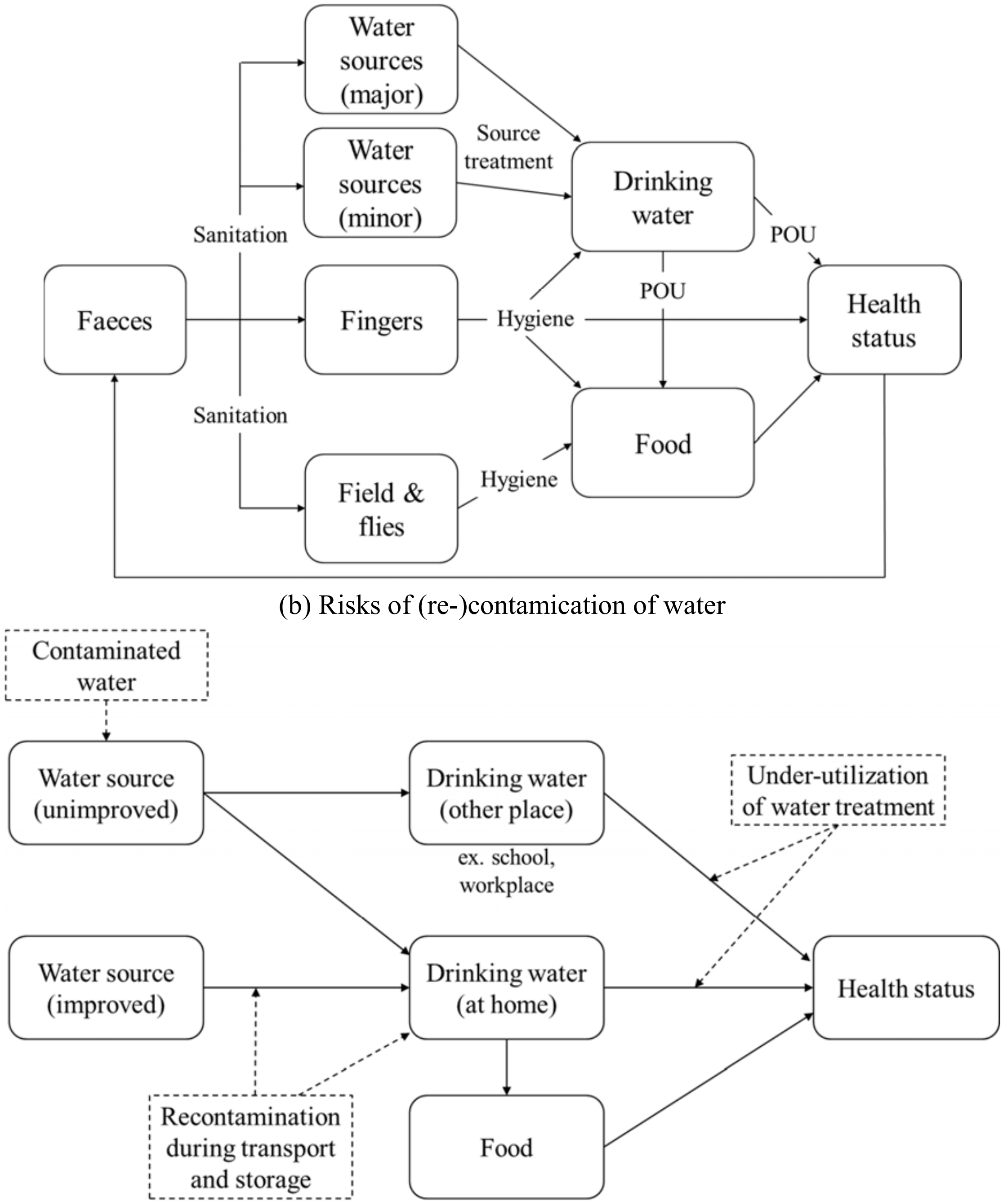
Table 9. Impact on utilization of water treatment methods

Dependent variable: Utilization of water treatment methods (=1)	All households		Upper-half households		Lower-half households	
	Project	Facility	Project	Facility	Project	Facility
	(A)	(B)	(C)	(D)	(E)	(F)
Project and year dummy variables						
Project site/Facility user	−0.158**	−0.183***	−0.231***	−0.258***	−0.0748	−0.0980
*Year 2013 (=1)	(0.0657)	(0.0672)	(0.0830)	(0.0842)	(0.0782)	(0.0810)
Project site *Facility non-user		−0.0021		(0.0470)		0.0471
*Year 2013 (=1)		(0.0789)		(0.0991)		(0.1090)
Year 2013 (=1)	−0.0401	−0.0396	−0.0032	−0.0046	−0.0496	−0.0498
	(0.0519)	(0.0517)	(0.0619)	(0.0620)	(0.0632)	(0.0632)
Project site/Facility user (=1)	−0.0184	−0.0157	−0.0132	−0.0106	−0.0207	−0.0165
	(0.0500)	(0.0505)	(0.0575)	(0.0569)	(0.0572)	(0.0596)
Project site *Facility non-user (=1)		−0.0461		−0.0414		−0.0519
		(0.0744)		(0.0996)		(0.0894)
Household characteristics						
Female head of household (=1)	0.106***	0.107***	0.120*	0.118*	0.105***	0.107***
	(0.0362)	(0.0356)	(0.0635)	(0.0623)	(0.0402)	(0.0402)
Head age dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Female education:	0.0489	0.0489	0.120**	0.120**	−0.0116	−0.0115
Primary [1–7] (=1)	(0.0393)	(0.0397)	(0.0568)	(0.0563)	(0.0547)	(0.0569)
Female education:	0.0734	0.0729	0.169**	0.168**	−0.0326	−0.0335
Secondary or higher [7+] (=1)	(0.0533)	(0.0540)	(0.0707)	(0.0712)	(0.0719)	(0.0739)
Male education:	0.0009	−0.0020	−0.1270	−0.1330	0.0784	0.0758
Primary [1–7] (=1)	(0.0562)	(0.0563)	(0.1020)	(0.1020)	(0.0613)	(0.0612)
Male education:	0.0381	0.0373	−0.0950	−0.0981	0.124*	0.123*
Secondary or higher [7+] (=1)	(0.0558)	(0.0557)	(0.0985)	(0.0979)	(0.0636)	(0.0636)
log (household size)	0.0515	0.0511*	0.0876*	0.0853*	0.0469	0.0488
	(0.0315)	(0.0310)	(0.0523)	(0.0499)	(0.0461)	(0.0455)
Ratio of children under 12 to	−0.163**	−0.165**	−0.250**	−0.250**	−0.0890	−0.0894
household size	(0.0665)	(0.0662)	(0.1050)	(0.1030)	(0.0892)	(0.0893)
log (consumption per capita)	0.0692***	0.0673***	0.0796***	0.0743***	0.0128	0.0148
	(0.0152)	(0.0151)	(0.0205)	(0.0215)	(0.0258)	(0.0252)
District dummy variables	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo R^2	0.0971	0.1012	0.1524	0.1569	0.0646	0.0681
Number of observations	1270	1270	634	634	636	636

Note: Average marginal effects are shown. Coefficients indicate changes in the probability of utilizing at least one of the water treatment methods (boiling water, chlorination, filter use, solar disinfection, and sedimentation) at home when the value of the dummy variable changes from zero to one.
Village-level cluster-robust standard errors in parentheses; *Significant at 10%; **Significant at 5%; ***Significant at 1%.

Figure 1: Causal mechanism of interventions and risks of (re-) contamination

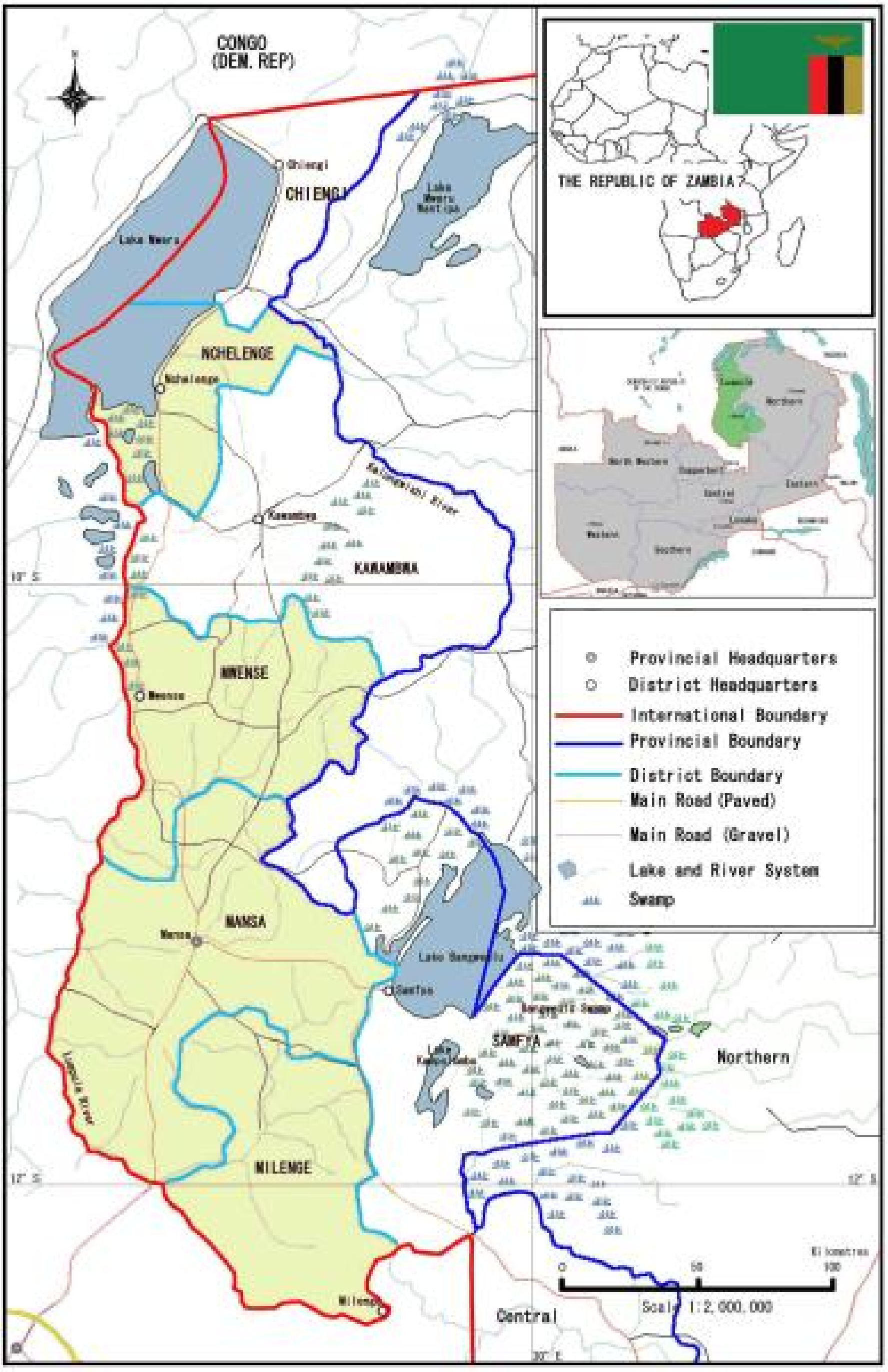
(a) Causal mechanism of interventions



Source: Adopted from Waddington and Snilstveit (2009).

Note: Dashed arrows in (b) show the possible risks of (re-) contamination of water.

Figure 2: Map of Luapula Province



Source: JICA (2014)

Figure 3 Timeline of the Project

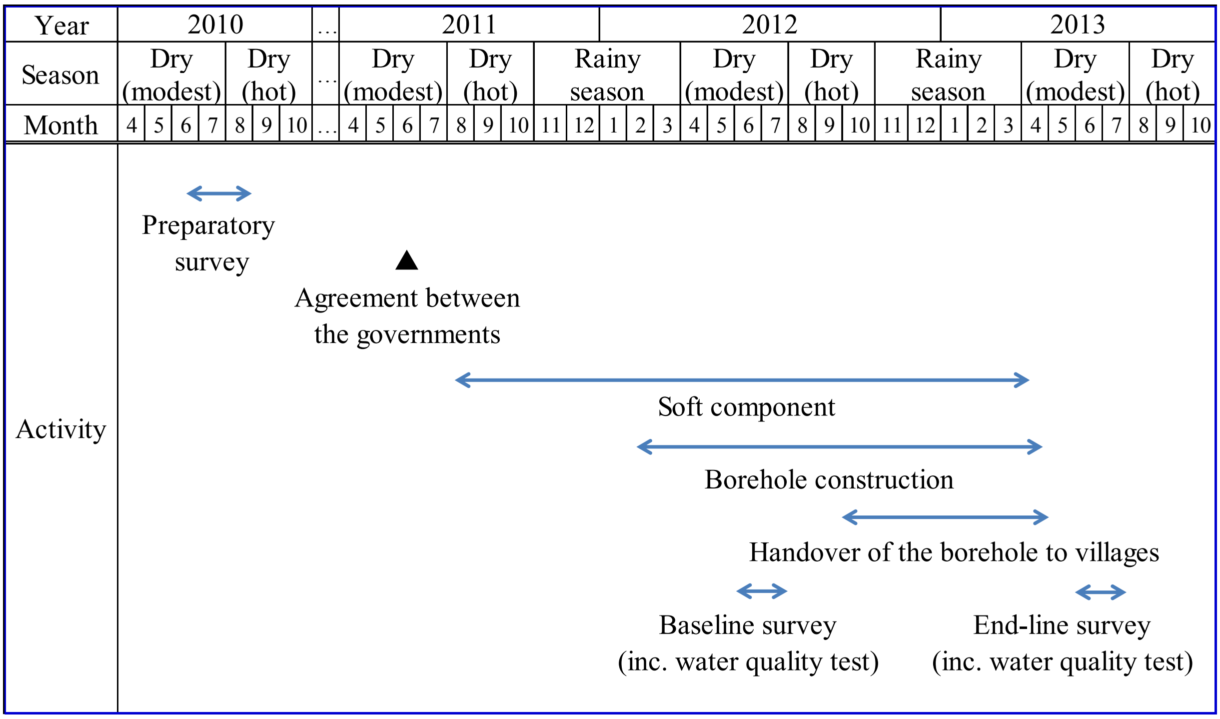
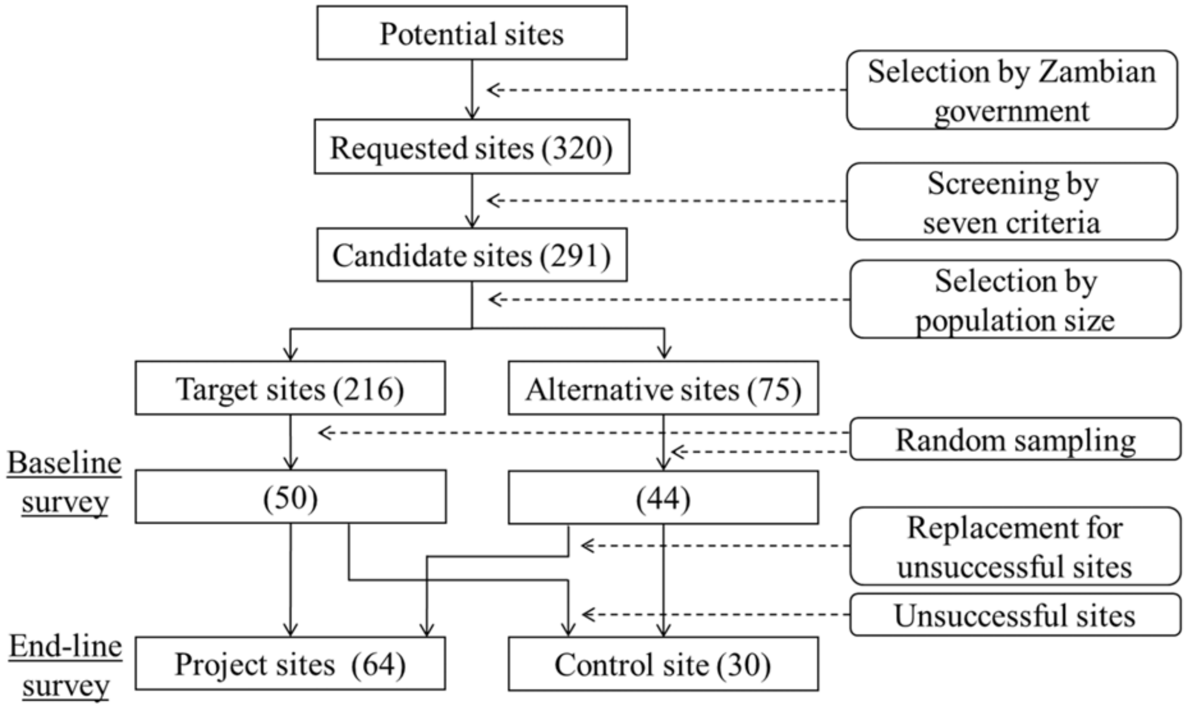


Figure 3. Procedure of site selection and sampling



Note: The selection criteria by Zambian government included the availability of existing water facilities, the population size, and the capacity of community. The subsequent seven criteria were (1) demand for safe and stable water, (2) accessibility to the site, (3) hydrogeological conditions, (4) availability of existing water facilities, (5) overlap with other related projects, (6) possibility of forming a V-WASHE Committee; and (7) residents' willingness to pay the operation and maintenance costs.