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Improved water supply and water handling technologies: Revealed complements but perceived substitutes for safe water quality

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ABSTRACT

We analyze the impact of public water infrastructure and water handling technologies on the water quality and water handling behavior of households in rural Benin using both quasi-experimental and experimental household-level panel data. We find that the installation of improved village-level water sources induces households to reduce water disinfection efforts at home, indicating that households perceive improved public water infrastructure as a substitute for improved water handling to obtain safe drinking water. Consequently, point-of-use drinking water quality does not change. A reduction of contamination with *E. coli* at points of use can only be achieved if interventions providing drinking water technologies at the water source are complemented by household-level interventions and efforts to teach households how to maintain good water quality.

1. Introduction

The United Nations' (UN) Sustainable Development Goal (SDG) 6, established in 2015, states that it is important to provide "equitable access to safe and affordable drinking water for all" (UN, 2016). In 2012, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) announced that the world had surpassed Millennium Development Goal (MDG) 7C, which aimed to halve the population without access to improved water sources (WHO/UNICEF, 2015). This claim, however, obscures the huge disparities in water access between regions: First, most of the progress toward water access has occurred in Asia, where the population with access to improved water sources increased from approximately 70 percent in 2000 to 90 percent in 2015. Sub-Saharan Africa is still far from achieving equitable access and nearly 50 percent of its rural population still does not have access to a safe source of drinking water (WHO/UNICEF, 2017). Second, access to an improved or safely managed water source does not necessarily mean that the population consumes safe drinking water because the water source itself may be unsafe (Bain et al., 2012, 2014); people may prefer unimproved, cost-free water sources; or the water may be re-contaminated between the source and the households' point-of-use (POU) (Wright et al., 2004). It is estimated that 1.8 billion people drink unsafe water: 844 million people still lack access to basic improved sources in countries that fall short of MDG 7C (WHO/UNICEF, 2017) and approximately one billion people drink water from technically improved sources that are still contaminated with fecal matter (Onda et al., 2012).

Aid directed at the water sector is meant to improve water quality and health, with the particular aim of reducing diarrhea incidence (Hutton et al., 2006). In rural areas, most water supply programs focus on public water infrastructure, such as water pumps and standpipes, to provide households with access to improved drinking water sources at a reasonable cost. However, the effectiveness of public water infrastructure for improving drinking water quality and decreasing diarrhea incidence has been challenged in the literature (e.g., Fewtrell et al., 2005; IEG, 2008; Peterson, Zwane and Kremer, 2007; Waddington and Snilstveit, 2009). Studies using microbiological evidence have shown that public taps and pumps considerably reduce water contamination with *Escherichia (E.) coli* bacteria at the source, but re-contamination during transport and/or storage is widespread (Jalan and Ravallion, 2003; Kremer et al., 2011; Wright et al., 2004). POU water quality is therefore significantly worse than water quality at the source and

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sometimes not better than water from unimproved water sources when water is tested at the provision level and at POUs (Günther and Schipper, 2011; Klasen et al., 2012).

Water-handling interventions, including (i) water treatment, such as filtration and chlorine treatment (e.g., Albert et al., 2010; Dupas et al., 2016; IEG, 2008; Rosa et al., 2014); (ii) behavioral changes, such as hand washing (Luby et al., 2004, 2006); and (iii) improved water transport and storage vessels (Günther and Schipper, 2013) are considered effective at improving water quality and health (Waddington and Snilstveit, 2009). Solely installing new water points may not cause the behavioral changes necessary to improve households' drinking water quality. Ahuja et al. (2010) discuss evidence from randomized evaluations that support this conclusion and highlight the challenges of changing demand and behavior for high water quality. One such challenge is that households may be unable or unwilling to pay for convenient access to improved water sources if chlorine products are not subsidized.

Bennett (2012) highlights the behavioral aspect of the effectiveness of water and sanitation projects. If households perceive clean water and sanitation as substitutes for each other, household-level interventions may have unintended impacts on the hygiene behavior of the target population. Although the causal relationship of behavioral risk compensation between water and sanitation might appear less likely, we provide evidence that compensation does occur in the water fetching process.

By analyzing the impact of both public water supply and water handling containers, this paper makes an important contribution to the literature regarding the effectiveness of water supply programs based on the following related outcomes: objective and subjective water quality at the source and POU, POU water treatment, water transport and storage behavior, and uptake of new, improved water points. We further add to the literature by analyzing objective and subjective measures of the water quality of improved water sources, both at the source and household levels, and include a behavioral dimension that helps explain POU water contamination despite improvements in water quality at the source. We use a household-level panel data set including household and water source–level *E. coli* testing.

We derive our results from a difference-in-difference (DD) analysis of public water infrastructure built under the 2007–2012 donor-supported national water and sanitation program in Benin (PPEA).[1] We complement this intervention with a randomized controlled trial in which improved water transport and storage containers were distributed throughout a random subsample of PPEA villages. The underlying theory of change from the interventions is that the provision of water infrastructure increases the use of safe drinking water from clean water sources, thus helping to reduce the intake of disease-inducing pathogens (here, *E. coli),* which, in turn, improves health outcomes like diarrhea. The consumption of safe drinking water is further ensured with proper hygiene behavior by using improved water containers during the water handling process.

Our findings are as follows: First, and in line with previous literature, we find that an improved public water supply increases the use of improved water sources and ameliorates water quality, measured by a decrease in *E. Coli* contamination at the source. However, it does not improve POU water quality. Second, we find that water point installation has an adverse effect on hygienic water handling, as households reduce or stop water treatment practices prior to consumption once an improved water point has been installed. We interpret this finding as a behavioral change caused by the objective and subjective improvement of the water quality at the source and the costs of hygienic water handling at the POU in terms of time, attention, and money. In other words, households regard improved public water sources and private investments in improved water handling as substitute inputs in their water quality (or health) production function. A public water supply provided as a standalone intervention signals the presence of clean water, leading households to disregard other potential contamination channels. Finally, we show that an intervention that considerably reduces the cost (both in terms of time and money) of improved water handling can—in combination with an improved water supply—lead to improved water quality and safer water handling at the POU.[2]

In the following section, we present the analyzed interventions, research design, and identification strategy. In Section 3, we introduce the data and discuss the baseline descriptive statistics. Section 4 details our empirical results and discusses the costs related to water supply and water handling at the household level. Section 5 concludes the study and discusses the implications for future water supply interventions.

2. Intervention and research design

This paper studies the impact of three types of interventions: a village-level water source intervention, a household-level water handling intervention and a combination of both. The first intervention is part of Benin's second national water strategy, PPEA, and involves installing improved water points, public standpipes, or pumps in rural communities. The choice of technology to be installed depends on the groundwater level and the population of each village.[3] The administrative process of allocating water points is partly driven by demand and partly by the government's goal of achieving water coverage equity between regions. Communities must apply for a water point and contribute approximately one percent of the construction costs ($450 USD for a standpipe and $225 USD for a pump)[4] to demonstrate demand for an improved water point. The study sample consists of 131 villages, randomly drawn in 2008 from the Beninese Water Services' planning lists for 2009 and 2010: 49 are water supply treatment villages randomly selected from the 2009 planning list, and 82 are water supply control villages randomly drawn from the Water Services' planning list of 2010.[5] Prior to conducting the baseline survey, the research team established a full household listing for each village. The household lists provided the sample frame to randomly select 10 households per village for interviews. The same households were interviewed in 2009 and 2010 with an attrition rate of 2 percent.

All villages in our sample had requested an improved water point, paid the requested financial contribution, and received a water point within two years (2009 or 2010) under the PPEA. The only difference between the treatment and control villages is that improved water points were installed with a one-year delay in control villages relative to

[1] *Programme Pluriannuel d'appui au secteur de l'Eau potable et de l'Assainissement.*

[2] We do investigate different measures of the health outcomes diarrhea but do not find any evidence that the new infrastructure has an impact on overall diarrheal incidence or for children below the age of 5 years. However, the study was not meant to be a health related study where sample sizes have to be larger.

[3] Both technologies are considered improved water sources according to the official WHO–UN definition. Improved drinking water sources, by nature of their design and construction, deliver safe drinking water and protect the water from being contaminated from the outside (WHO, 2008; WHO/UNICEF, 2012; 2017). The investment costs are approximately $55,000 USD (25,000,000 FCFA) for a public standpipe and $20,000 USD (9,000,000 FCFA) for a public pump, costs which are mostly covered by donor agencies. Larger villages are more likely to be targeted with standpipes and smaller villages with public pumps. Standpipes have an electrical pump for deeper levels of groundwater.

[4] Exchange rate 2009/10: $1 USD = 600 FCFA.

[5] The order in which villages appear on the planning list, i.e., the used sample frame, depends on central level financial constraints (Direction General de l'Eau, 2010). We find no measurable observable factors influencing the water point treatment strategy of either planned or realized treatment (results available from the authors). However, unobservable factors remain possible, e.g., political or geographical circumstances, the measurement of which goes beyond the scope of this study.

treatment villages, as the treatment villages were sampled from the 2009 planning lists and the control villages from the 2010 planning lists. This is a so-called phasing-in approach.

The second intervention distributed improved water transport and storage containers to households to analyze the impact of improved water handling behavior on related outcomes. The study team, in collaboration with the Centre Régional pour l' Eau Potable et l' Assainissement (CREPA), randomly allocated improved water storage and transport containers to a subsample of 12 water source treatment and 23 control villages. All households in the water handling treatment group received: (a) a clay or plastic storage container with a lid and a tap at the bottom, (b) a plastic jerry can with a narrow mouth for transporting the water from the source to the storage container, and (c) instructions highlighting the importance of not touching the water and collecting water only from improved sources, such as standpipes or pumps. The improved storage containers are meant to replace the widely used clay pots, which are not covered at the top and from which households take water by dipping a plastic or metal cup.[6] The traditional transport containers were the uncovered, multi-purpose sheet-metal bowls which the intervention intended to replace with the capped plastic jerry cans (see Appendix Figure A1). The new containers are advantageous for the households in that they are easy to handle because their designs are similar to the traditional containers. The water handling containers ensure clean water at the POU by maintaining water quality from the improved water source to the household. The POU water handling intervention implemented for this study was provided free of charge and thus increases neither the cost of water treatment nor the time required for water handling as only the transport and storage containers were replaced.

The study design and sample are described in Table 1. There are three possible treatment combinations: water supply treatment (TW), water handling treatment including the transport and storage containers (TS), and water supply and handling treatment (TWTS). Water was tested at the villages' main water sources and at households' POUs, i.e., the household's water storage container, for 10 households per village.

Table 1
Sample design.

Water Treatment Group			
Transport and Storage Treatment	Control	TW	Total
Control	59 (483)	37 (302)	96 (785)
TS	23 (179)	12 (92)	35 (271)
Total Villages (Households)	82 (662)	49 (394)	131 (1056)

Note: TW Water Source Treatment, TS Water Storage and Transport Container Treatment, numbers represent villages, numbers in parenthesis represent households.

The treatment group for the water handling intervention had to meet one criterion concerning the use of improved water sources (pumps, standpipes, and improved wells). We set a threshold requiring that over 40 percent of households must use the improved sources (among the whole sample, 62 percent of the population indicates usage of improved sources at baseline).[7] This choice is based on the assumption that improved household water storage and transport cannot lead to improvements in POU water quality if the population has very low or no access to improved water infrastructure.[8] If households lack basic access then walking distances are very long, so an improved source might not be chosen and if it is, water has a higher chance of being contaminated during transport from the source to the household.

The intervention budget allowed 35 randomly selected villages to receive the water handling treatment. Of these 35 villages, 12 belong to the water supply treatment arm, i.e., receiving a new water source and additional water transport and storage containers (TWTS). The remaining 23 villages are part of the water supply control arm, but more than 40 percent of the population already use improved sources at baseline and these households receive *only* additional water storage and transport containers as a treatment (TS).

To analyze the different effects of i) the water source intervention, ii) the water handling intervention, and iii) the combination of both, we rely on a panel of 131 villages and 1056 households where water has been tested for *E. coli*.[9]

The identification strategy outlined suggests that a DD estimation is appropriate to quantify the effect of the different treatments. We will back up our results with two robustness checks estimating a first differences (FD) model and conduct an analysis of variance (ANOVA). We estimate the impact of the interventions in a linear probability model using the following equation:

$$Y_{ijt} = \alpha + \beta_1 * Time_t + \beta_2 * TW_j + \beta_3 * TS_j + \beta_4 TW_j * TS_j + \beta_5 Time_t * TW_j + \beta_6 Time_t * TS_j + \beta_7 Time_t * TW_j * TS_j + \gamma_1 X_{it} + \gamma_2 V_{jt} + \varepsilon_{ijt} \quad (1)$$

where Y_{ijt} represents the outcomes of interest, namely water quality, several variables for water use and handling; $Time_t$ is a year indicator that equals one if the observation is from the 2010 (follow-up) survey; and TW_j is a treatment indicator that equals 1 if an observation is from the 49 villages where an improved water source has been installed during the study period. The water handling intervention is captured by the term TS_j, which equals 1 if village j belongs to the group of 35 villages where the water handling intervention (distribution of improved water transport and storage containers) was done. The water source treatment effect is given by β_5, the water handling impact estimate by

[6] See Appendix A1a for a picture of a traditional clay pot for storage and metal bowl for transport of water. Appendices A1b and A1c provide pictures of the items provided by the intervention (see Günther and Schipper [2013] for more details).

[7] Of the 131 villages, 88 met the criterion that at least 40 percent of the population used an improved water source at baseline. In the robustness checks we further analyze differences between treatment groups in the subsample of the 88 villages meeting the selection criterion for the water handling intervention.

[8] The WHO/UNICEF (2017) classify basic water access as having access to an improved source with a water collection roundtrip time no longer than 30 min. In the sample of 2009, the average roundtrip time for collecting a container of approximately 40 L from an improved source was 26 min (see Gross et al., [2018] for a detailed analysis of the time taken to collect water).

[9] Throughout the analysis we use a balanced household sample. We lose approximately 10 percent of observations (randomly distributed across villages) per round because the *E. coli* water testing in households is missing. Water testing was done separately from the survey team due to logistical requirements. The water testing team arrived 1 or 2 days after the survey team and spent little time in the villages. The water testing team experienced some difficulty finding household members who could provide them with information on the household water storage facilities. In our judgement, imputing this variable makes little sense and, therefore, we exclude all households with missing information for the POU *E. coli* variable. Table A2 in the Appendix shows the mean values for the sample of this study and the sample omitted due to missing information.

β_6, and the combined impact of the water supply and handling interventions by the coefficient β_7. As the selection of villages for the water handling treatment was based on the baseline use of improved sources, we control for baseline water access in all our estimates of the DD equation. X_{it} contains time-dependent household characteristics and V_{jt} contains village characteristics as control variables. Standard errors are adjusted for clustering at the village level.

The advantage of the DD method and its full set of parameter estimates is that more detailed information is shown with regard to the effects of the time dimension, the experimental groups, and their interactions because measurement occurs within the same units. DD also allows us to be more specific when testing the effects of different groups and different treatments effects and including the time dimension, as our dependent variables are all binary. As a robustness check, we initially conduct a FD analysis because we only have two time periods, measuring the impact of the treatment on changes in the outcomes. Second, we do an ANOVA using only the follow-up variables for the analysis but including the lag of the dependent variable. FD is for two time periods numerically the same as the DD estimator, but is more efficient in case of autocorrelation because the differenced errors are homoscedastic and serially uncorrelated (Wooldridge, 2015). McKenzie (2012) suggests that an advantage of ANOVA is that its statistical power is higher and post-treatment information is adequate if autocorrelation is low. If autocorrelation is low, the baseline data are independent from the follow-up data and thus have little predictive power over the effect of the treatment. A third robustness check will elaborate on the impact of the interventions in four different subsamples: villages with above 40 percent coverage with improved sources at baseline, villages with below 40 percent coverage, villages with above 40 percent coverage but excluding the TS group, and finally the TS sample alone.

3. Data

Our panel analysis is based on two household- and village-level surveys conducted in 131 villages in rural Benin in the dry seasons of February 2009 and February 2010. A survey-independent team of biologists tested the water for *E. coli* by visiting households and water sources within a few days after the household interviews took place and using a semi-quantitative test (Merck Envirocheck® Contact C Total Coliforms/*E. coli*). *E. coli* is a bacterium commonly found in the human gut; any presence of the bacteria in water indicates (recent) contamination with human or animal feces. It is a widely used, robust indicator associated with diarrhea incidence (Gruber et al., 2014; Luby et al., 2015). If the water is polluted, a very high number of germs can usually be found after a short period because the bacteria grow exponentially with a doubling time of approximately 20 min under optimal conditions at 37° Celsius. The WHO defines a zero-tolerance strategy for *E. coli* in drinking water. Therefore, a water sample containing any *E. coli* is considered contaminated (WHO, 2008) in our study, represented by a binary outcome variable equal to 1 if water is contaminated with any level of *E. coli*.

Table 2 shows the 2009 baseline household and village characteristics prior to any intervention taking place. The numbers of observations of villages and households are reported in the last column. We test whether each treatment group differs from the control group based on a regression using the baseline data, including only the treatment group variables and their interaction (see Appendix Table A3). Differences in basic household and village characteristics between the treatment groups and the control group are not especially pronounced regarding the households' water handling related and general household characteristics, such as the household head's education and age and household size. At the village level, there are few significant differences between groups. Most differences occur between the control group and the TS group as the latter experiences, by design, an intervention in the water program in the next year, but already has improved water sources in the village at baseline. TS villages are somewhat larger and better endowed with infrastructure such as schools and roads. Moreover, the level of *E. coli* contamination of a village's main water sources is lower as more households already use improved sources at baseline. Despite greater usage of improved sources in the TS group, more than one third of the households' POU drinking water is contaminated and there are no significant differences between all groups regarding contamination with *E. coli*.

4. Empirical results

The installation of an improved public water point in a village should have a direct positive effect on the availability of clean water and increase usage. Indirect effects on households may include changes in water use, consumption, and water handling practices. The water quality at the source *and* water handling behavior will determine the effect on POU water quality.

Table 3 presents our estimates of the DD impact equation for the main studied outcomes: i) Water quality measured by *E. coli* at the water source and at households' POUs; ii) POU water quality with the additional control of contamination level at the main water source; and iii) subjective water quality of the households' main water source which is a self-reported measure.

To appreciate the effect size of the intervention, we show the follow-up mean values of the outcome variables in the treatment group. In all regressions, we control for village characteristics (primary school available, access to paved road, electricity grid available) and household characteristics (asset index proxying wealth,[10] household size, gender, age, and household head's education).

The first set of coefficients represents treatment effects, the interaction between the treatment groups and time. The second set of coefficients shows the time-independent treatment group dummy variables and the time dummy variable. Subsequently, we present the coefficients estimated for of the household and village control variables.

Analyzing the three possible treatment combinations, TW, TS, and TWTS, shows interesting results regarding how the village level intervention and the household intervention influence key factors of the water handling process. While there is a decrease in *E. coli* at the source level in villages with a new water source (column 1) by 31.2 percentage points, there is no change in contamination levels for the other groups. By study design, 40 percent of the population of TS and TWTS villages already had access to improved water sources at baseline. TWTS villages received an additional new water source, while TS villages had no change in their sources, but will have one year later. Therefore, both groups already begin from a lower level of *E. coli* contamination at their main water sources. Accordingly, the insignificant treatment effects on *E. coli* presence for the TS group in column 1 could be expected. It appears that old improved water sources of the TS group provide clean water as measured by *E. coli* contamination at the source level as contamination levels of main water sources are low on average already at baseline. Nonetheless, on average, 8 percent of main water sources in TS villages remain contaminated between baseline and follow-up.

Looking next on the results of households' POUs *E. coli* contamination shows, that the positive effect of water source quality improvements does not transfer into gains in water quality for households in the TW treatment group (column 2). There is no significant effect of the water source improvement on the POU water quality. For the TS group, however, *E. coli* contamination at the household level is reduced

[10] The asset index is constructed from 20 binary variables on improved housing (roof, wall, floor, electricity connection, sanitation) and asset ownership (furniture [bed, armchair, chair, table], jewellery, livestock [chicken, pigs, goat/sheep], productive tools [sewing machine, mill, construction tools], TV, radio, bicycle, motorbike, and cell phones) using a principal component analysis as recommended by Filmer and Pritchett (2001). The index is standardized to a range from zero to one.

Table 2
Descriptive statistics baseline.

	Control		TW		TS		TWTS		Observations
Household Level									
POU *E. coli* contaminated	0.393	(0.028)	0.325	(0.035)	0.369	(0.040)	0.337	(0.072)	1056
Subjective water quality (good = 1)	0.708	(0.039)	0.713	(0.047)	0.878***	(0.031)	0.859	(0.037)	1056
Household treats drinking water	0.080	(0.018)	0.104	(0.026)	0.048***	(0.017)	0.065	(0.026)	1056
Covered transport container	0.193	(0.030)	0.124	(0.025)	0.196	(0.048)	0.098	(0.031)	1056
Covered storage container	0.492	(0.036)	0.604***	(0.042)	0.635***	(0.051)	0.587***	(0.052)	1056
Main drinking water source improved	0.660	(0.049)	0.645	(0.060)	0.956***	(0.017)	0.935	(0.026)	1056
Wealth index	0.341	(0.016)	0.398***	(0.017)	0.393	(0.024)	0.414	(0.019)	1055
Household size	5.699	(0.187)	6.127	(0.247)	5.952	(0.286)	6.913	(0.408)	1056
Female headed household	0.184	(0.019)	0.185	(0.025)	0.210	(0.024)	0.217	(0.043)	1056
Head with primary education	45.185	(0.717)	45.411	(1.054)	45.524	(1.139)	47.543	(1.920)	1056
Age of household head	0.329	(0.022)	0.320	(0.028)	0.351	(0.028)	0.348	(0.050)	1056
Child <5 years diarrhea during the last 4 weeks	0.125	(0.016)	0.150	(0.021)	0.144	(0.024)	0.130	(0.042)	1056
Village level									
Water source *E. coli* contaminated	0.305	(0.051)	0.327	(0.067)	0.086***	(0.048)	0.083	(0.080)	131
Number households per village	92.707	(10.095)	113.918***	(13.922)	112.486***	(14.535)	87.000***	(16.652)	131
Village has primary school	0.817	(0.043)	0.755	(0.062)	0.971***	(0.028)	1.000	(0.000)	131
Access to paved road	0.171	(0.042)	0.143	(0.050)	0.229***	(0.071)	0.083	(0.080)	131
Electricity (grid, solar) available	0.171	(0.042)	0.245	(0.062)	0.286	(0.077)	0.417	(0.143)	131
% of households using improved sources	0.645	(0.048)	0.635	(0.060)	0.931***	(0.023)	0.925	(0.034)	131

Note: Robust standard errors adjusted for clustering. POU point of use, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment. The significance levels stem from a regression using the baseline data including only the treatment group dummies and their interaction. The asset index is constructed from 20 binary variables on improved housing (roof, wall, floor, electricity connection, sanitation) and asset ownership (furniture [bed, armchair, chair, table], jewelry, livestock [chicken, pigs, goat/sheep], productive tools [sewing machine, mill, construction tools], TV, radio, bicycle, motorbike, and cell phones) using a principal component analysis as recommended by Fewtrell et al. (2005). The index is standardized to a range from zero to one.

significantly (column 2) by 18.6 percentage points. The TS households were instructed to use improved water sources when using the improved storage and transport containers. The results indicate that if the entire water handling procedure is improved, water quality in households improves as well. Improving only the water sources' quality does not change water quality in households.

To investigate this statement a bit further and having in mind that still some main sources are contaminated, we additionally control for water source contamination in the household level regression (column 3). Adding source contamination reveals that POU water quality worsens in the TW group if the main source is also contaminated. Households rightly assume that new water sources provide clean water, and most of the sources do, but in case contamination at source is present this will cause worse POU quality as well. For the TWTS group we see a high decrease when looking at the averages of 2010 at the bottom of Table 3. However, the sample is too small to detect a significant effect.

In line with the positive findings on water quality improvements at the water source, new sources have a positive impact on the self-reported, perceived water quality of the main water sources of households (column 4). The study did not induce changes for the TS group in water supply and, consistent with this, this group does not perceive improvements in water quality at the source. The TWTS group had access to improved sources at baseline and adding additional improved sources does not change their perception of water quality: both old and new sources are perceived to provide clean water.

The included control variables show no overall significance pattern and are, if significant, quite small in size. The control for the village baseline mean level of use of improved water sources controls for the sample design and also has the expected sign, though not always significant.

These results raise the question of why there are no changes in POU *E. coli* contamination or even worsening water quality despite objective and subjective quality improvements at the source for the TW group. First, if water sources are contaminated this transfers into the households' POU water if water does not get treated in households. Second, water might be contaminated between the source and the households' POUs, which would support the conclusions by former studies (Jalan and Ravallion, 2003; Kremer et al., 2011; Wright et al., 2004). In this case, improvements to water sources would not cause a significant improvement in household POU water quality. Third, not all households use the newly installed water source as the households' main source (Ahuja et al., 2010).

One reason why we do not find an improvement in the POU water quality following the water infrastructure intervention might be that the new infrastructure affects the propensity of households to apply appropriate water handling practices after fetching the water. To the best of our knowledge, this aspect of household water handling behavior in relation to improved water source installation has not yet been addressed in the literature. Therefore, we designed the water transport and storage intervention and deconstruct the water handling process to explore household behavior in more detail and explain why public water supply programs might not be successful to improve POU water quality.

Table 4 presents the indicators of household water handling behaviors, namely disinfecting water, water transport and storage, and choice of drinking water sources.

In general, household POU water treatment is not widespread in Benin. The Demographic and Health Survey 2006, a nationally representative data set, reports that only 7 percent of households in rural Benin use any method of water treatment, such as boiling, filtering, or chlorine water treatment. The share of households applying any of these POU water treatment methods in our sample is similarly low and at baseline lowest in the TS and TWTS groups that already use improved sources (see Table 2). At the time of the baseline survey, 9 percent of all households practiced any water treatment. Most of these households relied on traditional wells, rain, or surface water (i.e., unimproved water sources) as their main drinking water source instead of improved sources. This cross-sectional comparison before the interventions took place indicates that some households are aware of the risk of obtaining contaminated water from unimproved sources but when using improved sources households practice less water disinfection.

The first column of Table 4 shows that the installation of an improved public water point leads to a significant drop in purifying water before consumption of 11.3 percentage points in the TW group. The share of households practicing any POU water treatment (including boiling, filtering, and chlorine or solar disinfection) was low before the intervention but is significantly lower afterward. The high value of the DD coefficient is also of interest. While water treatment activities in the TW group drop from 10.4 percent at baseline to zero at follow-up, the

Table 3
DD main outcomes water quality.

	(1)	(2)	(3)	(4)
	Source E.coli contaminated	HH storage E.coli contaminated	HH storage E.coli contaminated	Subjective water quality
Group TW # Year 2010	−0.312**	0.077	0.110*	0.178***
	(0.128)	(0.063)	(0.062)	(0.063)
Group TS # Year 2010	0.035	−0.186***	−0.187***	0.021
	(0.121)	(0.066)	(0.067)	(0.054)
Group TW # Group TS # Year 2010	0.307	−0.032	−0.065	−0.129
	(0.197)	(0.115)	(0.118)	(0.093)
Group TW	0.023	−0.074	−0.077	0.010
	(0.096)	(0.052)	(0.049)	(0.056)
Group TS	−0.149*	0.005	0.021	0.075
	(0.086)	(0.061)	(0.060)	(0.054)
Group TW# Group TS	−0.055	0.011	0.018	−0.059
	(0.145)	(0.103)	(0.103)	(0.085)
Year 2010	−0.033	−0.104**	−0.101**	0.008
	(0.082)	(0.041)	(0.041)	(0.039)
Wealth index		0.007	0.013	0.289***
		(0.066)	(0.065)	(0.057)
HH size		0.004	0.004	−0.005
		(0.003)	(0.003)	(0.004)
Head female		−0.051*	−0.041	0.044
		(0.029)	(0.028)	(0.030)
Age of HH Head		−0.001	−0.001	0.001
		(0.001)	(0.001)	(0.001)
Education Head		−0.009	−0.006	−0.022
		(0.025)	(0.025)	(0.023)
School	−0.041	0.017	0.020	0.114**
	(0.076)	(0.041)	(0.042)	(0.055)
Access paved road	−0.159***	−0.018	0.000	−0.030
	(0.061)	(0.031)	(0.030)	(0.052)
Electricity	−0.035	0.021	0.021	0.042
	(0.075)	(0.034)	(0.032)	(0.041)
Baseline coverage improved sources	−0.284***	−0.033	−0.004	0.330***
	(0.068)	(0.038)	(0.036)	(0.057)
Source E.coli contaminated			0.109***	
			(0.034)	
Constant	0.597***	0.416***	0.346***	0.284***
	(0.091)	(0.060)	(0.062)	(0.072)
Observations	262	2112	2112	2112
R2	0.224	0.045	0.053	0.233
Clusters	131	131	131	131
TW 2010 mean	0.0612	0.246	0.246	0.898
TS 2010 mean	0.0857	0.0923	0.0923	0.934
TWTS 2010 mean	0.0833	0.0870	0.0870	0.935
Control 2010 mean	0.356	0.290	0.290	0.667

Note: Robust standard errors adjusted for clustering. HH Household, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; Regression 1 is on the village level, regression 2, 3, and 4 on the household level.

control group increases POU treatment activities by almost 4 percent. The absolute drop in POU treatment activities in the TW group indicates that households consider water quality from new water points safe enough to not require disinfecting at the household level. This behavior is rational in the sense that water can be expected clean at new sources and disinfecting water at the POU level is expensive with respect to time (collecting firewood for boiling water) or money (expenditure on chlorine).[11] After a new source is installed, the average purchasing price of water at the improved source in treatment villages is 10 FCFA per container – 2.5 times the price of water from traditional sources (4 FCFA). Households may assume that the price increase indicates the provision of good quality water and, therefore, substitute POU treatment activities for using the new source. This is a misconception, however, as taking water from the new source should be complemented with POU

[11] In our sample, the two methods most commonly used for water treatment are boiling and adding chlorine. As boiling water often does not result in direct financial costs but rather time costs of collecting firewood and cooking water, it is difficult to measure the costs of treatment in monetary terms. We estimate the cost of chlorine for one commonly used 40-L container to be between 6 and 9 FCFA ($0.01 USD to $0.015 USD) with liquid chlorine and up to 30 FCFA for chlorine tablets: a 1-L bottle of liquid chlorine costs between 1000 and 1500 FCFA ($1.70 USD to $2.55 USD) and a pack of 10 chlorine tablets costs approximately 125 FCFA ($0.21 USD) in local shops in Benin (one single tablet costs 15 FCFA). One chlorine tablet or 3 ml of liquid chlorine are necessary for 20 L of water. This is a non-subsidized product and therefore carries a much higher cost than in other studies (e.g., Dupas et al., 2016). Hence, cleaning one 40-L container of water costs approximately 6–9 FCFA with chlorine and up to 30 FCFA with chlorine tablets.

Table 4
DD outcomes on water handling.

	(1)	(2)	(3)	(4)	(5)
	HH treats water before use	Covered transport	Covered POU	Main source improved	HH uses only improved sources
Group TW # Year 2010	−0.113***	0.058	0.070	0.229***	0.105
	(0.042)	(0.036)	(0.066)	(0.085)	(0.085)
Group TS # Year 2010	−0.028	0.076	0.131*	0.021	−0.015
	(0.038)	(0.062)	(0.068)	(0.043)	(0.066)
Group TW # Group TS # Year 2010	0.047	0.019	0.106	−0.188*	−0.054
	(0.058)	(0.095)	(0.137)	(0.097)	(0.144)
Group TW	0.022	−0.048	0.120**	−0.016	−0.030
	(0.037)	(0.044)	(0.057)	(0.023)	(0.061)
Group TS	−0.000	0.068	0.136*	0.100***	0.237***
	(0.027)	(0.075)	(0.078)	(0.020)	(0.088)
Group TW# Group TS	0.022	−0.049	−0.095	0.026	0.142
	(0.054)	(0.089)	(0.130)	(0.037)	(0.138)
Year 2010	0.020	−0.039	−0.044	−0.020	0.053
	(0.027)	(0.028)	(0.036)	(0.038)	(0.036)
Wealth index	0.029	−0.098	0.196***	0.043	−0.053
	(0.033)	(0.076)	(0.069)	(0.041)	(0.082)
HH size	−0.004**	−0.013***	−0.007*	0.002	−0.006
	(0.002)	(0.003)	(0.004)	(0.003)	(0.004)
Head female	−0.017	−0.068***	−0.057*	−0.024	0.027
	(0.016)	(0.023)	(0.031)	(0.024)	(0.026)
Age of HH head	−0.000	−0.000	−0.001	0.000	−0.001
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)
Education head	0.027	0.001	−0.007	−0.021	−0.089***
	(0.018)	(0.023)	(0.026)	(0.018)	(0.025)
Village size	−0.000	0.000	0.001**	0.000	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
School	−0.074	−0.125***	−0.110*	−0.054	−0.028
	(0.048)	(0.047)	(0.058)	(0.039)	(0.053)
Access paved road	0.044	0.006	0.154**	0.037	0.191***
	(0.058)	(0.041)	(0.065)	(0.038)	(0.068)
Electricity	−0.030	−0.061*	−0.087*	−0.063*	−0.129**
	(0.025)	(0.035)	(0.045)	(0.032)	(0.055)
Baseline coverage improved sources	−0.110***	0.059	0.121**	0.776***	0.399***
	(0.035)	(0.044)	(0.054)	(0.035)	(0.066)
Constant	0.234***	0.361***	0.410***	0.147***	0.140**
	(0.055)	(0.066)	(0.075)	(0.042)	(0.058)
Observations	2112	2112	2112	2112	2112
R2	0.088	0.059	0.115	0.577	0.302
Clusters	131	131	131	131	131
TW 2010 mean	0.0102	0.162	0.546	0.810	0.495
TS 2010 mean	0.0185	0.266	0.742	0.970	0.749
TWTS 2010 mean	0.00	0.239	0.728	0.978	0.783
Control 2010 mean	0.116	0.137	0.398	0.528	0.306

Note: Robust standard errors adjusted for clustering, HH Household, POU point of use, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; Regression on the household level.

treatment to maintain good water quality from the source to the POU.

This adverse effect of water source treatment on hygienic water handling is further supported by examining the water handling variables covering transport and storage containers in columns 2 and 3 of Table 4. The estimated effect of a new public water source on the share of households covering water during transport and storage containers is only significant for the latter variable in the TS group. This might render the additional storage containers ineffective if the collected water becomes contaminated during transport. In general, covering water transport containers is not widespread. However, the use of improved storage containers might already be sufficient to improve water quality in the TS group (see Table 3, columns 2 and 3). Both containers do not experience a 100 percent uptake, but the covered transport containers are at least used by 75 percent of the TS and TWTS groups.

The last two columns of Table 4 report the households' choice of improved water source to partially or exclusively satisfy their demand for drinking water and other household purposes. This is a prerequisite to achieving the provision of clean water at POUs in households. Gross and Elshiewy (2019) analyze determinants of water point choice in a more sophisticated choice model and show that price and distance to the source, as well as subjective water quality, are important determinants of choosing a water source; in addition, wealthier households and female-headed households are more likely to use improved sources.

The question is whether the provision of new water sources and handling containers causes households to choose improved sources which come at a cost over unimproved, low cost sources. Column 4 of Table 4 shows that an (additional) improved water source results in a significant 22.9 percentage point increase in the share of households using an improved water point as their main source of drinking water in the TW group. Hence, even after an improved water point is installed, approximately 20 percent of households prefer to continue using an unimproved water source as their main drinking water source. In the follow-up survey, households frequently state the following reasons for not using the new water source: it is not working properly (32 percent); it is too far away (28 percent); it is too expensive (25 percent); there is another water source available (20 percent); and the quality of water at the new source is not good (5 percent).[12] Furthermore, the provision of improved water sources does not cause the exclusive use of improved sources (see Table 4, column 5).

These results provide evidence as to why the safe water quality of the

[12] Numbers exceed 100 percent because multiple answers were possible to that question.

new source does not lead to improved water quality at the household level: households do not maintain their previous POU water treatment activities or implement further treatment activities, nor do they protect water from contamination during transport and storage if necessary equipment is not provided. Moreover, almost 50 percent of households still rely on (additional) water sources that are not improved and might not be free from *E. coli*. To ensure that clean stays clean until household consumption points, it needs to be accompanied by additional interventions at the household level; for example, the distribution of improved transport and storage containers but also promotion campaigns to encourage households to abandon unimproved sources, at least for drinking water.

In the following section we conduct three robustness checks: an FD analysis (Table A4) and an ANOVA (Table A5), and analysis of different subsamples (Table A6 and A7).

4.1. Robustness checks – alternative estimation methods

The FD analysis measures the impact on changes in outcomes, the ANOVA is an OLS regression using follow-up values including the lag of the dependent variable. Both approaches are assumed to be more efficient than DD if errors are serially uncorrelated across time (McKenzie, 2012; Wooldridge, 2015). As there are several outcomes of the analysis, autocorrelation varies across the different variables but is not a huge problem.[13] The DD results can be considered the most conservative estimate in that case because we have two measures of the same unit.

The FD results are extremely similar to the DD results (see Table A4). The coefficients of the FD regression are slightly larger, but the standard errors are similar when comparing the two estimation approaches. Furthermore, ANOVA presents a similar picture (see Table A5). However, in the variables with some autocorrelation, such as subjective water quality, covered transport and storage containers, and household uses only improved sources, ANOVA might overestimate the effect as more groups show significant effects compared to DD.

4.2. Robustness checks – alternative sample definitions

As there were different selection strategies for the water supply treatment sample and the water handling treatment sample we elaborate on possible confounding effects of the selection strategy. The selection of villages of the water supply treatment was based on the planning lists of the Beninese water service agency and the sample for the water handling treatment was based on the criterion of 40 percent of the population in a village using improved sources at baseline. Table A6 of the appendix shows a comparison of the different treatment arms in the sample eligible for the water handling intervention. Table A7 shows the DD estimates for the water handling eligible sample, the TW effect for the not eligible sample, and the TW effect for the eligible sample excluding the TS group and in a last step, the TW effect for the TS group only. Overall we see that the sample eligible for TS is balanced except for the variable covered transport containers (Table A6). As we do not see a significant effect in any of the estimations for this outcome (except in Table A5 of the ANOVA) we assume that this intervention was not very successful, although we see improvements in the mean levels, but these were not enough to detect a significant effect.

What the sample split, however, shows clearly and thus confirming our DD results: households' POU treatment activities significantly drop to almost zero when villages receive improved water sources at low levels of coverage. In other words, installing improved water sources has a negative effect on hygienic water handling in the first place when households start using improved sources. The last two panels of Table A7 show that water supply treatment programs have little or no impact on water handling practices in environments where access to improved sources existed before the program took place.

5. Discussion and conclusion

This paper analyses the impact of improved water infrastructure on water quality and water handling behavior using objective and subject measures of water quality and detailed information on the water handling process using household and village panel data. We find that the provision of an improved public water supply in a village leads to several desired and expected results: it improves the quality of source water, both as measured by the absence of *E. coli* and as self-reported by users, and it increases the probability that households will use an improved water source. However, despite these positive results, about 6–8 percent of main improved water sources are not free from *E. coli*, and some households continue to use unimproved water sources or a mixture of improved and unimproved sources.

Concerning households' water handling behaviors, we find that households do not invest in maintaining the improved water quality from the new water source by continuing to engage in POU treatment once access to improved sources is given. Post-collection contamination is a threat to the effectiveness of water interventions because of recontamination between the safe source and households' POUs. Water point interventions only work if accompanied by improved water handling practices. Of even greater concern, we find that providing only an improved water supply has an unexpected negative effect as it leads to a decrease in the probability that households will disinfect or purify their drinking water. Improved water sources have an adverse effect on hygienic water handling because households seem to be unaware of contamination channels between the water source and their POUs and belief that all improved sources are free from *E. coli*, although there is an almost 10 percent chance in our sample that improved sources are contaminated. Because of this lack of information and expectations that are not met, water supply interventions cause households to stop engaging in safe water handling behavior. This is an important, yet neglected, side effect of public water provision that deserves further attention, both in research and policy.

Furthermore, we find that public water provision as a stand-alone intervention does not change POU *E. coli* contamination. Our results indicate that improving water handling behaviors by distributing improved technology—in this case, water transport and storage containers—can achieve the desired water quality benefits.

Our study highlights several implications for water sector policies: First, policymakers should not assume that public water provision increases the quality of water consumed by beneficiary households, which has already been noted in previous studies but not been anticipated by water programs as often only infrastructure is installed. Nevertheless, it is important to increase the coverage of improved sources to achieve a higher level of usage among the population. Second, our results suggest that providing clean water sources may have an adverse effect on hygienic water handling decreasing the (already low) propensity of households to engage in water filtration and disinfection practices. As safe water handling results in both monetary and time costs, and water from improved sources is sold at approximately 2.5 times the price of water from traditional sources, substituting improved water handling with perceived clean water from an improved public water source appears to be a rational choice for the local population.

Third, the results suggest that to achieve high water quality, water policies in developing countries must exploit the complementarities between water source improvements and improved water handling. Water point infrastructure in rural communities is an expensive, frequently donor-financed policy infrastructure program typically motivated by the need to improve the health of vulnerable groups,

[13] To detect autocorrelation, we run the DD regression in eq. (1), save the results and regress the follow-up survey residuals of the different outcomes on their lags. If autocorrelation is high, the observations are not independent, so the assumption of independent errors of ANCOVA is not met, and hence the conclusions are not valid.

particularly children. Our results show that as far as consumed water quality is concerned, water point installations as a singular intervention are ineffective and may even have unintended negative impacts on household behavior and water quality. This highlights the need for policymakers to design water programs that systematically safeguard the quality of water for consumers after collecting it from the water source. We show that improving the technology of commonly used household transport and storage containers is a possible solution to maintain the water quality between the source and the POU without adding chemicals, requiring disinfection, or increasing time costs. Water programs could be accompanied, for example, by job programs for craftsmen who build water handling containers out of locally used materials and assist in their maintenance, and she may be able to develop new and user-friendly solutions. Future research on water quality should collect water measures at the different stages of the water handling and consumption process to detect which methods to safeguard or improve water quality are most effective, which infrastructure or devices are more cost effective and durable and which applications are permanently used by the population.

Declaration of competing interest

The authors have no conflict of interest.

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Appendix A

Table A2
Comparison Study Sample and Drop Out Sample due to Missing Values

	Study Sample	SE	Drop out sample	SE	Observations	p-value
Perceived water quality	0.71	(0.014)	0.72	(0.026)	1365	0.69
Diarrhea age <5	0.13	(0.012)	0.13	(0.023)	1365	0.95
HH treats water before use	0.09	(0.009)	0.11	(0.018)	1365	0.37
Covered transport container	0.17	(0.011)	0.18	(0.022)	1365	0.77
Covered drinking water storage	0.53	(0.015)	0.62	(0.028)	1365	0.01
Main drinking water source improved	0.65	(0.015)	0.61	(0.028)	1365	0.17
Exclusive use of improved sources	0.36	(0.015)	0.37	(0.028)	1365	0.79
Containers per day/HH	2.08	(0.115)	2.03	(0.205)	1365	0.82
Wealth index	0.36	(0.006)	0.38	(0.012)	1362	0.34
HH size (individuals)	5.86	(0.109)	5.23	(0.197)	1365	0.01
Head female	0.19	(0.012)	0.16	(0.021)	1365	0.34
Age of HH head	45.27	(0.502)	42.87	(0.969)	1365	0.03
Head with primary education	0.33	(0.014)	0.31	(0.026)	1365	0.69

Note: Robust standard errors adjusted for clustering. HH Household, SE Standard Error. The last column shows whether the difference in means between the sample used in the study and the households that dropped out of the analysis due to missing values is significant.

Table A3
Baseline Regression for Significance Levels in Table 2

	TW		TS		TWTS		Constant		Observations
Source E.coli contaminated	0.016	(0.104)	−0.303***	(0.088)	−0.019	(0.145)	0.390***	(0.064)	131
Village size (No. of HH)	42.835**	(20.969)	45.969**	(23.037)	−81.618**	(33.525)	79.814***	(11.414)	131
Primary School	−0.087	(0.096)	0.194***	(0.071)	0.131	(0.106)	0.763***	(0.056)	131
Access paved road	0.044	(0.075)	0.186*	(0.106)	−0.265*	(0.147)	0.119***	(0.043)	131
Electricity	0.037	(0.081)	0.065	(0.099)	0.163	(0.187)	0.153***	(0.048)	131
Baseline access improved sources	0.008	(0.095)	0.403***	(0.068)	−0.018	(0.106)	0.532***	(0.061)	131
POU E.coli contaminated	−0.074	(0.052)	−0.010	(0.060)	0.026	(0.101)	0.395***	(0.034)	1056
Subjective water quality	0.027	(0.076)	0.246***	(0.063)	−0.057	(0.098)	0.642***	(0.049)	1056
Diarrhea age<5	0.040	(0.031)	0.035	(0.035)	−0.060	(0.059)	0.116***	(0.019)	1056
HH treats water before use	0.021	(0.040)	−0.056*	(0.031)	0.005	(0.053)	0.095***	(0.023)	1056
Covered transport container	−0.041	(0.045)	0.072	(0.075)	−0.107	(0.089)	0.174***	(0.032)	1056
Covered drinking water storage	0.179***	(0.063)	0.229***	(0.074)	−0.251**	(0.124)	0.431***	(0.041)	1056
Main drinking water source improved	0.010	(0.095)	0.420***	(0.063)	−0.041	(0.103)	0.547***	(0.061)	1056
Exclusive use of improved sources	0.007	(0.080)	0.444***	(0.086)	−0.014	(0.141)	0.248***	(0.049)	1056
Containers per day/HH	−0.013	(0.464)	2.393***	(0.615)	1.140	(1.220)	1.371***	(0.304)	1056
Wealth index	0.067**	(0.027)	0.057	(0.037)	−0.035	(0.053)	0.326***	(0.019)	1055
HH size (individuals)	0.099	(0.355)	−0.331	(0.363)	1.356*	(0.698)	5.789***	(0.233)	1056
Head female	−0.000	(0.038)	0.031	(0.036)	0.011	(0.065)	0.176***	(0.023)	1056
Age of HH head	−0.682	(1.429)	−0.957	(1.359)	3.739	(3.097)	45.443***	(0.907)	1056
Education of HH head	−0.010	(0.044)	0.031	(0.048)	0.006	(0.063)	0.321***	(0.026)	1056

Note: Robust standard errors adjusted for clustering. HH Household, POU point-of-use TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment. The significance levels stem from a regression using the baseline data including only the treatment group dummies and their interaction. The asset index is constructed from 20 binary variables on improved housing (roof, wall, floor, electricity connection, sanitation); asset ownership (furniture [bed, armchair, chair, table]; jewelry; livestock (chicken, pigs, goat/sheep); productive tools (sewing machine, mill, construction tools); TV; radio; bicycle; motorbike; and cell phones using a principal component analysis as recommended by Fewtrell et al. (2005). The index is standardized to a range from zero to one.

Table A4
First Differences Regression

	(1) Source E. coli contaminated	(2) HH storage E. coli contaminated	(3) HH storage E. coli contaminated	(4) Subjective water quality	(5) HH treats water before use	(6) Covered transport	(7) Covered POU	(8) Main source improved	(9) HH uses only improved sources
Group TW	−0.317**	0.070	0.107	0.191***	−0.121***	0.050	−0.083	0.227***	0.108
	(0.126)	(0.065)	(0.066)	(0.064)	(0.041)	(0.033)	(0.064)	(0.086)	(0.086)
Group TS	0.034	−0.187***	−0.184***	0.024	−0.029	0.077	0.131*	0.020	−0.013
	(0.120)	(0.066)	(0.066)	(0.054)	(0.039)	(0.061)	(0.068)	(0.043)	(0.066)
Group TWTS	0.317	−0.020	−0.059	−0.155*	0.052	0.048	0.137	−0.177*	−0.052
	(0.195)	(0.114)	(0.116)	(0.094)	(0.055)	(0.094)	(0.135)	(0.101)	(0.143)
Wealth index		0.040	0.042	0.265***	0.063	0.076	0.291**	0.151	−0.044
		(0.114)	(0.116)	(0.092)	(0.060)	(0.093)	(0.122)	(0.092)	(0.103)
HH size		0.006	0.005	−0.006	−0.009**	−0.007	−0.009	0.006	−0.007
		(0.008)	(0.008)	(0.006)	(0.004)	(0.007)	(0.009)	(0.007)	(0.007)
Head female		0.013	0.016	−0.013	−0.006	0.058	0.032	−0.092	0.049
		(0.081)	(0.081)	(0.051)	(0.045)	(0.052)	(0.078)	(0.068)	(0.044)
Age of HH head		−0.000	−0.000	0.000	0.000	−0.003	−0.002	0.002	0.000
		(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Education of HH head		0.038	0.051	0.015	−0.001	−0.011	0.016	0.006	0.030
		(0.049)	(0.048)	(0.038)	(0.022)	(0.036)	(0.044)	(0.029)	(0.029)
School		0.047	0.040	0.023	−0.055	−0.023	0.030	−0.037	−0.007
		(0.068)	(0.068)	(0.049)	(0.044)	(0.035)	(0.055)	(0.087)	(0.062)
Access paved road		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Electricity		0.112	0.120	−0.011	0.043	0.054	−0.036	−0.105	−0.214**
		(0.119)	(0.119)	(0.041)	(0.027)	(0.042)	(0.072)	(0.129)	(0.095)
Source E.coli contaminated			0.096**						
			(0.040)						
Constant	−0.034	−0.102**	−0.102**	0.011	0.015	−0.041	−0.049	−0.024	0.053
	(0.081)	(0.041)	(0.041)	(0.038)	(0.026)	(0.027)	(0.037)	(0.036)	(0.036)
Observations	131	1056	1056	1056	1056	1056	1056	1056	1056
R2	0.067	0.026	0.034	0.038	0.036	0.021	0.027	0.058	0.026

Note: Robust standard errors adjusted for clustering. HH Household, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; Regression 1 is on the village level, regression 2–9 on the household level.

Table A5
ANCOVA/OLS Regression follow up survey using lag dependent variables

	(1) Source E. coli contaminated	(2) HH storage E. coli contaminated	(3) HH storage E. coli contaminated	(4) Subjective water quality	(5) HH treats water before use	(6) Covered transport	(7) Covered POU	(8) Main source improved	(9) HH uses only improved sources
Group TW	−0.289***	0.005	0.024	0.201***	−0.102***	0.020	0.056	0.226***	0.108***
	(0.078)	(0.031)	(0.033)	(0.027)	(0.017)	(0.027)	(0.035)	(0.026)	(0.030)
Group TS	−0.178*	−0.190***	−0.176***	0.131***	−0.023	0.128***	0.242***	0.216***	0.173***
	(0.099)	(0.040)	(0.040)	(0.034)	(0.021)	(0.034)	(0.044)	(0.034)	(0.039)
Group TWTS	0.292*	−0.051	−0.070	−0.182***	0.075**	−0.025	0.000	−0.170***	0.049
	(0.158)	(0.064)	(0.064)	(0.054)	(0.034)	(0.055)	(0.071)	(0.054)	(0.062)
Wealth index		−0.024	−0.012	0.177***	0.038	0.040	0.217***	0.018	−0.039
		(0.072)	(0.072)	(0.062)	(0.038)	(0.062)	(0.080)	(0.061)	(0.070)
HH size		0.004	0.003	−0.003	−0.002	−0.008**	−0.007	0.007*	−0.000
		(0.005)	(0.005)	(0.004)	(0.002)	(0.004)	(0.005)	(0.004)	(0.004)
Head female		−0.014	−0.011	0.014	−0.002	−0.020	−0.034	−0.037	−0.022
		(0.037)	(0.037)	(0.031)	(0.020)	(0.032)	(0.041)	(0.031)	(0.036)
Age HH of head		0.000	0.000	0.001	0.000	−0.000	−0.001	0.000	−0.003***
		(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Education of HH head		0.036	0.035	0.006	−0.015	−0.003	0.028	−0.042	−0.078**
		(0.031)	(0.031)	(0.027)	(0.017)	(0.027)	(0.035)	(0.026)	(0.030)
School	0.067	0.080**	0.075*	0.052	−0.144***	−0.097***	−0.036	−0.101***	0.024
	(0.098)	(0.039)	(0.039)	(0.034)	(0.021)	(0.034)	(0.044)	(0.033)	(0.038)
Access paved road	−0.078	−0.107***	−0.102**	−0.002	0.051**	−0.062*	0.194***	0.073**	0.188***
	(0.105)	(0.040)	(0.040)	(0.034)	(0.021)	(0.034)	(0.045)	(0.034)	(0.039)
Electricity	−0.100	0.071*	0.076**	−0.024	−0.020	−0.061*	−0.084**	−0.101***	−0.189***
	(0.095)	(0.038)	(0.038)	(0.032)	(0.020)	(0.032)	(0.042)	(0.032)	(0.037)
Baseline coverage improved sources	−0.212**	−0.015	−0.001	0.180***	−0.091***	0.065**	0.133***	0.462***	0.117***
	(0.091)	(0.035)	(0.035)	(0.032)	(0.019)	(0.030)	(0.039)	(0.060)	(0.037)
Lag dependent variable	−0.010	0.026	0.026	0.174***	0.126***	0.237***	0.114***	0.110**	0.412***
	(0.082)	(0.027)	(0.027)	(0.028)	(0.025)	(0.030)	(0.030)	(0.053)	(0.033)
Source *E.coli* contaminated			0.072**						
			(0.036)						

(*continued on next page*)

Table A5 (*continued*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Source E. coli contaminated	HH storage E. coli contaminated	HH storage E. coli contaminated	Subjective water quality	HH treats water before use	Covered transport	Covered POU	Main source improved	HH uses only improved sources
Constant	0.442***	0.198***	0.169***	0.322***	0.265***	0.204***	0.276***	0.263***	0.285***
	(0.111)	(0.059)	(0.061)	(0.050)	(0.031)	(0.051)	(0.066)	(0.049)	(0.056)
Observations	131	1056	1056	1056	1056	1056	1056	1056	1056
R2	0.196	0.056	0.060	0.219	0.159	0.109	0.140	0.402	0.342

Note: Robust standard errors adjusted for clustering. HH Household, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment. Dependent variable and control variables are from follow-up. Lag dependent variable is from baseline.

Table A6
Descriptive Statistics Baseline of sample >40 percent coverage with improved sources

	Control		TW		TS		TWTS		Observations
Household Level									
POU *E. coli* contaminated	0.376	(0.033)	0.311	(0.042)	0.369	(0.040)	0.337	(0.072)	712
Subjective water quality (good = 1)	0.853	(0.033)	0.859	(0.031)	0.878	(0.031)	0.859	(0.037)	712
Household treats drinking water	0.048	(0.012)	0.067	(0.017)	0.048	(0.017)	0.065	(0.026)	712
Covered transport container	0.210	(0.041)	0.115***	(0.026)	0.196**	(0.048)	0.098***	(0.031)	712
Covered storage container	0.550	(0.045)	0.648	(0.048)	0.635	(0.051)	0.587	(0.052)	712
Main drinking water source improved	0.957	(0.016)	0.907	(0.029)	0.956	(0.017)	0.935	(0.026)	712
Wealth index	0.374	(0.020)	0.442	(0.017)	0.393	(0.024)	0.414	(0.019)	712
Household size	5.830	(0.219)	6.226	(0.277)	5.952	(0.287)	6.913	(0.408)	712
Female headed household	0.190	(0.020)	0.196	(0.028)	0.210	(0.024)	0.217	(0.043)	712
Head with primary education	46.061	(0.842)	47.056	(1.206)	45.524	(1.141)	47.543	(1.920)	712
Age of household head	0.344	(0.026)	0.374	(0.031)	0.351*	(0.028)	0.348	(0.050)	712
Child <5 years diarrhea during the last 4 weeks	0.326	(0.041)	0.456	(0.084)	0.421	(0.077)	0.543	(0.126)	712
Village level									
Water source *E. coli* contaminated	0.182	(0.052)	0.182	(0.068)	0.086	(0.048)	0.083	(0.080)	88
Number households per village	111.745	(13.438)	136.394	(17.759)	112.486	(14.563)	87.000	(16.684)	88
Village has primary school	0.891	(0.042)	0.879**	(0.057)	0.971	(0.028)	1.000	(0.000)	88
Access to paved road	0.200	(0.054)	0.212	(0.072)	0.229	(0.071)	0.083	(0.080)	88
Electricity (grid, solar) available	0.182	(0.052)	0.333	(0.083)	0.286	(0.077)	0.417	(0.143)	88
% of households using improved sources	0.936	(0.020)	0.909	(0.027)	0.931	(0.023)	0.925	(0.034)	88

Note: Robust standard errors adjusted for clustering. POU point of use, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment. The significance levels stem from a regression using the baseline data including only the treatment group dummies and their interaction for the subsample. The asset index is constructed from 20 binary variables on improved housing (roof, wall, floor, electricity connection, sanitation) and asset ownership (furniture [bed, armchair, chair, table], jewelry, livestock [chicken, pigs, goat/sheep], productive tools [sewing machine, mill, construction tools], TV, radio, bicycle, motorbike, and cell phones) using a principal component analysis as recommended by Fewtrell et al. (2005). The index is standardized to a range from zero to one.

Table A7
Robustness check - Different samples

Above 40 percent coverage at baseline	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Source E. coli contaminated	HH storage E. coli contaminated	HH storage E. coli contaminated	Subjective water quality	HH treats water before use	Covered transport	Covered POU	Main source improved	HH uses only improved sources
Group TW # Year 2010	−0.246*	0.094	0.118	0.052	−0.028	0.010	−0.028	0.006	−0.071
	(0.142)	(0.089)	(0.088)	(0.062)	(0.029)	(0.045)	(0.087)	(0.079)	(0.117)
Group TS # Year 2010	0.001	−0.200**	−0.197**	0.040	0.016	0.044	0.136*	0.112**	−0.010
	(0.136)	(0.079)	(0.079)	(0.061)	(0.033)	(0.067)	(0.079)	(0.055)	(0.076)
Group TW # Group TS # Year 2010	0.250	−0.056	−0.081	−0.010	−0.031	0.064	0.073	0.035	0.124
	(0.214)	(0.130)	(0.132)	(0.093)	(0.050)	(0.099)	(0.151)	(0.093)	(0.167)
Group TW	0.016	−0.073	−0.075	0.002	0.012	−0.048	0.163**	−0.060	−0.042
	(0.122)	(0.069)	(0.067)	(0.057)	(0.027)	(0.060)	(0.076)	(0.046)	(0.108)
Group TS	−0.132	0.026	0.038	0.039	−0.015	0.071	0.164*	0.015	0.208**
	(0.095)	(0.069)	(0.068)	(0.056)	(0.026)	(0.079)	(0.083)	(0.029)	(0.097)
Group TW# Group TS	−0.078	0.001	0.009	−0.006	0.014	−0.052	−0.188	0.064	0.159
	(0.165)	(0.113)	(0.113)	(0.085)	(0.045)	(0.099)	(0.140)	(0.068)	(0.173)
Year 2010	−0.002	−0.090	−0.090	−0.006	−0.027	−0.006	−0.059	−0.113**	0.043
	(0.102)	(0.060)	(0.060)	(0.048)	(0.017)	(0.038)	(0.053)	(0.050)	(0.051)
Source *E. coli* contaminated			0.094**						
			(0.040)						
Constant	0.240*	0.396***	0.366***	0.695***	0.077***	0.479***	0.452***	0.985***	0.579***
	(0.129)	(0.091)	(0.092)	(0.082)	(0.029)	(0.124)	(0.096)	(0.044)	(0.139)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	176	1424	1424	1424	1424	1424	1424	1424	1424
R2	0.109	0.053	0.058	0.053	0.029	0.064	0.088	0.081	0.149
Clusters	88	88	88	88	88	88	88	88	88

(*continued on next page*)

Table A7 (*continued*)

Above 40 percent coverage at baseline	(1) Source E. coli contaminated	(2) HH storage E. coli contaminated	(3) HH storage E. coli contaminated	(4) Subjective water quality	(5) HH treats water before use	(6) Covered transport	(7) Covered POU	(8) Main source improved	(9) HH uses only improved sources
TWTS2010 mean	0.0833	0.0870	0.0870	0.935	0	0.239	0.728	0.978	0.783
TW2010 mean	0.0303	0.230	0.230	0.922	0.00741	0.148	0.641	0.844	0.519
TS2010 mean	0.0857	0.0923	0.0923	0.934	0.0185	0.266	0.742	0.970	0.749
C2010	0.250	0.278	0.278	0.833	0.0266	0.179	0.430	0.837	0.487
Below 40 percent coverage at baseline									
Group TW # Year 2010	−0.426*	0.047	0.093	0.382***	−0.233***	0.122**	−0.135	0.573***	0.358***
	(0.226)	(0.089)	(0.086)	(0.096)	(0.085)	(0.057)	(0.102)	(0.086)	(0.092)
Group TW	0.001	−0.073	−0.074	0.006	0.006	0.016	0.177*	0.019	0.007
	(0.160)	(0.090)	(0.086)	(0.108)	(0.085)	(0.062)	(0.099)	(0.051)	(0.026)
Year 2010	−0.087	−0.121**	−0.112*	0.043	0.062	−0.068*	−0.014	0.100**	0.064
	(0.133)	(0.057)	(0.057)	(0.066)	(0.054)	(0.040)	(0.049)	(0.049)	(0.049)
Source E.coli contaminated			0.114*						
			(0.060)						
Constant	0.678***	0.416***	0.335***	0.285***	0.232***	0.271***	0.454***	0.049	0.052
	(0.136)	(0.105)	(0.111)	(0.100)	(0.082)	(0.067)	(0.116)	(0.057)	(0.048)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	86	688	688	688	688	688	688	688	688
R2	0.172	0.027	0.039	0.201	0.098	0.099	0.096	0.363	0.230
Clusters	43	43	43	43	43	43	43	43	43
TW2010 mean	0.125	0.282	0.282	0.847	0.0161	0.194	0.339	0.734	0.444
C2010	0.481	0.305	0.305	0.468	0.223	0.0864	0.359	0.159	0.0909
Above 40 percent excluding TS group									
Group TW # Year 2010	−0.252*	0.087	0.118	0.052	−0.029	0.009	−0.028	0.010	−0.069
	(0.142)	(0.088)	(0.088)	(0.063)	(0.029)	(0.044)	(0.088)	(0.079)	(0.119)
Group TW	0.018	−0.079	−0.082	−0.004	0.011	−0.058	0.167**	−0.064	−0.072
	(0.123)	(0.069)	(0.066)	(0.056)	(0.027)	(0.059)	(0.072)	(0.048)	(0.105)
Year 2010	−0.001	−0.092	−0.093	−0.007	−0.028	−0.005	−0.059	−0.112**	0.039
	(0.102)	(0.059)	(0.060)	(0.048)	(0.017)	(0.038)	(0.053)	(0.050)	(0.052)
Source *E. coli* contaminated			0.120**						
			(0.050)						
Constant	0.246*	0.426***	0.382***	0.620***	0.082**	0.429***	0.445***	0.956***	0.507***
	(0.137)	(0.093)	(0.092)	(0.095)	(0.034)	(0.135)	(0.104)	(0.054)	(0.156)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	106	882	882	882	882	882	882	882	882
R2	0.120	0.016	0.025	0.067	0.028	0.048	0.074	0.082	0.142
Clusters	53	53	53	53	53	53	53	53	53
TW2010 mean	0.00	0.303	0.303	0.916	0.0112	0.101	0.596	0.775	0.382
C2010	0.250	0.278	0.278	0.833	0.0266	0.179	0.430	0.837	0.487
TS treatment sample									
Group TW # Year 2010	0.017	0.006	0.006	0.041	−0.066	0.054	0.055	0.041	0.009
	(0.156)	(0.097)	(0.097)	(0.073)	(0.042)	(0.096)	(0.132)	(0.049)	(0.128)
Group TW	−0.002	−0.064	−0.065	−0.007	0.026	−0.097	0.033	−0.036	0.035
	(0.120)	(0.087)	(0.087)	(0.062)	(0.038)	(0.078)	(0.127)	(0.048)	(0.131)
Year 2010	−0.006	−0.279***	−0.279***	0.039	−0.009	0.040	0.073	0.000	0.046
	(0.094)	(0.047)	(0.047)	(0.039)	(0.029)	(0.058)	(0.061)	(0.022)	(0.061)
Source E.coli contaminated			0.011						
			(0.062)						
Constant	−0.005	0.586***	0.585***	0.851***	0.091**	0.741**	0.513***	1.042***	1.145***
	(0.059)	(0.191)	(0.191)	(0.095)	(0.036)	(0.297)	(0.099)	(0.026)	(0.100)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	70	542	542	542	542	542	542	542	542
R2	0.049	0.141	0.141	0.034	0.036	0.085	0.080	0.019	0.057
Clusters	35	35	35	35	35	35	35	35	35
TW2010 mean	0.0833	0.0870	0.0870	0.935	0.00	0.239	0.728	0.978	0.783
C2010	0.0870	0.0950	0.0950	0.933	0.0279	0.279	0.749	0.966	0.732

Note: Estimates based on different sample definitions. Robust standard errors adjusted for clustering. HH Household, TS Treatment Storage, TW Treatment Water, TWTS Water and Storage treatment, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; Regression 1 is on the village level, others on the household level. Controls are the same as in Tables 3 and 4

Figure A1a Conventional Containers

Figure A1b Clay Container

Figure A1c Plastic Container

Fig. A1. Fig. A1a Conventional Containers. A1b Clay Container. A1c Plastic Container

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