Water Supply and Water Handling – Complements or Substitutes for Quality Improvements

Elena Gross[1], Isabel Guenther[2] and Youdi Schipper[3]

Preliminary Draft, April 7, 2013 please do not cite or circulate.

Abstract

Recent studies have shown that improved public water supply does not necessarily improve water quality at point-of-use and/or health outcomes. In this study we provide a detailed analysis of this phenomenon, applying a quasi-experimental difference-in-difference analysis in combination with a randomized control trial to 200 villages and 1989 households. We find that households consider improved water supply and water handling as substitutes of water provision, whereas in reality they are complementary. Improved public water infrastructure improves water quality at the water source. However, there is no impact on the quality of the water consumed and/or on health outcomes. We show that an increase in the perceived water quality of households reduces the (already low) propensity of households to engage in water filtration and disinfection practices after the provision of modern water technologies. Only a combination of water point provision and water handling methods leads to a decrease in *E. coli* (-89 percent) contamination of water consumed in households and diarrheal incidence (-20 percent) in children.

Keywords: RCT, Diff-in-Diff, Water Supply, Water Handling, Health, Water Quality

JEL: I15, I38, D12

[1]Corresponding author: University of Göttingen, Faculty of Economics; egross@uni-goettingen.de
[2] ETH Zürich, Center for Development and Cooperation; isabel.guenther@nadel.ethz.ch
[3] VU University of Amsterdam, Faculty of Economics; j.y.schipper@vu.nl

1 Introduction

OECD estimates show that aid to water and sanitation programs has increased sharply in absolute terms since 2001. For DAC countries, the share of aid has increased by one percentage point over the period between 2003 and 2008, from 6 percent in 2003-2004 to 7 percent in 2007-2008. (OECD/DAC, 2010). Much of this aid is used for such basic water infrastructure as village-level water points, e.g., public standpipes or pumps, a form of access found often in low-income countries. This contributes toward the MDG 7 of increasing access to improved drinking water sources. These investments are often justified in terms of improved health, particularly in reduced diarrheal incidence for children under the age of five (Hutton et al., 2006).

The effectiveness of public water infrastructure to increase consumed water quality and decrease diarrheal incidence, however, has been discussed widely among researchers (see e.g. Waddington and Snilsveit, 2009; Fewtrell et al., 2005; Peterson Zwane and Kremer, 2007; IEG, 2008). Studies using microbiological evidence show that even if water is not contaminated with *E. Coli* bacteria at point of source (POS), recontamination during transport or storage is widespread (Wright et al., 2004; Kremer et al., 2011). Point of use (POU) water quality is therefore often significantly worse than water quality at POS.

In addition, an extensive body of literature has been able to show that interventions at POU, such as water filters or chlorine treatment (see IEG, 2008 for a list of treatment strategies), and/or individual behavioral change, such as hand washing or covering household drinking water containers, seem to have a larger impact on water-induced health outcomes than interventions at POS, i.e., installing or treating public water sources (Waddington and Snilsveit, 2009).

The paper builds on this previous literature, analyzing the impact of improved water supply on water quality at POS, POU and on individuals' health. Our study further analyzes induced changes in "water handling" of the target population as an outcome. Therefore the analysis goes beyond the MDG target on access to improved sources and examines whether increased access actually leads to the desired water quality and health effects. Water handling obviously affects water quality and health, and is normally targeted with hygiene interventions (see studies of Luby et al. 2004a, 2004b, 2006). At least to our knowledge, no previous study has analyzed the impact of improved water infrastructure on water handling.

We analyze the impact of improved village water provision (taps and pumps) using a sample of 200 villages and 1989[4] households from rural Benin. We apply a difference-in-difference (DD) analysis in a quasi-experimental design on the phasing-in of the national water program. The first analysis is complemented by a randomized control trial (RCT) in 66 villages where improved water sources were installed or were already present at the time when a water handling intervention was introduced. Subsidizing improved water transport and storage containers and promoting the separation of water coming from improved and unimproved water sources. We study the sole and combined impact of both interventions on water quality (*E. coli*) at POS and POU, health outcomes (diarrheal incidence) and water handling (coverage of water during transport and storage).

The main findings of this study can be summarized as follows. In line with previous literature, we find that public water point provision does improve water quality at POS, but it neither improves water quality at POU nor does it lead to a reduction in diarrhea of the target population. Our explanation is twofold: First, about 20 percent of households continue to use existing (free-of-charge) unimproved water sources or a combination (34 percent) of traditional and new water sources. Second, households have a low propensity to treat water and do not start to practice water treatment at the household level to maintain the improved water quality from the source to the household when new water infrastructure is built. Moreover, we provide evidence that measured and perceived improved water quality at POS may cause beneficiaries to discontinue household level water treatment. Hence, improved water quality at source does not guarantee the availability of good water quality at POU because of bad and even worsening water handling practices. However, we show that inducing households to improve water

[4] The target was to interview 2000 households. However, 5 villages have less than 10 households, so the total number of households goes down to 1989. In the case of smaller villages, all households were interviewed.

handling, in combination with improved water supply, can indeed improve water quality and health outcomes.

Our conclusion is that households consider water supply and water handling to be substitutes for one another, whereas in reality they are complements. Therefore it is important to communicate to households how to maintain good water quality between POS and POU and that other factors than the source itself, e.g., contaminated multi-user storage containers, can cause water to be contaminated with pathogens.

In the next section we introduce the research design. In section 3 we describe results, which are followed by a sensitivity analysis of the findings in Section 4. Section 5 concludes.

2 Data and Empirical Methodology

The data analysis is based on two household and village surveys in rural Benin during February in the dry seasons of 2009 (baseline wave) and 2010 (follow up wave) designed in a DD approach. The water intervention took place between the surveys during 2009.[5] The installations are part of the second national water strategy in rural Benin, which has been ongoing since 2005. The program follows a demand-led approach and either installs public standpipes or public manual pumps, depending on the groundwater level and the population size of a village.[6] All localities that received water in 2009 and after, applied late for the program. The order of localities on the planning lists depends on capacity constraints rather than on any endogenous selection strategy.

[5] All localities in the sample will receive water installations. Control localities receive a new water point after the study was conducted. This is a so called phasing in or pipeline approach. .

[6] Both technologies are considered as improved water sources according to the official WHO-UN definition (WHO, 2008; WHO/UNICEF, 2012). The investment costs are about $55,000 USD (FCFA 25,000,000) for a public standpipe and $20,000 USD (FCFA 9,000,000) for a public manual pump (Günther and Schipper, 2011a), which are mostly covered by donor agencies. Larger villages are more likely to be targeted with standpipes, smaller villages with public pumps. Villages have to contribute about $450 USD (FCFA 200,000) for a standpipe and $225 USD (FCFA 100,000) for a pump – or about 1 percent of the investment cost- to the construction. Local authorities have to collect water fees of around $1.6 USD cent per m^3 consumed (FCFA 20 for a container of app. 40 liters) for the maintenance of the water points (Günther and Schipper, 2011a).

To strengthen the plausibility of the common trend assumption, control villages were sampled from Water Services planning lists from 2010, whereas treatment villages were sampled from planning lists from 2009. Thus the water supply intervention was not randomly assigned; it took place in villages that were on the planning lists from 2009. In the following paragraphs we will show that counterfactual inference is supported by the data. To analyze the impact of water handling in more detail, we randomly allocated improved water storage and transport containers[7] to a sub-sample of villages after the baseline was conducted (see Günther and Schipper, 2011b for more details).

Our analytical framework is summarized in Table 1. The total number of villages studied, i.e., those where a household survey was conducted, was 200. In 129[8] villages randomly selected from the 200, in addition, we conducted water quality tests at both POS (main water source of the village) and POU (household water storage containers). Out of the 129 villages where water testing was conducted, 66 villages were selected for an RCT for the water handling intervention. In all 200 villages, 10 households were randomly sampled from complete village household lists and were interviewed before and after the water supply and water handling intervention took place.

Table 1: Research Design

(Non-random assigned) Water supply intervention	**(Random assigned) Water handling intervention**	**Number of villages**	**Villages with water testing**
Treatment	Treatment	12	12
Treatment	Control	12	12
Treatment	--	54	24
Comparison	Treatment	23	23
Comparison	Control	19	19
Comparison	--	80	39
Total		200	129

[7] Households were supplied with (a) a clay or plastic storage container with a lid and a spigot (tap) at the bottom; (b) a jerry can with a narrow mouth for transporting the water from the source to the storage container; and (c) a brief instruction on the importance of not touching the water.

[8] Because of capacity, time and budget constraints not all 200 villages could be visited for water quality tests.

The primary goal of our study is to estimate the impact of the installation of an improved public water point and/or improved water handling. The primary outcomes studied are *E. coli*[9] contamination of water at POS, POU and self-reported diarrhea among household members. Water testing for *E. coli* was done by a survey-independent team of biologists who visited households and water sources shortly after the survey took place. Diarrhea was used as a health outcome from a larger list of possible water-related diseases because the most often stated objective of donor-funded water programs is diarrhea reduction, which is recognized as a main cause of child mortality. Moreover, households perceive diarrhea as a major health problem related to water provision.[10] Diarrhea incidence is measured by asking each member within a household whether he/she has suffered from diarrhea within the last 4 weeks.[11] In order to reduce measurement error only information on adults present during the interview and children below the age of 5 was used.[12]

Furthermore, we analyze the effect of subsidized water supply and water handling on usage rates and actual water handling. Water handling is measured in three ways: water POU treatment (application of any water disinfectant treatment), the use of covered water storage and transport containers. Disinfectant methods applied on a household level at baseline are adding chlorine (41 percent), simple sedimentation (25 percent) and to a lesser extend methods like filtering, boiling and solar disinfection.

Next, we show the empirical estimation strategy used to identify the beta parameters in the following DD equation:

(1) $$Y_{ij} = \alpha + \beta_1 T_j + \beta_2 X_{ij} + v_j + \varepsilon_i,$$

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[9] *Escherichia (E.) coli* is a bacterium that is commonly found in the gut of humans. The presence of *E. coli* bacteria in water indicates (recent) contamination with human or animal feces and is widely used as an indicator of general bacteriological contamination of water. If water is polluted, usually a very high number of *E. coli* bacteria are found. The WHO defines a zero tolerance strategy as the maximum acceptable concentration of *E. Coli* in water intended for drinking

[10] When households were asked directly which was the disease that they thought had decreased because of an improved water source, the most often named diseases were diarrhea (40 percent) followed by vomiting, abdominal pain, fever, and fatigue (all about 3-8 percent).

[11] Health studies usually use a recall period between 1 and 4 weeks for diarrhea. An upper-bound recall period of 4 weeks was chosen here, given the relatively small sample for a health survey. This could, however, have lead to higher measurement error.

[12] Measurement error can reduce the statistical significance in any impact evaluation based on econometric techniques.

where T_j is an indicator function which equals 1 if an observation is from a treatment village where an improved water point has been installed during the last year. The vector X contains village and household characteristics. It is possible to include control variables, which are time-dependent and a possible source of bias. The advantage is to control for possible effect heterogeneity and to remove any trend-confounding influences. The error term reflects unobserved or omitted factors that may be correlated with treatment and thus bias the impact parameter estimates. In order to avoid such bias we use a combination of DD analysis and an RCT.

The underlying assumption of the DD approach to identify the impact of improved water supply and storage is that time-invariant, unobservable factors are the only source of selection bias while any time trends in treatment and control villages are equal in the absence of the intervention, so that

(2) $$Y_{ijt} = \alpha + \beta_1 D_t + \beta_2 T_j + \beta_3 D_t T_j + \beta_4 X_{it} + \varepsilon_{ijt}.$$

Counterfactual inference for our sample is supported by the results in Table 2, below. It shows the baseline differences between the treatment and control group, both for the water supply (upper panel) and the water handling intervention (lower panel). At baseline, little difference can be found between water supply treatment and control households for most household characteristics, except for the variable "Household head with primary education". For the RCT sample the situation at baseline looks the same, the significance of the difference in education of the household head vanishes completely. Given the non-experimental nature of our research design regarding water point treatment, this is a positive sign with respect to the assignment of treatment and counterfactual inference.

Table 2: Descriptive Statistics by treatment status

Water Supply	(1) Sample	(2) se	(3) Control	(4) se	(5) Treatment	(6) se	(7) Difference	(8) p-value
POS *E. coli* contaminated	0.37	(0.052)	0.362	(0.067)	0.374	(0.079)	-0.011	0.912
POU *E. coli* contaminated	0.42	(0.029)	0.45	(0.039)	0.37	(0.040)	0.086	0.125
Main drinking water source improved	0.58	(0.035)	0.62	(0.045)	0.52	(0.057)	0.100	0.167
Households treats drinking water	0.09	(0.014)	0.07	(0.014)	0.11	(0.026)	-0.033	0.275
Household size	5.92	(0.143)	6.05	(0.191)	5.71	(0.204)	0.335	0.233
Children age <5 in household	2.10	(0.076)	2.13	(0.100)	2.05	(0.113)	0.086	0.571
Wealth Index	0.37	(0.012)	0.36	(0.017)	0.37	(0.015)	-0.013	0.556
Most household members use a latrine	0.10	(0.013)	0.11	(0.018)	0.08	(0.018)	0.028	0.263
Female headed household	0.15	(0.013)	0.14	(0.018)	0.15	(0.020)	-0.009	0.749
Head with primary education	0.32	(0.016)	0.34	(0.022)	0.28	(0.022)	0.063	0.048
Age of household head	43.61	(0.597)	44.23	(0.789)	42.58	(0.880)	1.649	0.164
Person older 4 years had diarrhea last 4 weeks	0.05	(0.007)	0.06	(0.010)	0.04	(0.009)	0.015	0.255
Child <5 years had diarrhea last 4 weeks	0.15	(0.024)	0.16	(0.031)	0.12	(0.038)	0.044	0.371
Observations	1989		1219		770			
Water Handling	(1) Sample	(2) se	(3) Control	(4) se	(5) Treatment	(6) se	(7) Difference	(8) p-value
POS *E. coli* contaminated	0.12	(0.039)	0.152	(0.063)	0.086	(0.048)	0.066	0.407
POU *E. coli* contaminated	0.40	(0.033)	0.39	(0.052)	0.41	(0.041)	-0.020	0.762
Main drinking water source improved	0.94	(0.016)	0.96	(0.015)	0.92	(0.027)	0.039	0.207
Households treats drinking water	0.05	(0.013)	0.03	(0.011)	0.06	(0.023)	-0.031	0.215
Household size	5.85	(0.187)	5.81	(0.265)	5.90	(0.262)	-0.090	0.809
Children age <5 in household	1.95	(0.102)	1.91	(0.150)	1.98	(0.140)	-0.069	0.736
Wealth Index	0.42	(0.016)	0.43	(0.023)	0.41	(0.023)	0.021	0.514
Most household members use a latrine	0.14	(0.020)	0.16	(0.030)	0.11	(0.027)	0.048	0.238
Female headed household	0.20	(0.018)	0.19	(0.029)	0.20	(0.022)	-0.011	0.772
Head with primary education	0.36	(0.022)	0.34	(0.035)	0.37	(0.027)	-0.030	0.509
Age of household head	45.95	(0.789)	46.77	(1.157)	45.17	(1.060)	1.599	0.312
Person older 4 years had diarrhea last 4 weeks	0.06	(0.010)	0.06	(0.017)	0.05	(0.012)	0.007	0.734
Child <5 years had diarrhea last 4 weeks	0.15	(0.036)	0.14	(0.055)	0.16	(0.048)	-0.022	0.771
Observations	716		350		366			

Note: Upper Panel shows descriptive statistics for the whole sample, the lower panel for the RCT subsample. Statistics are on household level.

3 Results

The installation of a public water point in a village should have a direct effect on the water quality at source as well as a number of potential effects on water handling. These are likely to co-determine the effect of water supply on POU water quality and health. We first provide estimates of the direct effects: Table 3 gives impact estimates of equation (2) of the water point intervention on the water quality of the main village water source (column 1), a measure of households' subjective water quality of the water point (column 2 and 3) and the types of water sources used by households (column 4 to 9). The water handling intervention is included in the next steps of the analysis. This intervention has no effect on the outcomes analyzed in the first part on POS water quality and coverage.

Table 3 presents the results with and without household control variables to see if the DD results are sensitive to changes in specification. To appreciate the effect size the last row shows the counterfactual mean level (CF mean), defined as the baseline level in the intervention group plus the change in the control group. Herewith we can analyze what would have happened to the treatment group if no treatment had been carried out. The results show, first, a significant 30 percentage point drop in the incidence of *E. coli* contamination of water obtained from the main village source (column 1). For the source contamination incidence the CF mean is about 30 percent, so we find that the relative impact of the water source is minus 100 percent. In other words, the water point intervention does provide absolute cleaner water at source, which is also reflected in households' perception of changes in water quality (column 2 and 3). Households were asked to rank the quality of the water from their main drinking water source on a four point scale from "very good quality" to "bad quality". The DD analysis of water supply on households' perceived water quality at source level as the outcome variable (column 2 and 3) shows similar results as the objective measure for the water source.[13]

[13] We construct a binary "bad quality" indicator (yes = 1, no = 0).

Table 3: Impact of water point installation on quality and usage

	(1) *E. Coli* at water source	(2) Perceived water quality	(3) Perceived water quality	(4) Household uses improved drink water source	(5) Household uses improved drink water source	(6) Household uses alternative water source	(7) Household uses alternative water source	(8) Exclusive use of improved sources	(9) Exclusive use of improved sources
Water Source Effect	**-0.309***** **(0.061)**	**0.189***** **(0.037)**	**0.182***** **(0.037)**	**0.277***** **(0.042)**	**0.277***** **(0.042)**	**0.217***** **(0.076)**	**0.221***** **(0.080)**	**0.221***** **(0.084)**	**0.223***** **(0.085)**
Year 2010	-0.033 (0.064)	0.046* (0.027)	0.043* (0.026)	0.031 (0.026)	0.034 (0.027)	-0.028 (0.037)	-0.030 (0.039)	0.087** (0.037)	0.092** (0.039)
Village Water Treatment	0.122 (0.097)	-0.073 (0.056)	-0.077 (0.051)	-0.179** (0.073)	-0.178** (0.073)	-0.062 (0.056)	-0.049 (0.056)	-0.143** (0.068)	-0.151** (0.068)
Wealth index			0.488*** (0.076)		0.341*** (0.111)		0.310*** (0.071)		0.132 (0.093)
Household size			-0.001 (0.004)		0.008 (0.005)		0.011*** (0.004)		-0.003 (0.005)
Head female			0.084*** (0.027)		0.084** (0.037)		0.086*** (0.031)		0.077** (0.037)
Children under 5 in household			-0.000 (0.012)		-0.019 (0.015)		-0.021* (0.012)		0.001 (0.014)
Head with primary education			-0.003 (0.026)		0.038 (0.029)		0.069*** (0.021)		-0.023 (0.029)
Collines			-0.078* (0.042)		0.115* (0.062)		-0.018 (0.039)		0.092 (0.057)
Observations	268	3,977	3,783	3,977	3,783	3,977	3,783	3,977	3,783
CF mean	0.304	0.745	0.746	0.579	0.581	0.357	0.357	0.382	0.380

Note: Robust Standard Errors clustered at the village level in parenthesis, *** p<0.01, ** p<0.05, * p<0.1; Regressions 1 and 2 are done at the locality level for localities with water testing, Regressions 3-4 are done for the whole household sample. Coefficients are marginal effects of a logit regression.

The last 6 columns of Table 3 show that improved source installation results in a significant 27 percentage point increase, from 58 percent to 77 percent, in the share of households using an improved water point as their main source of drinking water. Hence, even after an improved water point is installed, 23 percent of households prefer to continue using an unimproved water source instead.[14] The next question is whether the installation of improved water points and the RCT on storage and transport containers in some of the villages has an impact on household level *E. coli* contamination and diarrhea incidence.

Table 4 presents marginal effects of logit estimates of equation (2) with *E. coli* contamination at the household level as the dependent variable controlling for household and regional characteristics as well as the water intervention (column 1) and the combined water supply and handling intervention (column 2) (estimates are replicated without control variables in Appendix Table 8).[15] Controls were added primarily to see if the DD results are sensitive to changes in specification, which proved not to be the case.

The estimates show that the installation of a new public water point alone does cause worsening household water quality as measured by *E. coli* contamination at POU (column 1). However, if improved water supply is complemented with improved water storage and transport containers, a reduction in *E. coli* contamination of water at POU is achieved (column 2). One might question, then, whether the water intervention alone causes worsening diarrhea outcomes, and whether the induced behavioral change can have a positive and significant health impact.

Columns 3 to 8 in Table 4 present our health impact estimates measured at the individual level. Columns 3 and 4 show results for all household members, columns 5 and 6 for children younger than age 5 and, finally, columns 7 and 8 for household members older

[14] The most often stated answer of households as to why the new water source is not used are that it is too far (28 percent), too expensive (25 percent), the habit of other water sources (20 percent) followed by few households stating that the source is not working properly yet.

[15] Controls were added primarily to see if the DD results are sensitive to changes in specification, which did not prove to be the case as magnitude and signs of the coefficients remain the same.

than age 4[16]. The coefficient of water treatment on diarrheal outcomes is positive, but in contrast to the POU *E. coli* results, we find no significant impact for improved water point provision on diarrhea outcomes when it is provided as a stand-alone intervention. For the combination of improved water provision and improved water handling we find a positive impact on health, i.e., lower diarrhea incidence, but only for children younger than 5 (column 6). There is no significant effect for the whole population and individuals older than 4. The impact for the under-5 group is large in absolute terms (-7 percentage points) but not in relative terms (-21 percent relative to the counterfactual mean). There is little difference in the effect size between specifications with (Table 4) and without (see Appendix Table 8) control variables.

We now turn to the behavioral side of the water interventions to explain why improved water supply does not lead to better water quality in the household and to lower diarrhea incidence. Therefore, we estimate the impact of the interventions on the propensity of households to apply POU water purification treatment, transport and storage techniques (Table 5). Here we look at both, the impact of water supply and water handling interventions. Regressions are estimated using control variables to show that the results are robust to different specifications. Table 9 of the Appendix again shows results without control variables.

[16] We find no effect when we distinguish between older age groups.

Table 4: E. coli and Diarrhea Impact

	(1) *E. coli* POU	(2) *E. coli* POU	(3) Diarrhea all household members	(4) Diarrhea all household members	(5) Diarrhea age<5	(6) Diarrhea age<5	(7) Diarrhea age>4	(8) Diarrhea age>4
Water Source Effect	**0.130***	**0.085**	**0.007**	**0.005**	**-0.013**	**-0.021**	**0.014**	**0.013**
	(0.073)	**(0.075)**	**(0.017)**	**(0.017)**	**(0.040)**	**(0.041)**	**(0.017)**	**(0.018)**
Storage Effect		**-0.174*** **		**0.001**		**-0.006**		**0.004**
		(0.063)		**(0.022)**		**(0.048)**		**(0.025)**
Water Source and Storage Effect		**-0.163*** **		**-0.023**		**-0.065***		**-0.012**
		(0.063)		**(0.019)**		**(0.038)**		**(0.022)**
Year 2010	-0.213***	-0.173***	0.054***	0.056***	0.152***	0.160***	0.063***	0.064***
	(0.037)	(0.045)	(0.009)	(0.010)	(0.022)	(0.026)	(0.009)	(0.011)
Village Water Treatment	-0.076	-0.085	-0.002	-0.001	0.007	0.017	-0.003	-0.003
	(0.050)	(0.054)	(0.012)	(0.012)	(0.033)	(0.034)	(0.011)	(0.012)
Village Storage Treatment		-0.027		-0.004		0.012		-0.006
		(0.069)		(0.016)		(0.047)		(0.015)
Village Water and Storage Treatment		-0.047		0.017		0.108		0.001
		(0.088)		(0.029)		(0.085)		(0.022)
Wealth index	0.049	0.069	-0.026	-0.026	0.032	0.027	-0.025	-0.024
	(0.081)	(0.081)	(0.017)	(0.016)	(0.055)	(0.053)	(0.016)	(0.016)
Household size	0.005	0.005	-0.003***	-0.003***	-0.006*	-0.006*	-0.002**	-0.002**
	(0.004)	(0.004)	(0.001)	(0.001)	(0.003)	(0.003)	(0.001)	(0.001)
Head female	-0.101***	-0.090***	-0.014	-0.014	-0.047*	-0.049**	-0.010	-0.010
	(0.035)	(0.034)	(0.009)	(0.009)	(0.024)	(0.024)	(0.009)	(0.009)
Children under 5 in household	0.032	0.030	0.014***	0.014***	-0.003	-0.003	-0.002	-0.002
	(0.028)	(0.028)	(0.003)	(0.003)	(0.011)	(0.011)	(0.003)	(0.003)
Head with primary education	0.007	0.011	0.000	0.000	0.020	0.018	-0.009	-0.009
	(0.029)	(0.028)	(0.006)	(0.006)	(0.017)	(0.017)	(0.007)	(0.007)
Collines	-0.002	-0.003	0.007	0.007	0.015	0.015	0.001	0.001
	(0.037)	(0.035)	(0.007)	(0.007)	(0.019)	(0.019)	(0.007)	(0.007)
Observations	2,381	2,381	23,034	23,034	3,092	3,092	17,855	17,855
CF mean	0.181	0.182	0.114	0.114	0.301	0.308	0.113	0.111

Note: Robust standard errors in parentheses clustered at the village level, *** p<0.01, ** p<0.05, * p<0.1, Regression 1 and 2 for households with water testing. Regressions 3-8 on individual level, coefficients are marginal effects of logit regressions.

Household POU water treatment is not widespread in Benin. The DHS 2006 reports that only 7 percent of households in rural Benin use any method of water treatment before drinking. The mean share in our baseline sample is slightly higher at 8 percent, and it is significantly higher for households that primarily rely on wells or surface water, i.e., unimproved water sources in treatment villages. However, a worrisome finding, shown in Table 5, is that water point installation causes a drop of 7.5 percentage points in the share of households practicing precautionary water treatment, which constitutes a 67 percent relative decrease.

It thus appears that, for households, water quality from new water points is considered sufficiently safe and more attractive than water from a traditional source which has been treated at the household level. This hypothesis is further supported by the positive impact of water supply on consumers' perceptions about water quality (see Table 3, column 2) that was found in the previous part of the analysis. The discontinuation of water treatment after an improved water source has been installed indicates that households perceive improved water supply and household water treatment to be substitutes of one another. This behavior has not attracted much scholarly attention so far, and reduces any beneficial impact of water point installation on POU water quality and health.

The impact of the water source and storage intervention on water handling, i.e., coverage of transport and storage, is shown in Table 5, columns 3 to 6. The provision of water sources or handling containers alone has no effect on covered transport. Possible reasons, therefore, are the scarcity of containers with a closure head in the household and the often multi-purpose use (water fetching and transporting other liquids, e.g. palm oil) of such containers.

Similarly as with the finding of POU water treatment, we find that the construction of a new water source causes a decrease in the number of households covering water storage containers (column 5). Only in the villages where an additional new water source was provided with the storage intervention is there a positive effect on covered storage containers, but only because part of the intervention was providing households with these storage containers. The installation of public water sources alone reduces the already low probability of water being treated and covered in the households.

Table 5: Impact of water interventions on behavior

	(1) POU treatment	(2) POU treatment	(3) Covered transport container	(4) Covered transport container	(5) Covered drinking water storage	(6) Covered drinking water storage
Water Source Effect	**-0.075***** **(0.014)**	**-0.081***** **(0.014)**	**-0.024** **(0.033)**	**-0.002** **(0.038)**	**-0.119***** **(0.036)**	**-0.074*** **(0.038)**
Storage Effect		**-0.051***** **(0.014)**		**0.144** **(0.118)**		**0.170***** **(0.049)**
Water Source and Storage Effect		**-**		**0.081** **(0.069)**		**0.168***** **(0.062)**
Year 2010	0.023 (0.019)	0.038* (0.020)	0.005 (0.026)	-0.017 (0.028)	-0.010 (0.021)	-0.054** (0.024)
Village Water Treatment	0.021 (0.023)	0.024 (0.025)	-0.012 (0.032)	-0.011 (0.035)	0.044* (0.026)	0.072*** (0.027)
Village Storage Treatment		0.001 (0.030)		0.014 (0.052)		0.109*** (0.037)
Village Water and Storage Treatment		0.032 (0.054)		0.002 (0.046)		0.096** (0.047)
Wealth index	-0.078** (0.035)	-0.071** (0.034)	-0.079 (0.068)	-0.094 (0.070)	0.193*** (0.045)	0.170*** (0.045)
Household size	-0.004** (0.002)	-0.004** (0.002)	-0.012*** (0.003)	-0.012*** (0.003)	-0.008*** (0.002)	-0.008*** (0.003)
Head female	-0.035*** (0.013)	-0.033** (0.013)	-0.075*** (0.018)	-0.079*** (0.018)	-0.016 (0.024)	-0.026 (0.024)
Children under 5 in household	0.007 (0.010)	0.007 (0.010)	-0.071*** (0.015)	-0.071*** (0.015)	-0.007 (0.018)	-0.006 (0.018)
Collines	0.056*** (0.019)	0.055*** (0.019)	0.072*** (0.026)	0.074*** (0.026)	0.316*** (0.016)	0.313*** (0.016)
Observations	3,977	3,977	3,977	3,977	3,977	3,977
CF mean	0.112	0.112	0.142	0.142	0.598	0.598

Robust standard errors in parentheses clustered at the village level, *** p<0.01, ** p<0.05, * p<0.1, Regressions are on household level for the whole sample, coefficients are marginal effects of a logit regression.

In the first part of the analysis we have shown that *E. coli* contamination at the water source, perceived water quality in the household and the usage rate of modern water sources increase with the provision of public improved water infrastructure. However, in the second part we saw that the water intervention alone has no effect on health outcomes and that it even has a negative impact on POU water quality. The results of the analysis on water handling then finally show why no positive household water quality and health effects are achieved, although the water quality at the source improves. Households decrease any POU activities, such as treating and covering water, because the water quality at the improved source has objectively increased and is subjectively perceived to be higher as well. Also, households that prior to the installation of an improved water point did not engage in POU treatment are not likely to start it after the installation. However, in the subsample of households where, in combination with the new water source, improved transport and storage containers are provided, the effect of the interventions on water quality at the household level and on diarrhea outcomes for children is positive. The containers designed for the storage intervention are highly accepted because they fulfill local preferences for keeping water cool (and clean), in a container very similar to traditional clay storage containers, and they are one possibility for maintaining good water quality from the source to the user.

4 Sensitivity Checks

In this section we discuss a few checks on the sensitivity and robustness of our diarrhea regression results. First, adding village fixed effects only causes a very minor change in the magnitude of the impact coefficient (results not reported, but available on request). Second, we look at the justification of the DD estimator. Generally, three tests are recommended (see Duflo, 2002):

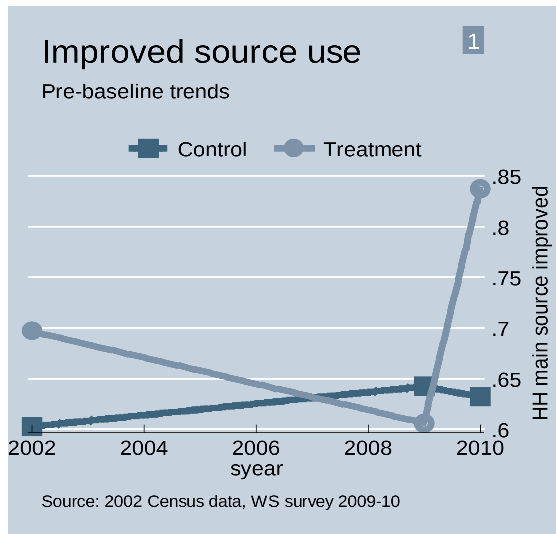
i) Using data for prior periods to redo the DD analysis and testing whether the impact coefficient is zero; ii) replacing the outcome variable with an alternative variable that is not supposed to be influenced by the intervention(s), and testing whether the impact coefficient is different from zero; iii) using an alternative control group and testing whether the impact coefficient changes. We can conduct test 1 in part and provide different alternatives for test 2, but unfortunately we cannot do test 3.

For the first test, we make use of the 2002 census which provides information on the share of households using an improved water source. We are able to merge 84 out of our 200 sample villages with villages in the census. This enables us to assess pre-baseline trends for the outcome variable “use of an improved water source”. Although the group is limited in size with 52 control and 32 treatment villages, it allows us to redo the most basic DD regression at the village level between 2002 and 2009 (i.e., before the water supply intervention we studied took place). Results are presented in Figure 8, below: we find that the pre-baseline (placebo) treatment effect is negative but not significant.

Figure 1: Pre-baseline DD analysis

	Improved Water Source used
Placebo treatment	-0.130
	(0.282)
Treatment group	0.0937
	(0.272)
Time trend	0.0395
	(0.595)
Constant	0.603***
	(0)
Observations	168
R-squared	0.009

P-value in parentheses *** p<0.01, ** p<0.05, * p<0.1



The large increase in the use of modern water sources in the treatment group between 2009 and 2010 is clearly not the continuation of a pre-baseline trend. In the pre-baseline period, our treatment villages display a downward trend in comparison to the control villages, which can be seen in the right graph of Figure 8. We conclude that these data do not reject the hypothesis of a parallel trend in treatment and control villages before the baseline, but neither do they confirm it strongly. Absent the treatment, however, it is very likely that treatment villages would have had a continuation of reduction in water coverage, similar to the control group from 2009 to 2010, which confirms the common trend assumption.[17]

Finally, we consider whether "placebo" outcome variables are sensitive to our treatment indicators; if they are, this would suggest that our interpretation of the DD results in Tables 3, 4 and 5 might be incorrect. We choose as alternative outcomes a few variables that should not be affected by public water supply within one year: education of the

[17] A reduction in coverage is possible through mechanical break-downs and drying out of water sources.

household head, gender of the household head, poverty status (household belongs to one of the two lowest wealth quintiles), and household size. For none of these placebo outcomes do we find a significant treatment effect (not for water, storage or the combined treatment). The results are shown in Table 7.

Table 7: Robustness checks, DD alternative outcomes

	(1)	(2)	(3)	(4)
	HH Head without Education	HH is Poor	Share female headed households	Household Size
Water Treatment Effect	0.009	0.041	0.005	-0.13
	(0.082)	(0.111)	(0.033)	(0.185)
Year (2010)	0.07	0.16**	-0.01	-0.61***
	(0.042)	(0.076)	(0.020)	(0.139)
Village Effect	0.13	-0.16	-0.01	-0.18
	(0.093)	(0.131)	(0.109)	(0.274)
Constant	0.45***	-0.33***	-0.94***	5.73***
	(0.060)	(0.098)	(0.073)	(0.187)
Observations	3,486	3,641	3,647	3,656

Note: Standard errors in parentheses clustered on locality level,*** p<0.01, ** p<0.05, * p<0.1

5 Discussion and Conclusion

Our paper analyzes the impact of improved water supply on water quality, water handling and health, namely diarrhea incidence. We find that the provision of improved public water supply in a village leads to a number of desired and expected results: it absolutely improves the quality of source water and increases the probability that households use an improved water source.

However, we also find that some households continue to use unimproved water sources and that households do not invest to maintain the improved water quality from the water source to the household level, e.g., through improved water storage and transport containers. Even more worrisome, we find that the provision of improved water supply has an unexpected negative effect as it leads to a decrease in the probability that households might treat their water to disinfect or purify it. Households are not aware of contamination channels between POS and POU. This is an important side-effect of public water provision that deserves further research.

Furthermore, we find that public water provision as a stand-alone intervention has a negative effect on POU *E. coli* contamination and no effect on self-reported diarrhea. This finding is in line with findings from other studies (such as Kremer et al, 2007; Jalan and Ravallion, 2003). We find that changing water handling, in this case through a water transport and storage intervention, in addition to providing improved water supply, can achieve the desired water quality and health benefits within households, showing the complementary effects of water supply and water handling.

Our study points to a number of implications for water sector policies. First, it should not be taken for granted that public water provision increases the quality of water consumed by beneficiary households; this was already known from previous studies. Moreover, our results reveal the possibility that providing clean water sources may actually decrease the (already low) propensity of households to engage in water filtration and disinfection practices. This danger emphasizes the need for policymakers to better safeguard the quality of water for consumers after it has been taken from the water source. Water programs have to communicate possible contamination channels to households and not only provide clean water out of a black box. We show that improved household transport and storage containers may be a complement to water point provision in order to maintain water quality up to the POU, if households cannot be persuaded to treat water that they perceive as improved quality already because it comes from modern technologies.

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Appendix

Table 8: Replication of Table 4 without control variables

	(1) E. coli POU	(2) E. coli POU	(3) Diarrhea all household members	(4) Diarrhea all household members	(5) Diarrhea age<5	(6) Diarrhea age<5	(7) Diarrhea age>4	(8) Diarrhea age>4
Water Source Effect	**0.161****	**0.115**	**0.005**	**0.003**	**-0.002**	**-0.011**	**0.014**	**0.014**
	(0.070)	**(0.074)**	**(0.016)**	**(0.017)**	**(0.042)**	**(0.043)**	**(0.017)**	**(0.018)**
Storage Effect		**-0.187*****		**0.002**		**-0.019**		**0.004**
		(0.063)		**(0.022)**		**(0.040)**		**(0.025)**
Water Source and Storage Effect		**-0.165*****		**-0.018**		**-0.064**		**-0.010**
		(0.064)		**(0.021)**		**(0.040)**		**(0.023)**
Year 2010	-0.219***	-0.177***	0.051***	0.053***	0.161***	0.170***	0.064***	0.065***
	(0.037)	(0.044)	(0.009)	(0.010)	(0.021)	(0.025)	(0.009)	(0.011)
Village Water Treatment	-0.079	-0.091*	0.003	0.004	0.006	0.017	-0.000	-0.001
	(0.049)	(0.053)	(0.012)	(0.013)	(0.034)	(0.035)	(0.012)	(0.012)
Village Storage Treatment		-0.038		-0.005		0.019		-0.008
		(0.070)		(0.016)		(0.047)		(0.014)
Village Water and Storage Treatment		-0.054		0.009		0.108		-0.002
		(0.089)		(0.028)		(0.089)		(0.021)
Observations	2,491	2,491	24,006	24,006	3,194	3,194	18,475	18,475
CF mean	0.182	0.180	0.113	0.113	0.299	0.309	0.111	0.109

Note: Robust standard errors in parentheses clustered at the village level, *** p<0.01, ** p<0.05, * p<0.1, Regression 1 and 2 for households with water testing. Regressions 3-8 on individual level, coefficients are marginal effects of logit regressions.

Table 9: Replication of Table 5 without control variables

	(1) POU treatment	(2) POU treatment	(3) Covered Transport Container	(4) Covered Transport Container	(5) Covered Drinking Water Storage	(6) Covered Drinking Water Storage
Water Source Effect	-0.086***	-0.091***	-0.022	-0.004	-0.106***	-0.066*
	(0.019)	(0.018)	(0.032)	(0.036)	(0.034)	(0.036)
Storage Effect		-0.058***		0.106		0.156***
		(0.018)		(0.104)		(0.048)
Water Source and Storage Effect				0.060		0.151**
				(0.065)		(0.061)
Year 2010	0.022	0.038*	0.008	-0.010	-0.006	-0.046**
	(0.021)	(0.023)	(0.024)	(0.026)	(0.019)	(0.022)
Village Water Treatment	0.028	0.029	-0.003	-0.000	0.080***	0.115***
	(0.029)	(0.030)	(0.036)	(0.039)	(0.024)	(0.025)
Village Storage Treatment		-0.010		0.022		0.139***
		(0.030)		(0.050)		(0.034)
Village Water and Storage Treatment		0.022		-0.002		0.122***
		(0.053)		(0.047)		(0.044)
Observations	3,977	3,977	3,938	3,938	3,977	3,977
CF mean	0.112	0.112	0.135	0.135	0.598	0.598

Note: Robust standard errors in parentheses clustered at the village level, *** p<0.01, ** p<0.05, * p<0.1, Regressions are on household level for the whole sample, coefficients are marginal effects of a logit regressions.