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Do Decentralized Community Treatment Plants Provide Better Water? Evidence from Andhra Pradesh

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Duke NICHOLAS INSTITUTE FOR ENVIRONMENTAL POLICY SOLUTIONS Celebrating 10 Years

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Abstract

Highly advanced, community-level drinking water treatment facilities are increasingly seen as water supply solutions in locations where piped in-house water systems are nonexistent or unreliable. These systems utilize combined technologies, such as advanced filtration plus ultraviolet disinfection or reverse osmosis, which are known to be highly effective for the removal of pathogens and other water contaminants. Yet there is a paucity of rigorous evidence on whether the community-level treatment model delivers water quality, health, or other benefits to households that source water from them. This paper utilizes a quasi-experimental approach that combines construction of counterfactual groups of villages and households and a difference-in-difference methodology to examine such impacts. We find low rates of sourcing water from the facilities (~10%), and little evidence of benefits among households living in villages receiving a community water system (CWS). Particularly among users of the CWS, we also observe short-term increases in the number of drinking water sources used and in monthly expenses on drinking water combined with decreases in in-house water treatment, and higher reported rates of diarrheal diseases among children. In the longer term, as the CWS model spread throughout the region, we observe that most of the differences between households in treated and control communities fade away. These findings suggest that caution and additional scrutiny is warranted before concluding that such systems provide safer water to households in communities facing drinking water quality problems.

Key words: Water quality, diarrheal disease, impact evaluation, community water kiosks, rural India

1. Introduction

In many less-developed countries, the majority of households obtain water for household consumption from sources located outside the home (WHO and UNICEF 2012). This is especially true in rural areas, where extensive and reliable piped water systems are rarely affordable for households and local governments. Accessing water for domestic purposes from such sources often costs households money as well as time, given the need to pay to use and store water from community sources and to travel to collect and bring water home (Whittington et al. 2012) . There are also significant health concerns related to these practices, given that such water is generally untreated, subject to contamination from a variety of natural and man-made contaminants, and difficult to manage hygienically following collection, even when water at the point of collection is of very high quality (Shaheed et al. 2014).

The literature on interventions designed to improve either the convenience or quality of water sources located outside the home is actually ambivalent about whether they deliver health or economic benefits to households. In fact, a general consensus has emerged within the water, sanitation and hygiene (WSH) community working in low-income countries that household-level treatment is typically more effective than community-level treatment, in part because high quality community sources may be inconvenient for many potential beneficiaries, but also because of the potential for recontamination between the point-of-source (POS) and point-of-use (POU) (Clasen and Bastable 2003; Wright et al. 2004). For example, the World Bank's Independent Evaluation Group published a summary of the research on effectiveness of WSH interventions in 2008 stating "there is overwhelming evidence that hand washing, sanitation, and household and point-of-use water treatment improve health outcomes. . . However, there do not appear to be health gains for water treatment at the source" (Independent Evaluation Group (IEG) 2008). Some of this consensus has emerged from meta-analyses of the health impacts of water, sanitation and hygiene interventions in the water sector (Fewtrell et al. 2005; Waddington et al. 2009). These meta-analyses; however, have included relatively few evaluations of water source improvements, which also tend to be less rigorous (i.e., non-experimental) than those for household-level interventions. There have also been a few relatively high profile experimental studies that show only modest improvements in in-house water quality as a result of community-level improvements (Kremer et al. 2011), although none that consider water purified using advanced treatment processes.

This negative view of source water improvements has not prevented a variety of community-level efforts and investments in less-developed countries – from both public and private actors – to expand access to decentralized and higher quality water sources. Examples of such efforts include water kiosks that sell highly treated drinking water, investments in spring protection, or the digging of boreholes to tap (presumably safer) water from deep aquifers (Arlosoroff et al. 1987; Kariuki and Schwartz 2005). One such program is the Safe Water Program (SWP), initiated in 2006 in rural Andhra Pradesh by non-profit institutions. The SWP is one of several kiosk-based programs that focuses on provision of drinking water to rural households from small-scale treatment plants – known in this program as Community Water Systems (CWS) – equipped with advanced water purification technologies (e.g., ultraviolet disinfection or reverse osmosis). Users of such water generally purchase the water directly from the kiosks, or access it through a home delivery service.

This paper examines the effects of the SWP on water sourcing, water and hygiene behaviors, and health outcomes, by comparing changes over time in 25 communities originally chosen to receive the SWP with changes observed in a matched sample of 25 control communities that were not originally chosen to receive the program. In this design, control communities represent "business as usual", rather than "doing nothing" (Ravallion 2008). In fact, as we will discuss in this paper, several of the communities originally assigned to receive the SWP ended up not receiving it, and eventually, some of the control communities did. Furthermore, households living in treatment and control communities were affected by a variety of other circumstances and programs during the evaluation period that affected the same household water, sanitation and hygiene behaviors and outcomes (e.g., health, safe water practices, access to water sources, sanitation) that we tracked in the evaluation.

Our evaluation strategy is to first measure the effect of the program over and above other activities that may have affected this broader study population, using a difference-in-differences (DiD) approach in combination with an intent-to-treat (ITT) estimator, whereby sample households are considered exposed to treatment if they reside in one of the 25 communities originally assigned to receive the SWP intervention. We also discuss how these results change when we instead implement the DiD methodology on a) households residing in communities that actually had received a CWS by 2008; and b) only households who sourced water from the CWS, first using OLS regression, and then using propensity-score matching (PSM) to construct a more appropriate control group that accounts for selection into sourcing of CWS water by examining observable baseline characteristics. Finally, we analyze use and outcomes in the treatment and control communities over the longer term, using follow-up data collected 5 years after the baseline. We examine a variety of outcomes related to access and use of the new water supplies, adjustments to other water-related behaviors, convenience and coping costs associated with drinking water, and water quality and self-reported diarrheal disease.

We find that treatment households were generally aware of the SWP intervention, but that only a minority (~10%) were sourcing water from the CWS at the time of the short-term follow-up conducted two years after the initiation of intervention planning. This rate of use then declines further to about 6% by 2011. Counter to initial expectations, using an intent-to-treat estimator we also observe little evidence of benefits among households living in villages initially assigned to receive a community water system (CWS). Such households do however become somewhat less likely to utilize in-house water treatment methods. Focusing on CWS users in particular, we observe increases in the number of drinking water sources used and in monthly expenses on drinking water combined with substantial decreases in in-house water treatment. This combination of changes may be responsible for the higher reported rates of diarrheal diseases observed among children in user households. Over the longer term, we observe few differences (on average or comparing CWS users to non-users) across households between the originally defined treatment and control communities. Overall, our findings suggest that the CWS plants serve a small fraction of households and do little to lessen the drinking water quality challenges faced by these households. This is noteworthy given that the basic intervention model for these plants has been successfully extended in Andhra Pradesh, and that similar alternatives are increasingly found across a range of locations in less-developed countries.

This paper is organized as follows. The next section briefly reviews the literature on community-level water interventions and water kiosks in particular. Section 3 presents the sampling design and DiD methodology used to evaluate the SWP. Section 4 describes the intervention in more detail. Section 5 explains the data collection procedures. Section 6 presents results, and a discussion of these results concludes.

2. Background

Over the past two decades, there has been steady growth in the number of rigorous impact evaluations of water, sanitation and hygiene (WSH) interventions in low-income settings, including ones geared toward improving the quality of drinking water. This body of evidence has contributed to arguments that household-level point-of-use interventions are generally more effective than community-level investments in drinking water treatment, and that the latter do not provide significant disease reductions. A closer look at the evidence on community water source improvements, however, reveals that there is a remarkable dearth of experimental, or even quasi-experimental, evidence about their effects on drinking water quality and health.

In fact, most water source improvements included in such evaluations do not actually focus on water quality, but rather aim to make water supplies more convenient and accessible to beneficiaries. The most prominent meta-analyses, e.g. Waddington et al. and Fewtrell et al. (Fewtrell et al. 2005; Waddington and Snilstveit 2009; Waddington et al. 2009), include only a handful of studies about community water source improvements, almost all of which are observational. Evaluations of community interventions are generally more difficult to conduct than household-level randomized controlled trials, in part because community-level infrastructure is much more expensive than point-of-use treatment (which inherently limits the scale of experimental programs) (Whittington et al. 2012), but also because large numbers of communities are required to construct sufficiently large treatment and control groups for comparison (Sanson-Fisher et al. 2007). This presents particular challenges for measuring effects on relatively low probability (and often correlated) outcomes such as self-reported diarrheal disease prevalence at the community-level, which is best measured over a relatively short time horizon (e.g. 7 days or 2 weeks) (Blum and Feachem 1983; Schmidt et al. 2007).

Among the more rigorous studies of community interventions to improve water quality, Kremer et al. (Kremer et al. 2011) used a randomized controlled trial to examine the effectiveness of community spring protection. The authors found that this intervention reduced fecal contamination in water by two-thirds at the source, but by only 25 percent for water stored at home, with a corresponding 25% reduction in childhood diarrheal disease prevalence (Kremer et al. 2011). A related study assessed the effectiveness of providing chlorine dispensers at the point of water collection, and found these to be highly cost effective for reducing diarrheal disease (Ahuja et al. 2010). To date, however, there has not been a rigorous evaluation of water treatment kiosks or refill stations, which are an increasingly common model for delivering improved water quality at the community-level (Sima and Elimelech 2013). Water treatment facilities of this type, which typically utilize a combination of technologies that include filtration as well as disinfection or even reverse osmosis, today exist in a large number of countries in urban as well as rural settings, for example in locations as diverse as Jordan, Indonesia and Ghana (Al-Jayyousi 2001; Sima et al. 2012; Opryszko et al. 2013). An important feature of such programs is that users pay for the water they collect from the kiosk.

The business model for these types of treatment systems can generally be categorized into two types: small entrepreneurial businesses and public-private partnerships with growth dependent on donor organizations, government support or community ownership (Sima and Elimelech 2013). The SWP considered in this paper is based on the latter model. For the first eight years, the kiosk is jointly owned by the community and Water Health International, a private company. At the end of this period, full ownership is transferred to the community. One major benefit of the kiosk model is that the management and ownership structures of the stations can be adapted to local conditions. Additionally, the competitive nature of these for-profit enterprises and the availability of other water alternatives in target communities provide incentives to system operators to maintain the quality of their service. A potential downside of such systems is their reliance on the demand for improved water quality; Sima and Elimelech (Sima and Elimelech 2013) for example argue that water kiosks are most viable in urban areas where demand and awareness of water quality problems is higher than in rural villages. The sustainability of ongoing operation and maintenance, as well as access to replacement parts and technical labor, also presents more significant challenges in rural areas.

This paper is the first quasi-experimental evaluation of the water kiosk model. In an observational study, Sima et al. (Sima et al. 2012) compared purified water from kiosks to tap and bottled water in Jakarta, Indonesia. The researchers monitored daily diarrhea and consumption of drinking water from different sources in a sample of 1000 children 1-4 years of age over a 5 month period, and found that diarrhea rates were lower for bottled and kiosk water users than for tap water users in an urban slum. In a peri-urban area, overall diarrhea rates were lower for all children, but diarrhea rates of kiosk users were not significantly different from those of people consuming water from other sources. Because of the high prices of bottled water, the authors argue that kiosks present a more cost effective way to reduce rates of childhood diarrhea, as water from kiosks is nearly four times cheaper than bottled water. A second study examined the effectiveness of for-profit water vending kiosks in Ghana (Opryszko et al. 2013). The study used before and after surveys of 49 households living in 5 different villages over a 3-year interval. The researchers found that the four intervention villages had somewhat lower rates of *E. coli* (though 60% still had such contamination) in household water storage containers than households that used surface water, but that purchases of treated kiosk water declined significantly (to 38% of households) over the three-year period. The authors interpret this as evidence that drinking water from kiosks is somewhat susceptible to recontamination prior to consumption. They argue that the deterioration of water quality at the point of use and declining usage rates over time are issues that need to be addressed for kiosks to be fully successful. These observational studies provide important background for understanding the challenges of kiosk-based water provision. However they stop short of providing convincing evidence that the observed changes were caused by the improvements in water quality delivered by kiosks, given that consumers of such water may be systematically different from non-users in ways that are correlated with in-house water quality and diarrheal disease outcomes.

Another issue for safe water interventions is households' use of water from multiple different sources. In one study by Evans et al. (2011), 64% of households across three different regions reported using a secondary water source, and 46% of those households had on-site water supply. The use of different sources implies that researchers should do more to understand why households choose to use multiple sources and how the use of multiple sources affects the overall quality of the water being consumed.

3. Methods

3.1. Primary evaluation strategy: Intent-to-treat analysis

The evaluation question in this study is whether the SWP causes differences in health, economic productivity, and/or other socioeconomic outcomes for individuals living in villages that adopt the system. To explore this question, we use a quasi-experimental design based on a dual strategy of community-level matching and DiD for estimation of impacts. Given that the SWP was not randomly assigned, we implemented PSM at the study design stage to reduce the risk that the community control villages were systematically different from SWP communities in terms of observable characteristics that are related to selection into the program (Rosenbaum and Rubin 1983; Pattanayak et al. 2010). We created this matched sample of intervention ("treatment") and non-intervention ("control") communities using pre-baseline characteristics from the 2001 Indian Census.

DiD then allows us to compare changes in household outcomes in treatment and control communities measured prior to intervention (at baseline) with those measured during the post-intervention follow-up. The difference in differences estimator approximates the "treatment effect" according to equation 1 (Heckman et al., 1998):

$$DID = \{E[Y_{1t}|p(X)] - E[Y_{1c}|p(X)]\} - \{E[Y_{0t}|p(X)] - E[Y_{0c}|p(X)]\}; \quad (1)$$

where Y is the outcome of interest, the subscripts 0 and 1 refer to pre- and post-treatment, and the subscripts t and c indicate intervention and control unit outcomes, respectively. E is the expectations operator; that is, the DiD measure of impact is the expected treatment effect across treatment units (note that individual subscripts have been suppressed). The estimate is conditional on the propensity score for community participation in the program, $p(X)$, which depends on the covariates X included in the propensity score estimation.

Using this approach, any time-invariant unobservable differences between treatment and control units (not controlled for using PSM) that are related to outcomes are differenced out. This helps to ensure that the measured changes in outcomes are the result of the intervention, and not to these types of time-invariant unobservable differences, or to general improvements or external factors affecting all units over time. The bias due to time-variant unobservables is likely to be negligible for many of the outcomes of interest in this study because we conduct pre- and post-treatment surveys over a relatively short time period and because control group members are drawn from communities that are very similar to treatment communities, at least in terms of the intervention probabilities calculated using PSM.

We implement the DID approach using a regression framework that includes an interaction variable for the study condition d and for the treatment period T:

$$Y_{ijt} = \alpha + \beta Z_{ijt} + \gamma T_{jt} + \delta d_{jt} + \kappa T_{jt} \cdot d_{jt} + \varepsilon_{ijt}; \qquad (2)$$

where d is equal to 1 if household i is in a treated community, and 0 otherwise, and T is equal to 1 once the intervention has occurred in community j. This regression is a multi-level model: treatment is assigned at the community-level, but we generally measure outcomes at the household level (e.g., diarrheal disease prevalence among children under the age of 5). Z_{ijt} represents a set of household specific controls that are related to the outcome of interest and that vary over time and is not included in our base case specifications (except for age in the regressions for diarrheal disease prevalence), and ε_{ijt} is a household-specific error term. The primary coefficient of interest is κ; this coefficient measures the change in the outcome Y for affected households relative to that for control households, while γ indicates the change in Y over time among controls. Because not all households in a given community choose to consume treated drinking water from the CWS (and because not all communities in the treatment group end up having a CWS by the follow-up survey in 2008), the coefficient κ represents an ITT estimate. This ITT estimate indicates the average effect of the community-level intervention across all households living in that community, whether or not they adopt the intervention improvements (Galasso et al. 2001).[1]

3.2. Secondary evaluation strategy: Estimating impacts on CWS users and other groups

We also estimate the effect of the treatment on the treated (the average treatment on the treated, or ATT) by analyzing the effect of the SWP program on households who actually purchase water from a CWS in the communities originally assigned to receive the intervention:

$$Y_{ijt} = \alpha + \beta Z_{ijt} + \alpha^{u} U_{ijt} + \alpha^{nu} N_{ijt} + \gamma T_{jt} + \beta^{u} U_{ijt} \cdot d_{jt} + \beta^{nu} N_{ijt} \cdot d_{jt} + \nu_{ijt}; \qquad (3)$$

where U is a dummy variable that is equal to 1 if household *i* is a purchaser of water from the CWS following the intervention, and 0 otherwise. β^{u} is the parameter measuring the effect of the SWP on users of the CWS, or the average effect of the treatment on the treated, while β^{nu} measures the impact of being in a SWP community among those who do not purchase water. In this model, the time trend for the change in the outcome of interest among households in (originally-assigned) control communities is again indicated by γ. Relative to the ITT estimates, interpretation of these ATT coefficients is complicated by the fact that purchasers of CWS water may not be directly comparable with non-purchasers, even after controlling for time-varying observable characteristics Z_{ijt} that affect outcomes Y_{ijt}.

As an additional way to study the effect of the treatment among users (ATT), we conducted propensity score matching (PSM) to more directly compare users to observationally similar households in the control villages. In implementing PSM, we specified the first stage for selection into use of the CWS using the following logit model:

$$U_{ij,post} = \alpha + \beta Z_{ij,baseline} + \nu_{ijt}; \qquad (4)$$

where $Z_{ij,baseline}$ is a vector of baseline characteristics that are related to the decision to use the CWS. Based on a combination of theoretical expectations and empirical considerations, we developed a parsimonious and more complete list of such characteristics for inclusion in the model. The full list of

[1] In sensitivity analyses, we also estimate equation 1 with the community treatment assignment specified according to whether the community actually had obtained a CWS by 2008. Due to concerns over the endogeneity of final treatment status, these are not our preferred estimates of the program's impact.

such criteria included household income, household size, the number of children under 5 and prevalence of diarrhea among those children, literacy of the household head, age of household head, the time spent collecting water, and indicators for whether the household reported being very satisfied with its main drinking water source, for treating water in-house, for believing that unsafe water causes diarrhea, for thinking that the government should pay for improvements to water supply, and for participation of household members in village cleaning activities. We tested the sensitivity of our results to inclusion of this full list and a shorter list of these variables.

4. Description of the intervention

The SWP implemented in Andhra Pradesh combines a CWS that uses advanced drinking water treatment with a health promotion program designed to encourage the consumption of safe drinking water. The CWS collects and conveys water from a community surface water source to a storage and treatment unit, using an electric pump. The water is then filtered, passed through UV radiation units (or in some cases, reverse osmosis), treated with ozone, and stored until it is distributed to customers via taps located at the facility. A non-profit foundation helps to identify eligible communities and facilitate the financing requirements of the SWP interventions, while a specialized international NGO is responsible for technical aspects, including construction of the system and operations and maintenance of the system during the first eight years. The intervention is designed such that most communities recover sufficient costs to gain ownership of the CWS at the end of this period.

At the time of this evaluation, community eligibility for an SWP was determined based on five factors: a) access to a perennial source of surface water; b) no chemical contamination in communities using systems other than reverse osmosis (as indicated by district engineers, with verification for arsenic and fluoride); c) a population of 4000 or more (or 2000 for a smaller, modified CWS); d) interest from both local leaders and the community as a whole; and e) the ability to mobilize a 20-40% down payment for construction of the CWS, in addition to the willingness to grant land and water use rights where it would be constructed.[2] Determining community interest and ability to mobilize a down payment involved a series of meetings and marketing efforts spread over weeks to months and targeted at local leaders. The

[2] The balance of the cost of the CWS was financed with commercial loans backed by the Acumen Fund's loan guarantee, that were repaid using revenues from sales of water produced by the CWS. The financial model for the program assumes that the average system would be paid off and ownership transferred to the community after 8 years.

first three of these eligibility criteria are directly observable, whereas the second two are not, which provides the motivation for using PSM to create a matched sample based on a wider set of community characteristics that are correlated with selection into the program.

Salaries for water operators and operations and maintenance expenses at the CWS are paid using revenues from the sales of water. The water and hygiene promotion staff were hired and trained by the institutions supporting the project. These promoters visited households to describe the system and provide water quality information, collect baseline data on water sources and perceptions, and build interest by communicating the benefits of water treatment. Once construction was completed, residents could register, pay the deposit for an approved 12 or 20 liter water container (80-120 Rs.), and begin purchasing water for a single-use cost of 1-2 Rs. depending on the facility and the size of the container.[3] The SWP continued to employ the water promoter to visit households and promote use of the facility and adoption of safe water handling practices during this time.

5. Evaluation sample design and data

4.1. Matching and sample selection

As described above, the sample of treatment and control communities was developed using PSM. Based on the geographic extent of the SWP, communities in three districts (Guntur, West Godavari, and Krishna) of coastal AP were included in the sampling frame. Given that the institutions promoting the intervention made the final decisions about community selection based on the latter's interest in the SWP, it is reasonable to assume that these communities would differ from communities that opted out of the intervention, never showed any interest, or were not targeted by the program.

Thirty treatment communities were determined to be eligible for the study based on three conditions: (1) they had not had significant interactions with the implementing organizations (and therefore did not yet have a CWS under construction) beyond their selection into the program at the time of the baseline survey in October 2006; and (2) they were expected to receive CWS units that would be completely operational for at least six months prior to the Round 2 survey. In addition, to ensure that control communities were sufficiently similar to treatment communities, the sample of control villages used for

[3] Users could purchase single-use coupons entitling them to fill their containers, booklets of coupons, or punch cards that were valid for one month. If they opted to discontinue use of the CWS, they could return the project water can and obtain a refund of their deposit

PSM was restricted to include only villages: a) located in the three study districts within Coastal Andhra Pradesh (Guntur, Krishna, and West Godavari); b) with populations exceeding the thresholds for SWP eligibility (based on Census data); c) with no known chemical contamination of drinking water sources (as reported in the 2003 National Habitation Survey); d) that were not included in lists for planned future marketing, construction, or operation of systems over the period 2006-2007; and e) for which Census data indicated that no households were using surface water drinking sources.

Then, using PSM, each treatment community was matched with an observationally similar control community in the same district (based on community-level data drawn from the Government of India's 2001 Census, the 2003 National Habitation Survey, the 2002-2004 Reproductive and Child Health (RCH) study, and the 1998-1999 National Family Health Survey. The variables included in the estimation of propensity scores for construction of the sample included the availability of perennial surface water sources, population, and indicators of socioeconomic status (occupation, education) of community members. The variables explaining participation had the expected signs – that is, they were consistent with the criteria that the CWS/SWP program purported to use to select project villages. We then conducted nearest neighbor matching without replacement, eliminating matches falling outside the common support region. For the final sample, the best 25 matches were selected, and covariate balance across the treatment and control communities was confirmed (Poulos et al. 2006).

The sample size of 2,500 households in 50 villages was developed to allow for detection of anticipated effects on diarrheal prevalence among children under the age of five (Poulos et al. 2006). In each survey village, households were randomly selected from village lists of all those residing in the community, and only those having at least one child under 3 years of age in 2006 were included. Fifty-five households were enrolled from each community; it was hoped that the extra 10% would protect against loss of power due to attrition of households between baseline and follow-up. Unfortunately, we found in the follow-up survey that an unexpectedly high number of study households could not be recontacted due to high rates of out-migration in these communities. As a result, we replaced households that could not be relocated with new households having at least one child under 5 years of age. So long as migration is not related to the SWP (which in the short term seems plausible and which we include in balance tests), these replacements should not affect our ability to accurately identify program impacts.

4.2. Data

The data for this study come primarily from two waves of surveys conducted in the 50 sample villages included in our sampling frame. Due to the threat of unobservable time-varying confounders, the bulk of our analyses use the data from the baseline (prior to any CWS project activities) and round 2 surveys conducted in 2006 and 2008, which are short-term impacts. Since diarrheal disease is a key outcome variable in the analysis, these two waves were conducted in October, shortly after the monsoon, in order to avoid inconsistencies arising from the seasonality of diarrhea prevalence, and to coincide with peak levels of diarrhea. The timing of the first follow-up survey (in October 2008) was determined based on qualitative assessments of field progress with CWS installations, which also indicated that use of the facilities was falling short of program expectations of 60% coverage during the first 9 months of operation. Also, for a reduced set of outcomes, we present long-term impacts using data collected in a later wave, conducted in January 2011. After 2008, CWS promoters broadened the marketing strategy for this technology, which led to implementation of new systems throughout the region (and in control areas). Analysis of the data from 2011 therefore allows us to see whether there were any long-term effects on treatment areas relative to the broader trends in this zone.

To assess the CWS' impacts, we used carefully pre-tested household and community surveys and water quality sampling to measure variables. The household questionnaires included questions on: demographics (e.g., age and sex of household members); caste and poverty levels; education; diarrhea prevalence (2-week and 1-month recall) and cost of illness; water sourcing and consumption; water handling, storage and treatment practices; sanitation and housing conditions; and a variety of socio-economic characteristics. The community questionnaire was used to collect information on a range of community-level variables, including roads, electricity, sanitation conditions, water sources, health and educational facilities; general availability of employment opportunities, credit, and markets; and key governmental and nongovernmental programs providing services in the community. This questionnaire was administered to key informants such as the village leader, governing council members, or a member of the local water and sanitation committee. In addition to these questionnaires, water samples were collected and analyzed from both community sources and household storage containers for a sub-sample of 1,396 households (and 1,161 in round 2). The samples were tested for total coliform and *E. coli* counts.

The key outcome variables analyzed in this paper are: 1) access and use of the CWS for drinking water; 2) in-house water quality; 3) several other water and hygiene-related behaviors (e.g., in-house water treatment, water storage and handling practices, and the use of safer storage containers); 4) changes in self-reported diarrheal disease prevalence; 5) time spent collecting water and other coping costs (e.g., expenses on drinking water, cost of illness).

6. Results

This section summarizes the results from our evaluation of the impacts of the SWP. We begin by describing the sample of households and communities, and present balance tests on the treatment and control samples, using the baseline data obtained in 2006. Then, we present the DiD results from the analysis of changes in short-term outcomes for various model specifications, using the data from the Round 1 and Round 2 surveys conducted in 2006 and 2008, and focusing on the ITT impacts among treated households. After that, we aim to characterize which households living in treatment communities actually become users of the CWS, and present estimates for impacts among those particular households (estimated using OLS DiD regression, and propensity score matching in order to account for the differential selection into sourcing of water from the CWS). We close by extending this final analysis to consider long term changes in community treatment status and outcomes among users, using DiD on a reduced set of outcomes that were collected in both 2006 and the abbreviated 2011 survey.

6.1. Descriptive statistics and sample balance

Table 1 presents summary statistics measured at baseline for the original sample (2752 households) and then again at follow-up (2361 households); baseline balance for a variety of relevant variables across treatment and control arms is then assessed in Table 2. Average household size was 4.5 members, with 1.4 of those members being children under 5 years of age. Almost all survey respondents were female and their average age was 23 years old. The average household income was roughly 2760 rupees (Rs.) per month.[4] By 2008, after a period of extremely rapid growth throughout Andhra Pradesh, households in both treatment and control villages were significantly better off, with average monthly household income rising to about 4290 Rs., though 47% of households still reported being below the poverty line (a very large reduction from the baseline level of 91%). Respondents reported that 54% of household heads were literate at baseline, while their average number of years of schooling was only 4.3 years. At baseline, community participation rates were relatively low, with only 13% of households stating that at

[4] At the time of the baseline survey, US$1 = 45 Rs.

least one member participates in neighborhood cleaning activities and 15% of households having at least one member who attended a community meeting (Gram Sabha) in the six months prior to the survey.

There was substantial variation in household sanitation and hygiene habits at baseline, with just under half of the sample (48%) practicing open defecation, and the rest having access to a private toilet. Respondents were asked when and how they washed their hands in the past 24 hours. On average respondents reported washing their own, and their young (under five years old) children's hands with soap 1.8 out of 5 and 0.6 out of 2 critical times, respectively – these were (1) before preparing food or cooking (adults only), (2) before eating, (3) before feeding children (adults only), (4) after changing baby/handling child's feces (adults only), and (5) after defecation. Handwashing with water alone, though, was more common: respondents used soap on their own and their young children's hands at only 4.3 and 1.7 of those times, respectively.

Safe water storage behaviors also varied considerably within the sample. In 2006, while 97% of households fully covered their water storage container and 84% washed their storage container daily, only 11% used a narrow mouth water vessel and only 8% elevated their main drinking water container more than 3 feet off the ground. Thirteen percent of households claimed to remove drinking water from containers using a method that minimizes the possibility of contamination. Additionally, enumerators observed flies near 32% of households' drinking water containers. Nearly half (48%) of households treated or filtered their drinking water by boiling, filtering or using chemicals. Households used an average of 1.6 water sources and reported consuming an average of 56 liters per capita per day.

At baseline, 9% of children under 5 and 10% of children under 3 had had diarrhea in the two weeks prior to the survey, while the rate of diarrhea prevalence for adults was only 2%. Ten percent of households whose water was analyzed tested positive for *E. coli* contamination. Cost of illness, measured as the sum of out-of-pocket expenditures and lost income, averaged 535 Rs. per month, and coping costs were estimated at 365 Rs. per month.[5] In 2006, prior to the implementation of the SWP, only 3% of households said they had access to some type of treated commercial (non-bottled) water supply, and

[5] Monthly coping costs were calculated as the sum of (1) the monetized value of time spent collecting water, (2) expenditures on water treatment (boiling, filtering, and using chemicals), and (3) expenditures on water storage. The value of the time spent collecting water was calculated as the time spent walking to the household's water source plus the time spent waiting at the main water source times the number of trips per day to the main water source times the average hourly wage of the person collecting water (as calculated as the village hourly wage over the rainy and dry seasons for men, women, and children, respectively).

none were regular users of such sources. By 2008, over 45% of households had access to such commercial water, though only 8% of households in the sample reported buying water from a CWS.

As indicated in Section 2, we used PSM to draw a sample of matched treatment and control villages prior to undertaking the baseline survey, using secondary data drawn primarily from the 2004 Indian Census. An analysis of the primary covariates of interest in the study using the more detailed data collected in 2006 confirms that treatment and control villages were generally balanced across 28 key variables not available prior to the matching procedure, including health outcomes, water and sanitation conditions, and socioeconomic conditions (Table 2). In addition, there was no differential attrition across treatment and control groups. The only statistically meaningful imbalances were that treatment communities reported significantly less satisfaction with their main drinking water source at baseline (p=0.04), although more than half (53%) of treatment households still reported being very satisfied (compared to 69% in control communities). Given that treatment households were sensitized to the fact that CWS construction was planned for their community at the time of the baseline survey (i.e., treatment communities had already been selected for the program), this difference is not surprising. Perhaps for similar reasons, treatment households were also more likely to think that water supply was the most important village environmental problem (p=0.02), and less likely to think that sanitation and hygiene was the most important problem (p=0.01).[6]

6.2. Short-term ITT impacts

Table 3 shows the results of our DID analysis for the impacts of the CWS on a variety of outcomes of interest. The results are mostly insignificant. Among treatment households, who reported access of 3% to commercial treated water at baseline, we find a large increase in access by 2008. The DiD estimate of 43 percentage points shows; however, that reported access in 2008 is not universal (it rises to 67% overall, since control households report access of 22% to such water in 2008). The lack of universal access in the treatment group is at least partly due to the fact that not all communities originally planned to receive a CWS actually had one by 2008 (of the 25 treatment communities, 20 received the planned CWS). Similarly, 2 control communities ended up receiving a CWS by 2008, such that some control households had gained access to a CWS in their villages while others in this group became aware

[6] A large number of other characteristics were also assessed for balance (results not shown). This set of tests revealed differences in the number of community surface water bodies and agricultural loans (higher in the treatment group), and use of neighbors' toilets, educational loans, and sewing machine ownership (lower in the treatment group). The number of such imbalances is not inconsistent with the expected probability of Type 1 errors.

of access in neighboring treated villages. Due to the endogenous selection into treatment, our preferred estimates of impacts are these ITT estimates; if we use actual treatment status in 2008 the effect on access in treated communities is a net increase of 83 percentage points over and above the reported access of 12.5% among households in the control group, representing nearly 100% reported access (results not shown).

Looking beyond access alone, we find that households are only 10 percentage points more likely to use water from a CWS than their counterparts in the control group in 2008 when using the ITT estimator (13% of treatment households report being users vs. 3% of control households). In those communities actually receiving a CWS by 2008, use reaches almost 18% (compared to 1% in communities without a CWS). These low levels of uptake of CWS water may partly explain why so few of the other outcomes tracked by the evaluation change significantly among treatment households, as summarized in Table 3. We do find that households in treatment communities report using 0.14 more drinking water sources on average, but also somewhat reduced water consumption (by about 7 liters/capita-day) and higher time spent per trip to the main water source (by 3.6 minutes/trip), compared to households in control communities. These changes may relate to the higher cost of CWS water (in money and distance, relative to baseline sources) and the inability of households to fully switch to the CWS to meet their drinking water needs. In addition to this, the percentage of households treating water at home is 7.3 percentage points lower in the treatment group, suggesting that many households see CWS water as a substitute for in-house water treatment. This may have negative implications for in-house water quality if these households continue to use other sources and/or mix water from different sources together. Reflecting this possibility, the percentage of households testing positive for detectable *E.coli* contamination also increase by 7.9 percentage points, though this result is not statistically significant. If we compare communities that were actually treated by 2008 with those that were not, these differences mostly increase, except for differences in in-house treatment and water consumption (which are 6.4%, and 1.2 L/capita-day lower among actually treated households, respectively).

Among the remaining variables in Table 3 (e.g., other safe water handling and storage behaviors, diarrheal disease prevalence, and measures of overall coping costs or expenses on water, in time and money), we find no statistically significant results. Nonetheless, there are consistent patterns towards higher diarrheal disease prevalence and cost-of-illness, as well as increased costs of water, in time and money. These are partly mitigated by lower coping costs, perhaps due to substitution away from in-house water treatment. For the most part, the statistical significance of the DiD coefficient for these variables does not change when considering the actual treatment assignment in 2008, except for 1-month diarrhea prevalence rates. These increase and become statistically significant at the 10% level among children under 3. Similarly, the addition of control variables for income, age of the respondent, and number of nearby water sources to the DiD model does not alter these coefficients in a substantial way.

Taken together, these results suggest that the CWS intervention had limited average impacts on households in these communities, and that the impacts it had appear negative. Since so few households in treatment communities actually became CWS users, it is also possible that there was insufficient statistical power to identify positive impacts. Another possibility is that compensating behaviors may have undone some of the expected benefits of the intervention. The direction of the changes in in-house water treatment, coping costs, and *E.coli* contamination among treatment households is consistent, though few of these results are statistically significant. Since users of the CWS had to pay to access water, they may have used it only partially and may have mixed water from safe and unsafe sources, even as they relaxed investment in other protective behaviors. To explore some of these possibilities further, we turn below to our attempts to isolate impacts among CWS users, first using standard regression models as shown in equation 3, and then using the two strategies discussed previously (propensity-score matching and a two-stage selection model approach) that seek to account for the problem of selection into CWS use.

6.3. Short-term impacts among CWS users using OLS regression

To estimate the effect of treatment among users (the average treatment on the treated, or ATT), we first estimate the model shown in equation 3. Table 4 presents these results. As expected, users from villages originally assigned to the treatment group (N = 163) report greater access to the CWS experience; reported access reaches nearly 100%, and represent 77% greater access than households in control communities, who report 21% access (not shown). Non-users (N =1,011) in treatment communities report 59% access (this corresponds to 21% + 38% increase over access among control group households). Users also experience an increase in spending on water purchases relative to non-users and households in control communities. Based on the prices charged in intervention communities, this increase corresponds to about 20-30 containers of water from the CWS each month. The changes in several other impact variables among CWS users however run counter to expectations; by 2008, households had 14% higher rates of E. coli contamination (though these are not statistically significant), and experienced increases in two-week diarrheal disease prevalence (by 4% and 7% among under 5 and under 3 year olds, respectively). Non-users did not experience a change in diarrheal disease outcomes that was different from households in control communities. On the other hand, there is no significant change in reported cost of illness among users or non-users.

A closer look at the evolution of household behaviors associated with use provides some insight into what may be driving these negative water quality and diarrheal disease results. On average, users report sourcing drinking water from 0.7 more locations than households in control communities, which suggests that these households only make a partial switch away from traditional sources. Thus, they may be mixing water from several sources of variable quality. They also spend an additional 18.4 minutes per trip to their main drinking water source. At the same time, households that use CWS water are 25% less likely to treat their water than control households at follow-up (there is no significant change among non-users relative to control households). These large declines in household water treatment, combined with the increase in number of drinking water sources used, may be responsible for the increases diarrheal disease risks for children living in these households. Users do have increased ownership of narrow mouth water containers, by 24% relative to controls, which is consistent with the CWS requirement that household own a narrow mouth container. They also use somewhat safer means of removing water from containers, 14% relative to controls. In general, except for access to the CWS, we observe very few changes among non-users relative to control households, in contrast to the larger number of significant differences between users and control households. As with the ITT analysis, these results are unchanged when control variables are added to the DiD model.

6.4. Short-term impacts among CWS users using propensity score matching

As an additional way to study the effect of the treatment among users (ATT), we conducted propensity score matching to more directly compare users to observationally similar households in the control villages who did not have the same opportunity to source drinking water from a CWS. For this analysis, 130 treated (user) households were matched to an eligible sample of 929 control households from untreated communities; the results of parsimonious and more complete selection models are shown in Table 5.[7] These selection models support the idea that there is positive selection into use of CWS: Users tend to be more educated and somewhat better off, and also tend to have more young children and are

[7] Six user households were excluded as being off support, and the remainder were excluded due to missing covariates required for the first stage selection model. These users missing covariates were mostly replacement households who were only enrolled in 2008 and therefore did not have the required data for the first stage.

more likely to engage in protective behaviors. They are also less likely to state that the government is responsible for paying for improvements to water supply.

We analyzed the same set of outcomes and downstream impacts for the matched samples of users and controls as in the ITT and OLS analyses for users discussed above. The results of the PSM and ATT analyses are generally consistent, but the former mostly appear stronger, consistent with the pattern of positive selection into use. User households have significantly greater access to commercial treatment plants and use a greater number of drinking water sources (Table 6). They have more positive E.coli tests (this time the effect is significant in one of the two models), and are significantly less likely to treat their water at home. Consistent with the DiD results discussed above, they are more likely to have narrow mouth drinking water containers and to remove water from those using a safe method. Among the other downstream impacts, the effects are also much stronger. Users clearly spend more money on drinking water (by about 40 Rs./month), and spend more time per trip to their main drinking water source (by about 14 minutes). As with the OLS estimates, however, users of the CWS also appear to suffer higher diarrheal disease and cost of illness.

As an added check on the robustness of these PSM estimates, we also assessed differences in outcomes between users and their matched controls for outcomes observed at baseline, prior to the installation of the CWS plants in treatment communities. We note very few statistically meaningful differences; users only have slightly higher treatment of water at home (the opposite of what is observed at follow-up), and somewhat lower likelihood of covering drinking water storage vessels at home. Baseline diarrheal disease rates are somewhat higher among eventual users, but these differences are not statistically significant, due to the higher and more variable overall disease rates in 2006 relative to 2008.

6.5. Long-term impacts among households in treatment communities and CWS users

We conclude the analysis of CWS impacts by examining longer term changes in treatment versus control communities. For this analysis, we utilize data collected later in 2011 in an additional wave of surveys. Given the changes detected among users in particular in the preceding section, we would ideally focus solely on users of CWS water for this assessment, but this is complicated by two issues. First, there is nearly total contamination of the treatment and control samples of communities by 2011. Specifically, 78% of households report access to the CWS in communities originally assigned to the treatment group in 2011, while access reaches 77% in those originally assigned to the control group (Figure 1). On the one hand, this can be taken as evidence that the matching algorithm used to create a sample of control communities for the study that were similar to treatment villages was successful; unfortunately it also means that we cannot easily compare users in treated communities to a set of control households that no longer have access to a CWS. Second, the set of users is dynamic and we only observe these households at very specific points in time. These dynamics make interpretation of the effects on users difficult, since use may be driven by factors that are not observed and that are not exogenous. Thus, for assessment of impacts over the longer term, we first present the results of ITT analysis to address the question of whether the original assignment to participate in the CWS program had any long term impacts on households living in those communities. We then consider users in more detail solely using DiD OLS regression (since PSM is no longer possible given the sample contamination).

Not surprisingly given the previous results, we find no impact of the program on average (ITT) outcomes for households in the original treatment communities over the longer term (Table 7 Columns A1 and A2). Even the impacts on use of the CWS over the short term disappear once control communities gain access to treatment facilities, as shown by the significant negative DiD coefficient on use in treatment communities during the later period. On the one hand, this could be seen as evidence of success of the business model for the CWS, which managed to spread across the region during this time. Nonetheless, the lack of positive impacts on users noted in the preceding section raises questions about the value of those changes. In addition, in both treatment and control communities, use of the CWS is very low by the end of the survey period (ranging from 3-6% across control and treatment communities in 2011) despite the widespread awareness of such supplies (Figure 1). In fact, the only persistent average impact on households in treatment communities appears to be in lower household treatment of drinking water, which decreases by 11% relative to in-house treatment in control communities.

Turning to the DiD analysis of impacts among users over the period 2006-2011, we explore impacts using two definitions of users. The first (reported in Columns B1 and B2) compares only users in communities originally assigned to the treatment group with all households living in control communities. Interpretation of results over the period 2008-2011 and 2006-2011 is complicated by the fact that many control households did gain access to CWS water over the later period, and by the fact that there is very little overlap between users in the two samples.[8] Nonetheless, the users in originally treated communities are less likely to be using narrow-mouthed containers in 2011 than households in the original control communities, and partake in less frequent hand-washing. The second set of

[8] In particular, there are 163 CWS users in treated communities in 2008, and 55 in 2011, but only 6 of these households are users in both periods.

comparisons (reported in Columns C1 and C2) offer similar evidence for users in both treated or control communities compared to non-users.[9] We again see few significant differences, and none for diarrheal disease outcomes. As with the ITT results, the addition of control variables for income, age of the respondent, and number of nearby water sources does not alter these coefficients in a substantial way. Using the same specifications for predicting use in 2011 as in 2008 (previously presented in Table 5), we also determine that user households in 2011 in both treated and control communities remain more likely to have been treating drinking water at baseline than non-users (results not shown), but that few other factors predict use in 2011. Overall, we conclude that these users are somewhat more aware of the CWS than nonusers even in 2011, but that the only changes in behavior and outcomes among users over the long term that are discernible using DiD analysis are in slightly lower hygiene or risk-averting water behaviors. Perhaps more importantly, very few (only 6 households) of the users from 2008 were still purchasing CWS water in 2011.

7. Discussion

This paper examined the impact of the SWP program, implemented in Andhra Pradesh, India, on a representative sample of households living in 25 communities included in the intervention. The SWP combined advanced community water treatment at village-level CWS facilities with hygiene and behavioral change messaging aimed at marketing the CWS water and improving safe water practices at the household level. Using a quasi-experimental approach that combined pre-intervention matching on village-level Census characteristics of treated and control communities with difference-in-difference analysis, we observe low purchase rates for CWS water (ranging from 5-10% over the time horizon for the study) and little evidence of impacts on households in treated communities, at least on average, in either the short (2 years post-baseline, in 2008) or long term (5 years after baseline, in 2011). In fact, in parallel with the increase in CWS water use, we observe a slight decline in in-house water treatment (by about 7 percentage points) and an increase in expenditures on and time spent per water collection trip.

Additional analysis using both regression and post-survey propensity-score matching methods suggests that CWS users in treated communities regularly collected water from more sources, were especially likely to stop using in-house treatment, and had worse water quality as well as marginally higher child

[9] In this case, there are 200 users in 2008, and 86 in 2011, but only the same 6 households are users in both periods.

diarrheal disease rates in 2008, suggesting that the substitution to CWS water was neither complete nor sufficient to improve water quality at the household level. Because such households were wealthier, had more education, and were more likely to treat their water at baseline, the results obtained using PSM (to find similar households in control communities) are somewhat stronger than those obtained using simple DiD regression. Finally, by 2011, the majority of households in control villages had also gained access to CWS water plants, and we observe few differences between treatment and control households, or between user and non-user households, with the exception of somewhat lower in-house water treatment among CWS users.

Overall, our findings suggest that the CWS plants have succeeded in serving a relatively small fraction of households in their communities and do little to lessen the drinking water quality challenges faced by these households. The results are also largely consistent with the theory of constrained utility maximization for production of household environmental health (Pattanayak and Pfaff 2009), since additional expenditures on water from the CWS would naturally lead to substitution away from other time and resource-intensive activities such as household water treatment. In addition, the other features of the SWP did not appear to have significant positive effects on safe water practices in treated communities. More intensive social marketing or use of salient messaging regarding water quality may be required to promote these and other changes (Pattanayak et al. 2009; Hamoudi et al. 2012).

These results are noteworthy given that the basic intervention model of advanced water treatment plants has been successfully extended across many communities in rural Andhra Pradesh, and that similar kiosk-based alternatives are increasingly found across a range of locations in less-developed countries (Kariuki and Schwartz 2005; Sima et al. 2012; Opryszko et al. 2013). While this spread of the decentralized community water treatment model suggests that it is often financially viable, there is no rigorous evidence that it provides water quality and health improvements in settings where in-house water storage is required. In effect, the relatively modest rates of household consumption of water from such plants may stem from the cost of such water, the inconvenience of accessing a community-level kiosk (relative to other water sources), or the knowledge that water quality and protection from diarrheal diseases is not effectively provided by it.

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Tables and Figures

Table 1. Sample descriptive statistics

	2006		2008	
Variable	**N**	**Mean**	**N**	**Mean**
Demographics				
Female Respondent	2752	1.00	2361	0.99
Respondent's Age	2752	23.0	2361	25.1
Average total monthly HH income (Rs.)	2751	2756	2349	4292
HH faced serious crisis in the past year	2749	0.16	2292	0.06
HH is below poverty line (bpl)	2725	0.91	2310	0.47
Average years of schooling of HH head	2749	4.31	2353	3.69
Average HH size	2752	4.48	2344	4.57
Number of children under 5	2752	1.36	2361	1.19
Community participation				
HH participates in neighborhood cleaning	2751	0.13	2357	0.10
HH attended Gram Sabha, prior 6 months	2742	0.15	2311	0.22
Water supply				
HH uses a private connection for drinking	2752	0.29	2361	0.25
HH uses a public tap for drinking	2752	0.51	2361	0.43
HH uses a public well for drinking	2752	0.07	2361	0.11
HH uses a private well for drinking	2752	0.11	2361	0.08
HH uses surface water for drinking	2752	0.04	2361	0.02
Access to commercial treatment plants	2752	0.03	2361	0.45
HH uses water from CWS	2752	0.00	2361	0.08
Water consumption (lpcd)	2752	56.1	2361	27.7
Number of water sources used	2752	1.56	2361	1.67
Number of drinking water sources used	2752	1.08	2361	1.14
HH very satisfied with main drinking water source	2752	0.61	2361	0.70
Water treatment, handling, sanitation, and hygiene				
HH practices open defecation	2751	0.48	2357	0.40
Flies observed near main drinking water vessel	2645	0.32	2352	0.13
Main drinking water vessel is fully covered	2751	0.97	2352	0.99
Main drinking water vessel has narrow mouth	2749	0.11	2352	0.12
Main drinking water vessel elevated > 3 feet	2684	0.08	2352	0.13
Wash drinking water storage containers daily	2752	0.84	2361	0.81
Water is removed from container with safe method	2750	0.13	2352	0.07
Treats or filters water before drinking	2752	0.48	2361	0.30
# of times adults wash hands with soap at critical times	2752	1.83	2358	1.33
# of times children wash hands with soap at critical times	2752	0.61	2358	0.59
Water quality and diarrheal disease				
HH has ecoli	1396	0.10	1161	0.20
2 week diarrhea, all children under 3 years old	2524	0.10	1196	0.05
2 week diarrhea, all children under 5 years old	3745	0.09	2818	0.03
2 week diarrhea, all adults	8573	0.02	8044	0.01
Cost of diarrheal illness (Rs./month)	2752	535	2361	142
Coping costs				
Time spent collecting water (minutes/month)	2752	664	2361	1027
Costs of treating water (Rs./month)	2752	296	2361	181
Costs of storing water (Rs./month)	2622	8	1807	11
Water purchase cost – all sources (Rs./month)	2752	14.9	2361	17.6

Total coping costs (Rs./month)	2752	364	2361	287

<u>Notes</u>: Due to laboratory constraints, *E coli* was only tested in a randomly selected half of the sample. Observation of drinking water containers was attempted, but was not possible in 102 households in 2006 and 534 households in 2008; outcomes for these households are self-reported. Prevalence of diarrhea, measured based on having 3 or more loose stools within any 24 hour period, is for all sample children within the specified age groups. Coping costs are calculated as described in the text.

Table 2. Balance tests for treatment and control communities

Household Characteristic	**Treatment**	**Control**	**p-value**
Sample size	1377	1375	n.a.
Demographics			
Respondent is female	99.9%	100%	0.15
Respondent's age	22.9	23.1	0.27
Average household income (Rs./month)	2,786	2,726	0.67
Household faced a serious crisis in the prior year	18.1%	13.0%	0.18
Household is below the poverty line (bpl)	92.1%	90.9%	0.65
Average schooling of respondent (years)	4.3	4.4	0.82
Respondent is literate	53.4%	53.8%	0.91
Average size of household	4.5	4.5	0.98
Household was lost to follow up	16.2%	14.9%	0.55
Water sourcing			
Household uses drinking water from a private water connection	33.8%	33.6%	0.97
Household uses public taps for drinking water	87.5%	89.7%	0.65
Household uses public wells for drinking water	70.1%	71.4%	0.91
Household uses surface water for drinking water	15.3%	13.3%	0.75
Household is very satisfied with main drinking water source	53.0%	68.8%	0.04**
Distance from house to nearest surface water source (in minutes)	8.5	8.2	0.78
Water treatment, handling, sanitation, and hygiene			
Household practices open defecation	50.6%	45.0%	0.27
Household has a private toilet	50.1%	52.9%	0.55
Flies observed near main drinking water storage vessel	32.8%	30.8%	0.69
Main drinking water storage vessel is fully covered	96.7%	96.8%	0.96
Main drinking water storage vessel has a narrow mouth	10.1%	12.1%	0.72
Respondent washes drinking water storage containers daily	84.5%	83.3%	0.79
Household treats or filters water before drinking it	51.5%	44.2%	0.17
# of times adults wash hands with soap at critical times	1.9	1.8	0.64
# of times children wash hands with soap at critical times	0.6	0.6	0.76
Community environmental problems			
Respondent thinks sanitation / hygiene is the most important problem	14.9%	25.4%	0.01***
Respondent thinks water supply is the most important problem	14.2%	7.2%	0.02**
Household members participate in activities for cleaning neighborhood	14.1%	12.9%	0.77
Diarrheal disease			
Child (≤3 years old) had diarrhea in the prior two weeks	11.5%	11.5%	1.00
Child (≤5 years old) had diarrhea in the prior two weeks	12.8%	13.3%	0.82
Any member of household had diarrhea in last two weeks	21.3%	21.2%	0.98
% lost to attrition in 2008	22.1%	19.3%	0.34

Notes: Balance tests were conducted by regressing the variable value in 2006 on treatment assignment using OLS. Standard errors are clustered at the community level, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). Observation of drinking water containers was attempted, but was not possible in 102 households in 2006; outcomes for these households are self-reported. Prevalence of diarrhea, measured based on having 3 or more loose stools within any 24 hour period, is for all sample children within the specified age groups.

Table 3. Comparison of key outcomes for treatment and control households—Intent to Treat Analysis

Outcomes	DiD estimate	R-squared	N
Access to commercial water treatment plants	0.43*** (0.11)	0.40	5108
Use of commercial water treatment plants	0.10*** (0.033)	0.076	5108
Time spent collecting water from main source (minutes/trip)	3.6** (1.5)	0.03	5108
Number of drinking water sources used	0.14*** (0.051)	0.026	5108
Water consumption for all uses (lpcd)	-6.8* (3.5)	0.19	5108
% household samples with E. coli	0.079 (0.051)	0.022	2556
% of households treating water at home	-0.073* (0.041)	0.036	5108
% of households using drinking water storage vessels with a narrow mouth	0.020 (0.057)	0.001	5108
% of households covering drinking water storage vessel	-0.00 (0.016)	0.009	5108
% of households elevating drinking water storage vessel	0.022 (0.028)	0.008	5108
% of households that use safe method to remove water from vessel (ladle or spigot)	-0.024 (0.039)	0.014	5108
# of critical occasions at which adult respondent washes hands with soap	0.027 (0.11)	0.035	5108
Downstream impacts			
2-week diarrhea prevalence in children under 5 years of age	0.017 (0.013)	0.022	6559
2-week diarrhea prevalence in children under 3 years of age	0.016 (0.018)	0.013	3719
1-month diarrhea prevalence in children under 5 years of age	0.021 (0.016)	0.036	6556
1-month diarrhea prevalence in children under 3 years of age	0.026 (0.023)	0.025	3717
Water purchase cost – all sources (Rs./month)	13.0* (7.5)	0.01	5108
Monthly costs of coping with inadequate and unsafe water (Rs./month)	-24.1 (43.8)	0.005	5108
Total time spent collecting water (minutes/month)	183.1 (134.7)	0.023	5108
Cost of treating water in-house (Rs./month)	-42.6 (43.4)	0.011	5108
Household cost of illness due to diarrhea in previous month (Rs./month)	64.4 (96.9)	0.019	5108

Notes: We report the coefficient κ on T*d shown in equation 2, where treatment is assigned at the community level based on planned CWS installation in 2006. These coefficients were estimated using a linear probability model for the simple specification that does not include any covariates *Z*, except for the diarrhea prevalence regressions, which control for age. Additional controls for income, age of the respondent, and number of water sources within 5 minutes of the home did not alter the results (not shown). Standard errors, shown in parentheses, are clustered at the community level, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). Due to laboratory constraints, *E coli* was only tested in a randomly selected half of the sample. Observation of drinking water containers was attempted, but was not possible in 636 households; outcomes for these households are self-reported. Prevalence of diarrhea, measured based on having 3 or more loose stools within any 24 hour period, is for all sample children within the specified age groups.

Table 4. Comparison of Key Outcomes and Impacts for Users and Non-users—Treatment on the Treated Analysis, OLS Regressions

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Outcomes	**1- DiD: Users**	**2- DiD: Non-users**	**R-squared**	**N**
Access to commercial water treatment plants	0.77*** (0.082)	0.38*** (0.12)	0.42	5108
Number of drinking water sources used	0.68*** (0.12)	-0.04 (0.11)	0.066	5108
Time spent collecting water from main source (minutes/trip)	18.4*** (2.4)	1.4 (1.6)	0.055	5108
Water consumption for all uses (lpcd)	-0.8 (6.3)	-7.6* (3.5)	0.20	5108
% household samples with E. coli	0.14 (0.094)	0.07 (0.04)	0.022	2556
% of households treating water at home	-0.25*** (0.060)	-0.048 (0.043)	0.038	5108
% of households using drinking water storage vessels with a narrow mouth	0.24*** (0.088)	-0.014 (0.058)	0.016	5108
% of households covering drinking water storage vessel	0.013 (0.034)	-0.001 (0.015)	0.010	5108
% of households elevating drinking water storage vessel	0.032 (0.040)	0.020 (0.028)	0.008	5108
% of households that use safe method to remove water from vessel	0.14* (0.076)	-0.050 (0.038)	0.026	5108
# of critical occasions at which adult respondent washes hands w/ soap	0.048 (0.19)	0.016 (0.15)	0.035	5108
Downstream impacts				
2-week diarrhea prevalence in children under 5 years of age	0.041%* (0.021)	0.013 (0.013)	0.022	6559
2-week diarrhea prevalence in children under 3 years of age	0.073* (0.043)	0.006 (0.019)	0.015	3719
1-month diarrhea prevalence in children under 5 years of age	0.021 (0.035)	0.019 (0.016)	0.037	6556
1-month diarrhea prevalence in children under 3 years of age	0.038 (0.048)	0.021 (0.023)	0.027	3717
Water purchase cost – all sources (Rs./month)	37*** (9.3)	8.9 (8.6)	0.023	5108
Monthly costs of coping with inadequate and unsafe water (Rs./month)	-131 (85)	-50 (54)	0.012	5108
Time spent collecting water (minutes/month)	213 (148)	187 (142)	0.023	5108
Cost of treating water in-house (Rs./month)	-4.1 (75)	-45 (44)	0.011	5108
Household cost of illness due to diarrhea in previous month (Rs./month)	-133 (158)	80 (103)	0.02	5108

Notes: We report the coefficient β^u from equation 3 for users in column 1, and β^{nu} for non-users in column 2. For all but the diarrheal disease outcomes, there are 163 users and 1,011 non-users, with the balance being control households. Standard errors are shown in parentheses, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). As in Table 3, these are estimated using a linear probability model for the simple specification that does not include any covariates *Z*. Additional controls for income, age of the respondent, and number of water sources within 5 minutes of the home did not alter the results (not shown). Standard errors, shown in parentheses, are clustered at the community level. Due to laboratory constraints, *E coli* was only tested in a randomly selected half of the sample. Observation of drinking water containers was attempted, but was not possible in 636 households; outcomes for these households are self-reported. Prevalence of diarrhea, measured based on having 3 or more loose stools within any 24 hour period, is for all sample children within the specified age groups.

Table 5. Logit Model for first stage of PSM: Selection into CWS use in 2008

Variable	Full model	Parsimonious model
Household income ('000 Rs/month)	0.019 (0.022)	0.038* (0.023)
Household size	-0.048 (0.084)	
Number of children under 5 in household	0.34*** (0.13)	0.30*** (0.12)
Household head is literate	0.48** (0.22)	0.33* (0.20)
Age of head of household	0.020** (0.008)	
Household diarrhea prevalence among children under 5	0.41 (0.31)	
Household head is very satisfied with main drinking water source	0.21 (0.30)	0.21 (0.30)
Time spent collecting water ('00 minutes/month)	-0.01 (0.013)	-0.012 (0.014)
Household treats drinking water	0.21 (0.15)	0.27* (0.16)
Household head thinks unsafe drinking water can cause diarrhea	0.25 (0.27)	
Household thinks government should pay for improvements to water supply	-0.49*** (0.18)	-0.49*** (0.17)
Household members participate in village cleaning activities	0.035 (0.39)	
Constant	-3.3*** (0.83)	-2.5*** (0.48)
N	1146	1156
Pseudo-R^2	0.039	0.029

Notes: Dependent variable is use of the CWS at the time of the survey in 2008, and regressors are survey measures at baseline, in 2006. Standard errors, shown in parentheses, are clustered at the village level, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). These models are used to generate the propensity scores used for obtaining the matched samples that are considered in Table 6.

Table 6. Propensity Score Matching- ATT Estimates

	Outcomes in 2008		Outcomes in 2006		N
Outcomes	**ATT: Full model**	**ATT: Parsimonious model**	**ATT: Full model**	**ATT: Parsimonious model**	
Access to commercial water treatment plants	0.82*** (0.045)	0.81*** (0.049)	0.008 (0.013)	-0.008 (0.018)	124
Number of drinking water sources used	1.2*** (0.063)	1.2*** (0.072)	0.064 (0.047)	0.081 (0.054)	124
Time spent collecting water from main source (minutes/trip)	13.6*** (2.2)	13.8*** (2.2)	0.42 (1.6)	0.76 (1.5)	124
Water consumption for all uses (lpcd)	-0.24 (2.67)	-1.2 (2.5)	2.6 (4.6)	-2.2 (5.1)	124
% household samples with E. coli	0.079 (0.094)	0.16** (0.079)	0.00 (0.046)	-0.045 (0.058)	66
% of households treating water at home	-0.13* (0.066)	-012* (0.070)	0.072 (0.075)	0.14** (0.063)	124
% of households using drinking water storage vessels with a narrow mouth	0.12** (0.061)	0.21*** (0.055)	0.024 (0.042)	-0.008 (0.047)	124
% of households covering drinking water storage vessel	0.00 (0.006)	0.008 (0.009)	-0.040* (0.023)	-0.024 (0.024)	124
% of households elevating drinking water storage vessel	0.032 (0.056)	-0.032 (0.058)	-0.024 (0.041)	-0.032 (0.045)	124
% of households that use safe method to remove water from vessel	0.14*** (0.044)	0.12** (0.050)	-0.008 (0.051)	-0.032 (0.054)	124
# of occasions at which adult respondent washes hands w/ soap	0.18 (0.20)	0.23 (0.17)	0.14 (0.18)	-0.056 (0.19)	124
Downstream impacts					
2-week diarrhea prevalence in children under 5 years of age	0.036* (0.020)	0.032 (0.023)	0.028 (0.044)	0.012 (0.039)	124
2-week diarrhea prevalence in children under 3 years of age	0.056** (0.022)	0.051* (0.028)	0.056 (0.054)	0.019 (0.052)	107
1-month diarrhea prevalence in children under 5 years of age	0.080*** (0.029)	0.077** (0.031)	0.045 (0.050)	0.054 (0.050)	124
1-month diarrhea prevalence in children under 3 years of age	0.075*** (0.027)	0.070** (0.033)	0.075 (0.064)	0.075 (0.062)	107
Water purchase cost – all sources (Rs./month)	45*** (7.3)	38*** (9.4)	8.9 (5.8)	0.5 (6.6)	124
Monthly costs of coping with inadequate and unsafe water	-20 (84)	-37 (79)	-94 (90)	-17 (79)	124
Time spent collecting water	62 (162)	16 (153)	52 (111)	104 (83)	124
Cost of treating water in-house	-40 (74)	-53 (72)	-97 (87)	-25 (80)	124
Household cost of illness due to diarrhea in previous month	125 (80)	115 (100)	272 (265)	220 (245)	124

Notes: The first stage propensity scores were obtained using the logit model specifications shown in Table 5. To maintain the same samples for comparison across all 4 sets of columns, only households present during the baseline survey are included. Total eligible user households for the comparison is thus 130, except for e.coli (only 66 users tested), and diarrhea among children under 3 (112 users). A small number of these users (3-6) were found to be off support and are therefore excluded; the final sample of users for each comparison is shown in the rightmost column. Similarly, there are 929 households from control communities eligible for matching (and 463 for e.coli); all of these were on support. We use 1-1 nearest neighbor matching, trimming the worst 5% of matches. All standard errors are bootstrapped and shown in parentheses,, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). Differences in outcomes for 2006 (prior to treatment) are included as a falsification test.

Table 7. Outcomes for treatment households over the longer term —DiD Analysis

	A. Intent-to-treat		B. Users in treated villages		C. Users in all villages	
	2008-2011	**2006-2011**	**2008-2011**	**2006-2011**	**2008-2011**	**2006-2011**
Outcomes						
Access to commercial water treatment plants	-0.46***	-0.030	-0.095	0.20***	0.28***	0.23***
	(0.12)	(0.062)	(0.18)	(0.047)	(0.094)	(0.032)
Use of commercial water treatment plants	-0.080**	0.025	n.a.	n.a.	n.a.	n.a.
	(0.038)	(0.022)				
Average time spent collecting water (minutes per trip)	-5.1***	-1.6	-3.9	-3.1	-2.5	-2.2
	(1.5)	(1.6)	(3.5)	(3.2)	(2.2)	(2.1)
% of households treating water at home	-0.040	-0.11	-0.10	-0.12	0.15**	0.073
	(0.066)	(0.068)	(0.10)	(0.089)	(0.067)	(0.083)
% of households using drinking water storage vessels with a narrow mouth	-0.002	0.019	-0.21***	-0.18**	-0.19***	-1.8***
	(0.028)	(0.063)	(0.072)	(0.057)	(0.058)	(0.061)
% of households covering drinking water storage vessel	-0.008	-0.008	-0.006	0.004	0.005	0.016
	(0.010)	(0.014)	(0.019)	(0.035)	(0.012)	(0.024)
# of occasions at which adult respondent washes hands w/ soap	-0.015	0.007	-0.78**	-0.74	-0.67***	-0.60*
	(0.16)	(0.15)	(0.24)	(0.45)	(0.17)	(0.30)
Downstream impacts						
2-week diarrhea prevalence in children under 5 years of age	-0.012	0.004	-0.040	-0.048	-0.33	-0.037
	(0.015)	(0.018)	(0.028)	(0.033)	(0.033)	(0.038)
2-week diarrhea prevalence in children under 3 years of age	-0.028	-0.013	-0.083	-0.084	-0.058	-0.024
	(0.029)	(0.027)	(0.070)	(0.066)	(0.071)	(0.070)

Notes: We report the coefficient κ on T*d shown in equation 2 in columns A1 and A2, where treatment is assigned at the community level based on planned CWS installation in 2006. We report the coefficient β^u from equation 3 for users in columns B1 and B2; and columns C1 and C2 show the same coefficient but for a model in which non-users (rather than households in control communities) are the reference group. The reported coefficients were estimated using a linear probability model for the simple specification that does not include any covariates *Z*, except for the diarrhea prevalence regressions, which control for age. Additional controls for income, age of the respondent, and number of water sources within 5 minutes of the home did not alter the results (not shown). Standard errors, shown in parentheses, are clustered at the community level, and statistical significance is denoted by the asterisks (1% level ***; 5% level **; 10% level *). Prevalence of diarrhea, measured based on having 3 or more loose stools within any 24 hour period, is for all sample children within the specified age groups.

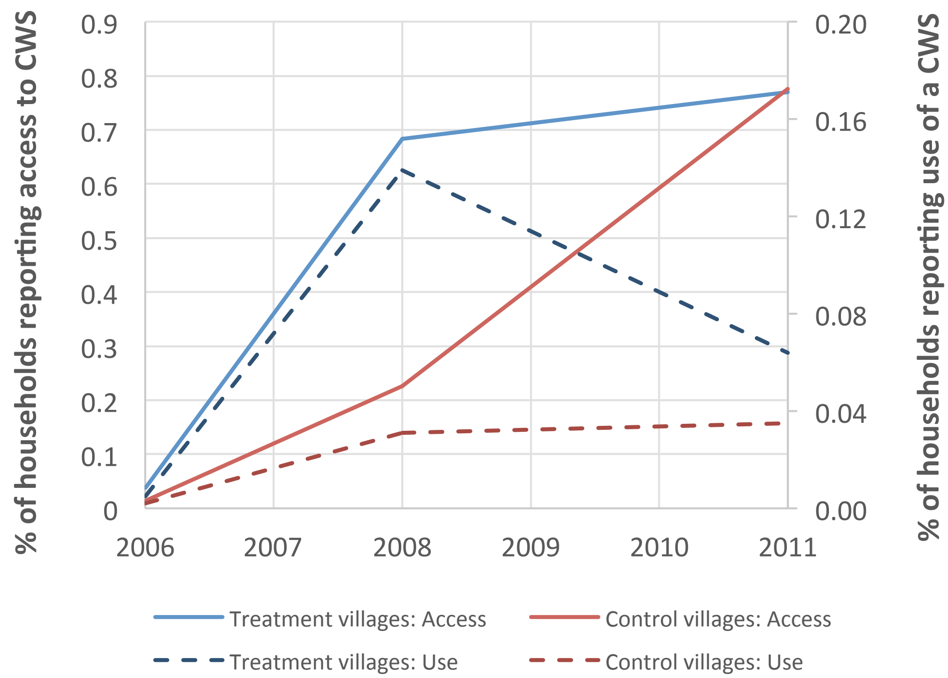

Figure 1. Access to community water systems in treatment and control communities over time