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Stephan Klasen, Tobias Lechtenfeld, Kristina Meier, Johannes Rieckmann

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Wilhelm-Weber-Str. 2 · 37073 Goettingen · Germany
Phone: +49-(0)551-3914066 · Fax: +49-(0)551-3914059

Email: crc-peg@uni-goettingen.de Web: http://www.uni-goettingen.de/crc-peg

Benefits trickling away:

The health impact of extending access to piped water and sanitation in urban Yemen[1]

Stephan Klasen[2], Tobias Lechtenfeld, Kristina Meier, Johannes Rieckmann

Development Economics Research Group
University of Göttingen, Germany

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Abstract

This article investigates the impact of piped water supply and sanitation on health outcomes in urban Yemen using a combination of quasi-experimental methods and results from microbiological water tests. Variations in project roll-out allow separate identification of water and sanitation impacts. Results indicate that access to piped water supply *worsens* health outcomes when water rationing is frequent, which appears to be linked to a build-up of pollution in the network. When water supply is continuous no clear health benefits are found compared to traditional urban water supply through water vendors. Connections to piped sewers can lead to health improvements, conditional on regular water supply. The findings suggest that investments in piped water supply should not be made when availability and reliability of water cannot be guaranteed.

Keywords: water supply; water quality; sanitation; hygiene; child health; diarrhoea; impact evaluation; infrastructure; Yemen

JEL classification: I10, I38, Q53

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[2] Corresponding author: sklasen@uni-goettingen.de; University of Göttingen, Platz der Göttinger Sieben 3, 37073 Göttingen, Germany

1. Introduction

Diarrhoea is the leading cause of child mortality in developing countries, about 90 per cent of which are caused by poor water quality and lack of sanitation (Black, Morris and Bryce 2003). Using cross-country observational micro data, it has been estimated that access to clean water and adequate sanitation could prevent 2.2 million child deaths every year (Fink, Günther and Hill 2011). However, recent impact evaluations of interventions have shown that improved water and sanitation infrastructure, while showing positive outcomes in other dimensions, have rarely been found to translate into better health outcomes. The reasons for this apparent lack of impact on health have only been partially identified (Waddington and Snilstvei 2009).

It is widely accepted that piped household connections can lead to better health outcomes than public standpipes (Zwane and Kremer 2007). In addition, most practitioners agree that investment in piped water should be complemented by piped sewerage and ideally also by hygiene training to reduce health risks from increased water use (World Bank 2004). This is particularly important in cities, where crowded living conditions in combination with exposed wastewater can pose serious public health hazards. Yet, most of the empirical evidence on the health impacts of improved water supply and sanitation in developing countries comes from rural projects, with only limited external validity to cities.[3] Very different types of water supply and sanitation are used in urban areas, where water sources are typically found nearby, dwelling-based water access is much more common, and water vendors deliver water to the doorstep. Urban sanitation practices also differ from villages. Open defecation is virtually non-existent. Instead, toilets and latrines are widely used, which discharge into open sewers, underground cesspits, or piped sanitation systems.

This paper contributes to the evaluation literature by examining the impact of interventions to provide piped water supply and sanitation on health outcomes in urban Yemen. It thereby contributes to the literature by examining the impact of such schemes in water-scarce regions where reliability of water supply can often not be assured. Yemen is a country that provides complex challenges to project designers: Renewable water sources are extremely scarce; annual population growth in urban areas is very high at 4.7 per cent; female education levels and general health knowledge are low; governance structures are weak; and social conflicts regarding land and water rights are frequent. To make matters worse, the majority of Yemen's

[3] Recent examples of rural evaluations include Rauniyar *et al.* (2011) on Pakistan, and Fan and Mahal (2011) on India.

population of 24 million lives in the very arid central mountains where ground water levels are rapidly falling (also due to heavy over-use by agriculture) and have reached depths of up to 1000 meters. While these conditions might seem extreme, similar environments can be found throughout the Middle East and North Africa.

The analysis uses detailed survey data from 2500 households covering treatment and control areas in several provincial towns. The study contributes to the empirical evidence base on urban water and sanitation access by using a mix of quasi-experimental methods which improve the robustness of the results over a reliance on a single method (given the assumptions underlying each).. These include propensity score matching, instrumental variable regression and difference-in-difference analysis. A second contribution is the combination of results from water tests and disease incidence data (self-reported and facility-based). This allows a more in-depth analysis of the transmission channels from such interventions to health outcomes.

The main results show that when piped water supply is frequently interrupted, diarrhoea among children and adults actually *increases* as a result of piped water access. Additional access to piped sanitation does not show any significant health effects in such a setting of frequent water rationing. When piped water access is combined with reliable water flows, the negative health effects disappear (although no positive impact is found) and piped sewerage leads to a reduction of the health burden from water borne diseases. Additional trend analysis from secondary health facility data confirms this picture and provides some evidence that the short-term impact may have been positive but dissipated within a few months.

In order to identify the origins of water pollution at point-of-use, microbiological data was collected from 9000 water quality tests covering the water chain between wells and drinking cups. The epidemiological analysis suggests that more than half of the pollution at point-of-use comes from unreliable water supply and possible leaks in the water pipe system. In addition, a sizable share of water pollution can be directly attributed to unhygienic household behaviour.

The main policy message that emerges is that investment in piped water supply should not be made when reliable water supply cannot be guaranteed.[4] In such cases engaging with existing networks of trucked water vendors or designing public standpipes might generate better health

[4] See Vairavamoorthy, Gorantiwar and Mohan (2007) for an introduction to the design and control of intermittent water distribution systems.

outcomes at lower costs. In addition, the analysis suggests that rural and urban water supply and sanitation pose different challenges. Evaluation results from rural settings are unlikely to apply.

The remainder of the paper is structured as follows. Section 2 reviews the literature on water, sanitation and hygiene and provides a brief project description. Section 3 introduces the data and lays out the empirical strategy. Section 4 discusses the impact results and investigates the origin of water pollution. Section 5 provides some concluding remarks.

2. Background

Water and sanitation projects are widely assumed to lead to substantial health improvements. This section provides a brief review of what is known regarding the health impacts of piped water and sanitation systems. The second part of this section presents the project under investigation and provides details on project roll-out, selection effects, project intervention history, and explains some relevant engineering issues.

2.1 Literature Review

Water, Sanitation and Hygiene

Large-scale investments in water and sanitation infrastructure are typically advocated to reduce diarrhoea and child mortality. For example, the Millennium Development Goal 10 addresses this point by encouraging developing countries to reduce the share of people without access to improved water and sanitation by half. The *Task Force on Water and Sanitation* from the related UN Millennium Project asserts that massive investments would indeed help to dramatically reduce the staggering number of 3900 children that die every day from a lack of proper water and sanitation (Bartram et al. 2005).

This notion that piped water supply will lead to improved health is shown for Argentina by Galiani, Gertler and Schargrodsky (2005), who investigate the impact of water utility privatization on the incidence of child mortality by exploiting the variation of public and private ownership of water utility across time and space. On average, the authors find reductions in urban child mortality of 8 percentage points. The impact increases more than threefold for the poorest areas of the country.

Focusing on another middle-income country, Gamper-Rabindran, Khan and Timmins (2010) present more heterogeneous findings. The marginal impact of piped water supply on infant mortality in Brazil is the largest in areas with high initial child mortality, unless underdevelopment is excessive. Using a quantile regression approach for panel data, the authors address a series of potential measurement problems and unobserved heterogeneity.

This picture from Latin America is largely confirmed by a meta-analysis covering 46 peer-reviewed studies, nearly all of them from South Asia and Sub-Saharan Africa, focussing on the health impacts of water, sanitation, and hygiene interventions in urban and rural areas, (Fewtrell *et al.* 2005). By pooling the various results the authors find that the average intervention on water, sanitation, or hygiene helps to reduce the relative risk of diarrhoea by somewhere between 25-37 per cent. Importantly, water treatment at point-of-use (e.g. water boiling, use of water filters, etc.), is the most effective intervention. The authors also caution that estimates of the impact of hygiene training (e.g. hand washing) are likely to be overstated because they suffer from publication bias.

In direct contrast to the positive impacts of these case studies, the World Bank, in a recent review of its activities over the past decade, concludes that it is exceptionally rare to find any health improvements among beneficiaries of piped water schemes (World Bank 2010). This picture is supported by a literature review of randomized control trials by Zwane and Kremer (2007). The authors assert that infrastructure projects in water and sanitation rarely translate into health improvements when effective hygiene training is lacking. Inadequate water storage and handling at the point-of-use can cripple any potential health effects from improved water sources. It is argued that smart hygiene training is urgently needed.

Designing effective hygiene interventions has proven extremely difficult because it implies changing habits of human behaviour. Adults are unlikely to change their hand washing practices even when familiar with health knowledge. In addition, even if behavioural changes can be induced, they tend to vanish soon after training, as found by Waddington and Snilstvei (2009) who review impact evaluations from 35 countries.

The central role played by behaviour and education is also confirmed by Jalan and Ravallion (2003) who apply propensity score matching techniques on a sample of Indian villages, where treatment villages were connected to piped water schemes. Prevalence and duration of diarrhoea is reduced for children living in households with piped water. However, the effect disappears when mothers have low education and the household is very poor, which is interpreted as a proxy for inadequate hygiene and water handling.

More explicitly, in a randomized control trial from urban Pakistan Luby *et al.* (2004) find that hand-washing substantially reduces diarrhoea among children. The diarrhoea incidence among children below 15 reduced by 53 per cent, while the duration of diarrhoea among infants reduced by 39 per cent. Unfortunately, the follow-up study reveals that the health effect had vanished within 18 months, because treatment households stopped purchasing soap for hand-washing (Luby *et al.* 2009).

This lack of sustainability is also identified by Kremer and Miguel (2007), who show in randomised interventions at household and community level that health education does not affect behaviour. This is not to say that information campaigns will never work, but much still needs to be understood about how to alter human health related behaviour (see Dupas 2011 for a comprehensive introduction).

To date, no randomized studies exist that evaluate the impact of improved sanitation, such as piped sewerage. Norman *et al.* (2010) provide a meta-analysis of 25 observational studies, only 16 of which control for socio-economic differences between treatment and control groups. Nevertheless, their review is particularly relevant, as it focuses on urban settings in which households are connected to sewers, similar to that of the project design considered here. The estimates from the pooled meta-analysis indicate that large reductions of up to 30 per cent of relative risk of diarrhoea incidence are possible. While such results sound encouraging, the authors conclude that such estimates are largely inflated and driven by non-causal research designs. More importantly, the authors point out that sewerage networks are difficult to maintain as they require continuous water supply to avoid clogging. Sufficient water flow can be difficult to maintain in countries with insufficient ground water sources, which can easily jeopardize any positive health impacts of piped sanitation.

In fact, more reliable estimates of the health impact of improved sanitation tend to be much lower. A large-scale evaluation of water supply and sanitation using panel data in Mozambique finds that latrine use reduces the disease burden by a modest 3 percentage points. The overall disease burden decreased from 30 per cent at baseline to 27 per cent after the intervention (Elbers, Gunning and Vigh 2011).

Overall, the impact of water and sanitation projects seems to be unclear. Most randomized and quasi-randomized studies lead to the conclusion that water and sanitation interventions can be expected to achieve their health targets if households use hygienic practices for storage and handling of drinking water (see for example Clasen *et al.* 2007, Curtis and Cairncross 2003, or Gundry, Wright and Conroy 2004). How to best achieve and sustain such behaviour among poor households has yet to be shown and appears to be highly context specific (Waddington and Snilstvei, 2009).

The secondary effects from water and sanitation largely depend on positive health impacts. They include lower health care cost and increases in labour productivity and school attendance (World Bank 2006). In addition, access to piped water can lead to reduced water costs and increases in consumed water quantity. On the negative side, it is possible that in traditional societies piped household connections reduce the time women spend outside the house, with potentially detrimental effects on their social capital and learning through peers (Janssens 2011). While the research design of this evaluation addressed all these issues, no impacts were found regarding such secondary effects.

2.2 Project Description

More than two thirds of Yemen's population of 24 million lives in the rugged central highlands that range between 2000 and 3200 meters. Rainfall is rare and erratic and most people live from farming crops on small terraces on steep cliffs. The rest of the population lives in the desert-like coastal plain that stretches along the Red Sea in the west, and in small towns and hamlets on the southern coast. Very few people live in the eastern half of Yemen in what is commonly referred to as the 'Empty Quarter'. The urban population is largely engaged in local trade, the service sector or employed by the public sector.

The northern part of Yemen, which today comprises nearly 85 per cent of the population, only emerged from total isolation in 1970. Under the Imamite, modern water and sewerage networks, electricity and telephone grids, cars and many other technological innovations had been banned. Piped water supply is still lacking today in many urban areas, forcing families to primarily rely on water vendors who fill their tanks at agricultural wells outside the city. Very few wealthy families can afford to drill and operate their own borehole, especially in the mountains where the water table is several hundred meters deep.

The Provincial Towns Program (PTOP), a program of the Yemen government with partial support by German Financial Cooperation (KfW Development Bank) to improve urban water supply and sewage systems in Yemen, was designed to drill new wells in eight provincial towns, located along the southern and western coast and in the central mountains. Wells were equipped with pump stations and water treatment facilities which are operated by independent public Water Utility Companies. Piped water schemes were designed to connect all existing households and have the capacity for future expansion. As the program led to an increase in water use it brought the existing waste water systems – consisting of underground cesspits and open sewers – to the verge of collapse. In response, sewerage schemes and wastewater treatment plants were constructed. They connect a large share of households with access to piped water to a sanitation network which allows wastewater to flow through sewerage pipes to a wastewater treatment plant.

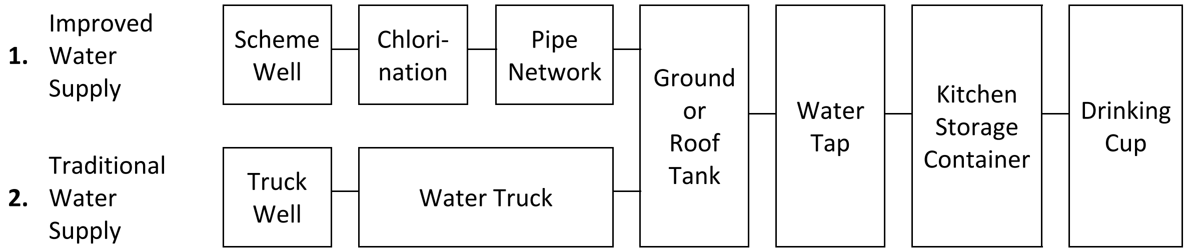
For the impact evaluation two locations were selected by the research team based on five criteria. First, the town needed to be large enough to draw a sizeable sample. Second, a preference was given to towns in which connections to water or sewage systems were not universal in order to create in-town control groups that could be used during analysis to control for unobserved town effects. Third, the two towns were chosen to resemble the main topographic characteristics of Yemen. Fourth, locations with a suitable nearby control town that is located in the same aquifer were given preference. Fifth, towns for which baseline data could be retrieved were preferred.

The first selected location, the city of Amran, is situated on the mountainous plateau, north of the capital Sana'a. The second city, Zabid, is near the Red Sea on the western coastal plain. In the mountain town, the water supply network was installed in 2002 and covers approximately 55 per cent of all dwellings. Of those with piped water supply, 58 per cent were connected to the new sewerage system in 2004. Connection to sewers is conditional on a piped water connection. In the coastal treatment town, all households were connected to the piped water scheme in 1998. The sewerage system became operational in 2005 and covers 85 per cent of the city. The remaining households use traditional cesspits and open drains to dispose their wastewater.

Within each town, construction followed topographical conditions. The piped networks are laid out in a way that they follow the natural slope of both cities. Central parts of the town were connected first, followed by outward extension into other neighbourhoods. Consequently, households without piped water and sanitation are only found in the outskirts of each town. The econometric implications of such cluster-level selection effects are discussed below. If a street was chosen for inclusion in the project, all households were connected with no option of individual opt-in or opt-out.

The flow of water for connected and unconnected households is illustrated by Figure 1. For households with improved water supply, groundwater is pumped from boreholes located outside the treatment towns. The water runs in large pipes to the water utility for chlorination. A few major underground feed-pipes then carry the clean water to distinct areas of the town. Smaller distribution pipes branch off at control points. The latter can be used to shut off entire neighbourhoods for repairs or water rationing. The smaller distribution pipes run underneath streets and alleys and connect each building at ground level. In the mountains, households typically store the water temporarily in large metal tanks with an average capacity of 2-3 cubic meters. Water storage tanks are located in the compound (ground tanks) or on roof tops (roof tanks). From the storage tank, a pipe runs to a water tap, typically located in the kitchen. For cooling purposes, virtually all families fill their daily drinking water in a smaller kitchen storage container every morning, which holds 10-20 litres. For drinking, many families share a single cup when drinking from the kitchen storage container.

Figure 1: Water supply chain and test points



In areas where no piped water is available, drinking water is purchased from water vendors using water trucks (mountain region) or donkey carts (coastal region). Water vendors obtain their water from agricultural wells outside the town. Truck water is directly pumped into the water storage tank. It is also purchased by connected households during extended periods of water rationing.

3. Data and Empirical Strategy

3.1 Data

This article uses an array of data sources, combining household survey data, microbiological water test results and secondary data from schools and health facilities.

Household Sample

The household survey was conducted in the four treatment and control towns in the second half of 2009, covering 2518 randomly selected households. The sampling frame is based on an innovative remote aerial mapping approach using satellite images, where each rooftop is assigned a building ID. The sample is then drawn from this building inventory. This is done by dividing each town into equally spaced clusters, all of which entered the sample to ensure representative coverage of all urban neighbourhoods. Households within each cluster are drawn following a stepwise procedure beginning from a random starting point. In these provincial towns, very few buildings are home to more than one family. In such cases, an additional sampling-procedure allowed field supervisors to select a random household for the interview. Overall, sampling based on satellite images facilitates field work, since interviewers can use detailed street maps where selected houses are marked. Even in small alleys exact locations can be confirmed using GPS coordinates. In the absence of recent reliable and available census data, such an approach is the best available alternative to ensure proper sampling.

A cross-sectional baseline survey exists from 2004 for the mountain town of Amran that was used to ex-ante evaluate the feasibility of the intervention. The baseline instrument contains questions on education, health, and demographic structure which were replicated in the endline survey to allow the calculation of double differences.

Outcome Variables

Following best-practice in survey design, the household interviews collected information on symptoms rather than diseases. In environments with poor health knowledge, limited access to well equipped health facilities and existing folk medicine, self-reported symptoms are much more reliable. A useful categorization of water borne diseases and transmission channels has been compiled by Esrey *et al.* (1991), on which the list of symptoms was developed and tested with medical personnel from Yemen.

Diarrhoea is the principle predictor of water borne diseases. Secondary symptoms include vomiting, abdominal pain and fever which are combined with data on the incidence of watery and bloody diarrhoea (dysentery) to create an overall disease measure for robustness analysis. Additional outcomes are school and work days missed due to water-related symptoms. Analysis takes place at the household level, using morbidity rates within each household. The *Severity* indicates the share of reported symptoms classified as severe. Since disease incidence among small children is a crucial impact indicator, the variables *Disease*, *Diarrhoea* and *Severity* are also included for the subgroup of children up to the age of five.[5]

Main Covariates

In line with existing empirical literature, a set of household characteristics is included in the analysis to control for differences in hygienic practices, education, wealth, and demographic structure. Education, hand washing, soap use, water purification (incl. the use of water filters, chlorination and boiling), and knowledge about water-related diseases are expected to reduce the relative disease burden. Respondents were also asked about problems with water supply,

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[5] For a full list of variables see Appendix 8.

water quality and the sewerage system, which are expected to be negatively associated with health. The demographic structure of the household might also affect the disease burden. Infants and young children are prone to water borne diseases given their weak immune system. In addition, illnesses spread fast within households, putting more people at risk in larger households.

Wealth is an important control for unobserved health practices. At the same time, perceived health status is typically negatively correlated with income which could create a reporting bias among the better-off and is important to be controlled for. House owners are expected to invest more into water tanks and pipes and are exposed to reduced health risks.

Water Test Data

To supplement survey data on subjective water quality with hard evidence, water tests were conducted using physical, chemical, and microbiological indicators.[6] While water pollution can have many origins, this study focuses on *Escherichia coli* (e.coli), a bacterium that is associated with human faeces. E.coli directly causes dysentery, sometimes referred to as bloody diarrhoea, and is a common indicator for health studies in the developing world. It is easily detectable in water samples and there is at most incomplete resistance as a result of continued exposure.

Water tests were conducted along the water supply chain of a random subsample of 500 households after the main household survey was completed. Additional interviews with well owners, water vendors and household members complemented the tests.

Health Facility Data

Data on diagnosed illness was collected on a monthly basis spanning 12 years from 1998 to 2009. Based on inpatients and outpatients registration books with information on diagnosis and prescription, the incidence of several water-related diseases was aggregated, including diarrhoea.[7] Because of data gaps and changes in official coding, diarrhoea data can be used from 2004 to 2009 for the mountain towns. This covers the period from just before the sanitation intervention until the endline survey. For the coastal towns, trends can only be

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[6] Physical indicators are Electrical Conductivity, Total Dissolved Solids and Ph Value. Chemical indicators are Hardness; and content of Calcium, Chloride, Total Iron and Fluoride (only measured at source) and Nitrate and Sulphate (measured at source and point-of-use). Biological indicators are contamination with E.Coli and Total Coliform.

[7] The water-related diseases are bilharzias (intestinal and urinary) and schistosomiasis, amoebic dysentery and giardia, diarrhoea, hepatitis A, typhoid, malaria and intestinal worms (including flukes, hookworm, pinworm, roundworm, tapeworms, whipworm, and others).

compared between 2008 and 2010 which is ex-post for water and sanitation. Health facility data are coded as monthly stock variables and are logged and deseasoned for analysis. Only diarrhoea incidence is used for analysis given data gaps in the other indicators.

3.2 Empirical Strategy

The empirical strategy does not rely on a single preferred method or result. Instead, a wide array of quasi-experimental approaches is used to identify robust relations between treatment and health outcomes. This is necessary because access to piped water and sanitation is purposively assigned to entire neighbourhoods and streets, given the enormous financial inefficiencies that would result from randomized treatment. In effect, systematic differences between treatment and control areas might exist which can influence the success of the intervention. To illustrate this crucial point, consider a simple impact model

$$y_i = \alpha + x_i'\beta + T_i\gamma + \varepsilon_i, \quad (1)$$

where y_i denotes the outcome (e.g. diarrhoea) for observation i, x_i is a vector of covariates, β is a vector of parameters, T_i is a variable indicating treatment, and ε_i is an idiosyncratic error term, with $\varepsilon \sim N(0, \sigma^2)$. In the case of non-random assignment of treatment T, $Cov(T, \varepsilon) \neq 0$, which biases γ, the estimated impact of treatment. The possibility of selection bias is addressed using propensity score matching and instrumental variables regressions on cross-sectional survey data. Difference-in-difference impact estimates are also presented using the baseline data.

Propensity Score Matching

In all PSM procedures, treatment and control households are matched on their predicted probability of being part of the treatment group (Rosenbaum and Rubin, 1983). The model used to estimate the propensity score should include all covariates that determine treatment without being affected by treatment themselves. The propensity score model used here includes the education level of the household head, household size, dependency ratio, house ownership, and an indicator for knowledge of water-related diseases.[8] Since PSM is limited to observable characteristics results may still be biased if the selection of the treatment group was driven by unobservables. Usually one would presume that such a bias would overestimate positive effects of an intervention to the extent that neighbourhoods selected for treatment might have unobserved favourable characteristics that would lower their disease incidence.

[8] A large set of alternative model specifications was tried, including the use of geographical conditions (distance to city center, rocky ground), age of house, and other socio-economic variables, none of which improved performance of the propensity score model.

Instrumental Variables

The instrumental variable (IV) approach is a complementing alternative of dealing with potential selection bias when such bias is due to unobservables. The impact is calculated from the predicted treatment status $\hat{T}_i$, which is estimated by a set of instrumental variables that are not correlated with the error term ε_i and which may not affect the outcome variable directly.

The instruments used here are based on project documents and in-depth interviews with stakeholders. The construction of water and sanitation schemes followed three principles which can be exploited as instruments. First, construction always began in the city centre. Second, the Old City was prioritized, where buildings are substantially older. Third, in the mountain region pipe construction excluded streets built on particularly hard rock due to increased construction cost. Suitable instruments are therefore *Distance to the City Centre* of each household, the *Age of the House* and *Rocky Ground* around the dwelling, all of which perform well with regard to first stage F-tests[9] and Hansen tests. While these instruments are useful when quantifying the impact using the in-town control group, an additional binary instrument taking the value of one for the *Project Town* is included when the sample contains both in-town and out-town control groups in order to allow for unobserved differences between the control groups.

Double Differencing

Double Differencing (DD) is an alternative for identifying causal effects when baseline data is available and no time-variant unobservable confounders have affected the outcome. The analysis is done using mean point estimates from two cross sectional surveys, which accounts for differences in sample size. Since sanitation is only provided to a sub-sample of the water treatment group, which can be used to quantify the relative sanitation impact, by taking the additional difference between the double difference results of piped water and access to piped sewerage. This DD analysis can only be done for Amran as the baseline survey is only available for that town. Questions for eliciting the disease burden are identical in the baseline and endline survey instruments. However, even in case of differences in measurement, DD results would be unbiased because the disparities would cancel out.

[9] The only exception is the F-test for the analysis of sanitation in the coastal town, which is always well below ten. This means that results there have to be interpreted with caution.

Trend Analysis using Health Facility Data

Moving averages are used to estimate trends of between-town differences in waterborne disease burden. Unfortunately, within-town comparisons are not possible because record books of health facilities do not contain full addresses but only city of origin of patients. For the mountain towns, the available data allow an investigation of the sanitation intervention. For the coastal towns, trends can only be compared over the three years prior to the endline survey when all interventions had long been completed. This provides an interesting opportunity for investigating long term effects by using information on converging or diverging trends.

Potential Caveats

Health outcomes such as diarrhoea incidence are self-reported and might be biased for two reasons. First, poorer people tend to underreport the disease burden of very common illnesses, which can make wealthier cohorts look worse off. Second, health knowledge may be limited among less educated cohorts and hence symptoms underreported. While it cannot be excluded that such measurement bias affects the survey data, relative comparisons between treatment and control groups will be unbiased when measurement error affects both groups in a similar way. Nevertheless, a wealth indicator is used in the analysis to directly control for measurement bias.

Externalities of water and health related interventions have been shown for rural setting (Miguel and Kremer 2004). In the case of benefit spillovers to the control group the econometric identification of the causal impact would be invalid. This could be the case if the risk of water-borne diseases such as cholera is reduced for the entire urban population even though only part of the population is connected to improved water sources. It might also happen if the use of piped sanitation by part of the populations reduces the risk of overflow of open sewers among unconnected households along with a reduction in health risk. In such situations the health outcomes of the control population would increase due to the project. Since the impact estimates rely on the differences in health outcomes, the estimates would be biased downwards. The use of control towns addresses this problem. Since control towns are located at a distance of 10-20 km from treatment towns, externalities affecting health risk can be excluded.

4. Results

This section begins with the results from the quasi experimental impact estimation. The second part of this section discusses possible causes of water pollution between water source and point-of-use to explain the limited health impact of the intervention.

4.1 Project Impact

a. Evidence from the Descriptive Analysis

The descriptive analysis of disease incidence among treatment and control groups reveals an a priori unexpected picture in Table 1. Connection to piped water is associated with a higher disease burden in both the mountains (Amran) as well as the coast (Zabid). At the same time, households connected to the scheme in Amran complain about substantial rationing, where no water is available 60 per cent of the time. As a result, more than 25 per cent of treatment households did not use any piped water in the 90 day reference period. In comparison, no rationing is reported in the coastal treatment area, and consequently all surveyed households used only piped water in the reference period.

Table 1: Disease Burden among Household Members

Indicator	Disease	Disease (child)	Diarrhoea	Diarrhoea (child)	Severity	Severity (child)	Workdays missed	Schooldays missed	Households
	Mean prevalence among applicable household members								*N*
Mountain									
Water	9.9	30.2	5.3	13.8	7.6	34.8	0.9	0.3	201
Water & Sanitation	11.2	46.8	5.8	15.9	8	44.3	6.4	1.4	270
None	8.2	25.8	3.4	9.8	6.1	27.6	1.8	0.2	374
Control	6	20.5	3.3	4.9	5	21.8	2.3	0.1	298
Coastal									
Water	11.2	37.1	5.1	11.8	6.6	37.6	1.3	5.4	127
Water & Sanitation	7.2	26.1	3.5	10.6	4.7	29.1	1.6	1.4	714
Control	6.4	21.9	3.3	8.2	4.3	17.9	1.8	1.2	434
Total	**7.9**	**28**	**3.9**	**10.2**	**5.6**	**28.7**	**2.2**	**1.2**	**2418**

Among mountain households with access to piped water and sanitation, about 11 per cent of household members reported water-related symptoms during the past month. For children aged 0-5 this share is four times higher, and such higher disease incidence among treated households also carries over to the severe disease indicators. In the coastal treatment town, the disease burden is more pronounced among households with access to piped water only, while the additional access to sanitation for those households appears to reduce disease incidence. Regarding secondary effects (workdays or schooldays missed), there are no clear patterns; if anything more work- and schooldays are missed in treatment than control households.

b. Evidence from Propensity Score Matching

Water

Table 2 shows the matching results for access to piped water.[10] The first two columns show the results for the between-town analysis by region. The results suggest sizable and significant increases in disease burden among mountain households connected to piped water. Children in particular are affected by an increase of diarrhoea incidence of nearly 10 percentage points. The picture is confirmed by the severity of diarrhoea among children and by the aggregate measure of five waterborne diseases. The effect remains significant for the aggregate waterborne disease incidence and its severity for all age groups, implying a widespread increase in illnesses in the population. In the coastal region, between-town matching shows an increase in total disease incidence by about 4 percentage points among households with access to piped water; but results for the other disease indicators are insignificant. In addition, the number of missed school days seems to have slightly increased among school-aged children.

The third column in table 3 contains the findings of within-town matching in the mountain region. Again, adverse health effects of piped water are found, albeit with somewhat lower magnitude, especially for children up to 5 years of age. Recall that drinking water quality cannot be included in the propensity model, because it is directly affected by treatment. Given that part of the treatment group regularly uses traditional water sources during periods of water rationing, i.e. the same water as the in-town control group, the negative health impact from the in-town matching is a conservative estimate and possibly underestimated.[11]

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[10] Results are reported for radius matching using a calliper of 0.05. Similar results are obtained when applying smaller or larger callipers, nearest neighbour matching, and kernel matching using a Gaussian kernel with different bandwidths. Refer to the appendix of Klasen *et al.* (2011) for a more complete overview of these results.

[11] In theory, positive health externalities of piped water might be an alternative explanation for the more similar health outcomes within the mountain project town. They are not very likely, given that health outcomes are in fact worse among the treatment group.

Table 2: Propensity Score Matching – Impact of Water

Outcome	Coastal Region out-of-town control			Mountain Region out-of-town control			Mountain Region in-town control		
	ATT	t-value	N	ATT	t-value	N	ATT	t-value	N
Disease	0.0399**	1.98	560	0.0455***	2.76	488	0.0268*	1.72	567
Diarrhoea	0.0111	0.73	560	0.0193	1.53	488	0.0195*	1.75	567
Severity	0.0184	1.21	560	0.0329**	2.25	488	0.0239*	1.76	567
Workdays missed	-0.0074	-0.59	560	-0.0076	-0.6	496	-0.003	-0.19	573
Schooldays missed	0.0441*	1.81	560	0.0018	0.84	496	0.0018	0.57	573
Disease (child)	0.1328	1.36	338	0.1078*	1.71	361	0.0631	1.17	409
Diarrhoea (child)	0.0151	0.38	338	0.0954***	3.19	361	0.0412	1.3	409
Severity (child)	0.1879	1.62	338	0.1347*	1.87	361	0.1041	1.63	409

Note: To analyse the impact of piped water supply only, the treatment group excludes households with access to the sewerage system. For the between-town calculations only out-town control groups are used. Matching with the in-town control group is only possible in the mountain region.

Sanitation

Since improved sanitation is conditional on access to piped water, the impact of sanitation in Table 3 is estimated by matching households from the water group (controls) to households from the water and sanitation group (treatment). Estimates need to be interpreted relative to the impact of piped water.

Table 3: Propensity Score Matching - Impact of Sanitation

Outcome	Coastal Region out-of-town control			Mountain Region out-of-town control		
	ATT	t-value	N	ATT	t-value	N
Disease	-0.0373*	-1.79	841	0.0187	0.99	458
Diarrhoea	-0.0207	-1.3	841	0.0087	0.62	458
Severity	-0.0244	-1.53	841	0.0077	0.48	458
Workdays missed	0.0086	0.78	841	0.0567*	1.87	469
Schooldays missed	-0.0346	-1.32	841	0.0097*	1.75	469
Disease (child)	-0.1172	-1.03	418	0.1382*	1.73	327
Diarrhoea (child)	-0.0223	-0.51	418	0.015	0.4	327
Severity (child)	-0.0899	-0.64	418	0.0684	0.84	327

In the mountain town, additional negative health effects are found for children. The difference between the matched treatment and control groups is nearly 14 percentage points. These detrimental health outcomes lead to a significant increase of days that children miss school due to waterborne diseases. The effect for missed work days is also significant.

For the coastal town, no health effect is found for children or health related absenteeism. Interestingly, a slight reduction of the disease incidence of almost 4 percentage points is found for the overall population. Water rationing – which is common in the mountain town – could be the transmission channel for the additional disease burden from the sewerage scheme. The probable reason is that without regular water flow, sewers are prone to clogging.

c. Evidence from Instrumental Variable Regressions

Water

The IV results for access to piped water are summarized in Table 4**Table 4** (see full results in Appendix 6). Specification tests suggest the validity of the instruments. The results are very similar to the matching estimates.[12] Access to water supply in the mountain town is associated with a higher disease burden for children and adults. Again, the magnitude of the impact is larger for children.

Table 4: Instrumental Variable Analysis – Impact of Water

Outcome	Mountains			
Water	Impact	F-test First Stage	Hansen p-value	N
Disease	0.0723**	78.71	0.561	1072
Diarrhoea	0.035	78.71	0.38	1072
Severity	0.0669**	78.71	0.294	1072
Disease (child)	0.213*	57.76	0.795	784
Diarrhoea (child)	0.155***	57.76	0.645	784
Severity (child)	0.307**	57.76	0.557	784

Note: The sanitation indicator is included as an additional covariate in the analysis to allow the use of the full sample. There is no in-town control group for water in Zabid, as all households are connected to piped water, which is why the analysis cannot be meaningfully performed for the coastal region.

The covariates of the IV regressions shed some light on the transmission channel of the observed negative impact. Access to *sanitation* is insignificant in all specifications, suggesting that a connection to piped sewers does not have sizable health effects in this project. The positive and significant effect of *trucked water* used by connected households indicates that

[12] As already mentioned in the methodology section, a dummy variable indicating location in Amran is included as an additional instrument in the analysis. As a robustness check, the analysis is repeated without the dummy, using only the in-town control group for water in Amran. Results were very similar in magnitude, although some of the coefficients were no longer significant (also due to the much smaller sample size). Nevertheless, the general conclusion of a negative effect of piped water on health remains clearly visible and is significant for several of the disease indicators.

illnesses are partly caused by contaminated water purchased from tanker trucks. No effect is found for *water purification,* probably due to the surprisingly small number of households engaging in water treatment at point-of-use. Among the socio-economic factors, the most influential variables are *house ownership* which reduces disease incidence, and the *share of children and elderly* living in the household which increases the disease incidence. These effects are consistent in both regions.

Sanitation

The results for sanitation in the mountain area do not show significant positive or negative effects for any of the outcome variables or age groups (Table 5). Estimates for the coastal region cannot be meaningfully interpreted as we have a weak instrument problem. This could explain why IV results are not significant with regard to sanitation, despite the coefficients having the same direction as the matching results.[13]

Table 5: Instrumental Variable Analysis – Impact of Sanitation

Outcome	Mountains				Coastal			
Sanitation	Impact	F-test First Stage	Hansen p-value	N	Impact	F-test First Stage	Hansen p-value	N
Disease	0.008	46.91	0.887	436	-0.152	3.16	0.330	826
Diarrhoea	0.011	46.91	0.335	436	-0.071	3.16	0.420	826
Severity	0.024	46.91	0.518	436	-0.079	3.16	0.792	826
Disease (child)	0.103	34.38	0.907	311	-0.552	4.938	0.703	411
Diarrhoea (child)	0.001	34.38	0.632	311	-0.187	4.938	0.496	411
Severity (child)	0.158	34.38	0.667	311	-0.626	4.938	0.793	411

Overall, propensity score matching and instrumental regressions generate very similar results. Water access appears to have increased health problems in the mountain town where water rationing is frequent, with access to sanitation aggravating the unintended health consequences even further. In turn, no health improvements are found in the coastal town related to piped water supply, while piped sewers are associated with a reduced disease burden.

[13] Values of the first stage F-test are below 10.

d. Evidence from Double Difference Calculations

Analysis using cross-sectional survey data from before and after the water and sanitation project confirms the above results. Table 6 shows the disease burden for diarrhoea among all age groups, which has increased by 1.37 percentage points in the mountain town among households connected to piped water.[14] This is considerably less than the matching and IV estimates, because it is relative to the previous water supply scheme that was replaced by the project. At baseline, a water pipe scheme existed of abysmal quality. In fact, it was so inadequate und unreliable that the city qualified for participating in the project to upgrade its water supply network. The old water system is very likely to have posed serious health threats to the connected population.

Table 6: Double Difference Results for Water and Sanitation

Mountains	Diarrhea *percentage points*	Baseline *Individuals*	Endline *Individuals*
First Difference: change over time			
Water	3.44	1744	1832
Sanitation	4.35	1744	2256
Control	2.07	1118	2922
Double Difference: treatment – control			
Water	1.37	Impact of Water	
Sanitation	2.27		
Treatment Difference	0.91	Impact of Sanitation	

Access to sanitation is conditional on access to water. By splitting the sample of households connected to water in two groups defined by access to sanitation, the difference between treatments can be obtained, yielding impact of sanitation in addition to water. Estimates for the mountain town imply an additional increase of diarrheal disease incidence by 0.91 percentage points when households are connected to piped sewerage.

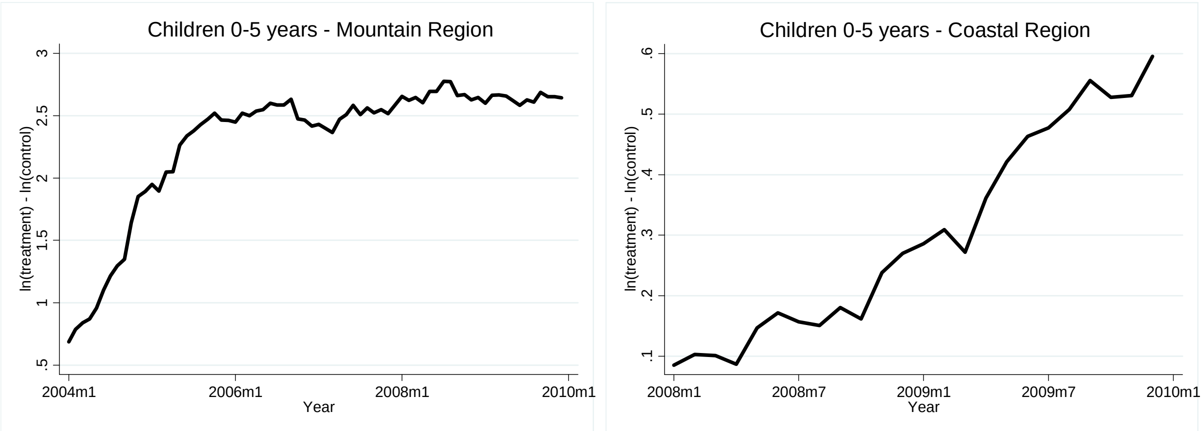
[14] Results are point estimates based on two cross sectional surveys covering the entire city at baseline and endline. T-tests indicate that these results are significant at conventional levels. To exclude possible confounding effects from population growth the analysis is also done with a restricted endline sample that only includes neighbourhoods surveyed at the time of baseline, which does not yield very different results. Analysis cannot be performed for the coastal region because no in-town control group for water exists at the endline.

e. Evidence from Health Facility Data

To complement the health impacts from self reported health, secondary data from health facilities is analysed which contains the monthly diarrhoea incidence. Figure 2 shows relative diarrhoea incidence between treatment and control towns for each region for children.

For the mountain region, the relative disease burden in the treatment town increases sharply for children during the first year after project completion (see the low starting level in 2004, when treatment households were connected to sanitation).[15] Unfortunately, limited data availability means that no ex-ante trend can be established to further analyse why the disease burden worsened over time.

Figure 2: Differences in Diarrhoea Incidence between Treatment and Control Towns



The trends level off after a few months, but remain on a much higher level than in the control town. The effect is very pronounced and remains visible even though in-town control households with a lower reported disease burden were also visiting the health facilities of the treatment town.[16] For the coastal region, the estimated trend of the relative disease burden is increasing over time in the treatment town, although the variance is quite large. Since the sanitation and water projects have been completed before 2008, the figure only provides a snap-shot of a medium-term impact. But these data clearly are consistent with our other analyses that suggest that extension of water and sanitation access did not improve health outcomes, but appears to be associated with a worsening of health outcomes in treatment towns.

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[15] In principle, the same result can be caused by a major outbreak of waterborne diseases in the control town, e.g. cholera. However, the control town health data do not show a surge in diarrheal diseases in the first half of 2004 but rather a decline.

[16] Since reported health status is similar among control groups inside and outside of treatment towns the possibility of in-town control households driving the results can be excluded.

4.2 Sources of Water Pollution

The objective of the Provincial Towns Program was to improve the health situation of the population by providing access to safe drinking water and an effective sanitation infrastructure. The impact results show that health did not generally improve from the investments in water and sanitation. Only in the coastal town marginal reductions in disease burden was achieved for households additionally connected to sanitation. This raises the question about causes of water pollution in households connected to piped water.

Microbiological tests reveal that water pollution at point-of-use is rampant in treatment and control areas (see Appendix 3). In the mountains, e.coli was detected inside the drinking cup of 20.0 per cent of households only connected to piped water. Virtually the same incidence (20.3 per cent) is found among control households using traditional water sources. This implies that the water scheme made no difference to water quality at point-of-use. Worse, e.coli incidence among households that are additionally connected to sewers is at a staggering 38.4 per cent. This is very similar to the e.coli incidence in the mountain control town without any water or sanitation facilities (40.0 per cent). In the coastal area, water pollution at point-of-use is even higher, affecting 46.6 per cent of all households connected to piped water and 36.6 per cent of households connected to water and sanitation.

Two major channels for water pollution exist that could help explain these findings. First, the piped network might be a source of pollution, for instance through broken pipes, insufficient chlorination, and frequent water rationing. Second, unhygienic household behaviour when storing and handling water might be an additional cause.

a. Pollution from the Pipe System

Following the water from the well to the household, several sources of contamination are possible. First, no signs of pollution are found in any of the wells of the water schemes. Second, in the coastal town one of the two main water pipes running into the town was tested positive for e.coli pollution, which indicates leaks in that pipe. The main pipes in the mountains were clean. Third, leaks in the small distribution pipes might cause additional pollution, which leads to streets with an above average pollution level. As shown graphically in Appendix 7, two such streets can be identified for the coastal town of Zabid, implying wastewater intrusion into the drinking water system.

b. Pollution from Water Storage Tanks

Most households store drinking water in large tanks which could be a source of pollution. Descriptive analysis suggests that water tanks are not related to water pollution. This includes the existence of a water tank, the size of the tanks, the storage time of water in the tanks, and the location of the tank (roof vs. ground). In addition, none of the surveyed households is trying to reduce pollution in their tank by adding chorine or other methods, or has cleaned the inside of their tank in the 12 months prior to the interview. In effect, water tanks do not help explain any differences in water pollution at point-of-use. Since tanks are closed and out of reach of humans, e.coli pollution found inside the tanks must come from the pipe network or from truck water pumped into the tanks.

c. Pollution from Water Rationing

The impact estimates show a negative effect from piped water in the mountain town, which suggests a mechanism of water pollution not found in the coastal town. Since pollution of the main pipes can be ruled out, the remaining suspect is irregular water supply. Such water rationing is found in all neighbourhoods of the mountain town but is only reported by a fraction of the coastal households. Interviews with the engineers of the water utility confirm that water availability is very irregular in the mountains since 3 out of 5 source wells have fallen dry shortly after project inauguration. The resulting water flow is insufficient to provide permanent drinking water for the entire town. Consequently, water is only available on a few days per week in each neighbourhood.

Epidemiological literature has shown that water rationing itself can be a serious cause of pollution through three channels (see Friedman *et al.*, 2003 for an introduction to the topic and Semenza *et al.*, 1998 for an excellent empirical contribution from an urban setting). First, during periods of rationing, microfilm grows in the pipes and is flushed out through household connections when water pressure resumes. Second, without reflux valves, water schemes are prone to pollution reversely entering from water taps, when falling water pressure sucks in any residues. Third, given the change in water pressure, even minor pipe leaks can cause pollution of the piped water during rationing. This is especially important where water pipes run nearby underground cesspits, which is reportedly very common in urban Yemen.

In addition, extended periods of water rationing cause connected households to refer to traditional water sources. Pollution in the tanks could thus stem from households using a mix of improved and traditional sources. In fact, controlling for the mixing of water sources during the past 4 weeks helps to explain about half of the e.coli pollution in water storage tanks. This source of pollution is a direct consequence of water rationing. The remainder of the e.coli pollution inside the tanks is, by implication directly caused by pollution in the pipes.

d. Pollution from Household Behaviour

Lastly, it is well established that lack of hand washing and other unhygienic household behaviour can adversely affect water quality at point-of-use (Jensen *et al.* 2002). Compared to water pollution at the tap, e.coli incidence increases towards the drinking cup. The average change in e.coli incidence within the household is 24.1 percentage points from the storage container to the drinking cup with very little variation between treatment and control areas (see Appendix 4). In other words, at least a quarter of all households suffer from pollution caused by their own behaviour.

Overall, this section shows that water pollution is rampant in both treatment and control areas. In the treatment group e.coli incidence averages 35.4 per cent at the point-of-use. By investigating the pollution at different locations along the water chain, more than half of the overall pollution is found to be due to leaking pipes and water rationing. The remainder of e.coli pollution can be directly attributed to household behaviour.

5. Conclusion

Lacking access to clean drinking water and improved sanitation is the largest cause of child mortality in the developing world and responsible for a large share of the global disease burden. Increasing the number of people with access to improved water and sanitation is therefore a priority among policy makers. Massive investments in piped infrastructure for water and sewerage are common and are expected to decrease the risk of diarrhoea among beneficiaries. Although the evidence is mixed, a significant impact on health outcomes is rarely identified. According to a vast literature, this is primarily due to unhygienic household behaviour which causes pollution at the point-of-use. Effective methods on how to sustainably alter behaviour have not yet been identified.

This study quantifies the health impacts from a large scale water and sanitation project in urban Yemen. Health outcomes include diarrhoea among children and adults, and several health related factors, including school and work-place attendance. By exploiting differences in the roll out of project components, the impact for water and sanitation can be analyzed separately.

Using a range of quasi-experimental methods on survey data from treatment and control towns, the overall health impact of the infrastructure investment is mixed, at best. In the mountain town of Amran, health has deteriorated for households connected to the water scheme. The existence of piped sewerage has no significant health effects. For the coastal town of Zabid, no clear effects are found for piped water supply. Additional access to sewers seems to marginally improve the water- borne health burden.

To explain these results, microbiological water tests were conducted on several points between the wells (water source) and the drinking cups within a sample of households (point-of-use). Water pollution is extremely high in treatment and control areas. The average incidence of e.coli at the point-of-use is 35.4 per cent for treatment households, while the water source is found to be clean. When dividing the pollution between piped scheme and household behaviour, more than half of the total pollution is found to come from leaking pipes and water rationing. The remainder of e.coli pollution can be attributed to household behaviour. These results are likely to apply to water and sanitation projects in many urban settings characterized by water scarcity and fast population growth in the Middle East, North Africa, and elsewhere in the developing world.

Five policy implications emerge from this study. First, water networks should only be extended if reliability of supply can be assured, because otherwise they can pose serious health risks. Thus in severely water-stressed regions such as many countries in the Middle East and North Africa, such projects must be preceded by water policy changes that assure that water supply for human consumption can be assured at sufficient quantities (which typically implies reallocation from often heavily subsidized irrigation use). Second, providing piped sewers without adequate and reliable water access can worsen community health. Third, frequent water quality tests along piped networks are needed to monitor water quality. Fourth, purification at household level could address water quality concerns. Fifth, training to improve water handling at household level has huge potential, as it accounts for nearly half of the pollution at point-of-use. The last two implications require more investigation about the feasibility and design of such interventions, where rigorous impact evaluations could again play an important role.

Providing safe water supply is most challenging in locations with scarce water resources. This paper has shown that simply replicating existing methods and technologies is not enough to achieve the desired health impacts in such settings. Future research might also want to try a chlorination program for vendors of truck water, which appears to be a market-based solution available in any urban area with insufficient piped water. Additional research is also needed to test the long-term effectiveness of different interventions on hygiene practices and water handling at household level. Here, experimental approaches are likely to be useful to test a range of possible interventions and their relative merits.

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Appendix 1: Household Sample

		HHs	*Population*
Mountains			
	Water	201	1777
	Sanitation	270	2257
	None	374	2977
	Control	298	2508
Coast			
	Water	127	859
	Sanitation	714	4746
	Control	434	3101
Total		2418	18225

Appendix 2: Socioeconomic Characteristics in Treatment and Control Groups

Indicator	HH Size	Children (<16 yrs)	Elderly (>64 yrs)	Dependency Ratio	Age Head	Headship	Yrs of Edu Head	School Enrolment Children	Income per capita per day	HHs
Unit	*Persons*	*Persons*	*Persons*	*Ratio*	*Yrs*	*% Male*	*Yrs*	*% of children*	*USD*	*N*
Mountain										
Water	8.84	4.03	0.33	1.28	44.78	95.02	6.74	59.86	2.19	201
Sanitation	8.36	3.53	0.23	1.08	45.86	94.44	6.13	55.10	2.09	270
None	7.96	3.87	0.20	1.33	41.74	95.99	6.12	60.09	2.11	374
Control	8.42	3.96	0.16	1.27	44.03	92.28	5.36	47.92	1.94	298
Coastal										
Water	6.76	2.81	0.19	1.03	45.74	85.83	5.76	78.77	1.91	127
Sanitation	6.65	2.36	0.24	0.88	46.17	88.80	7.85	85.82	2.55	714
Control	7.15	3.19	0.26	1.24	45.74	91.47	4.64	72.00	1.87	434
Total	7.54	3.23	0.23	1.12	44.97	91.81	6.31	67.20	2.17	2418

Appendix 3: Contamination of Drinking Cup

			E.coli	HH
			%	*N*
Mountain				
	Water	Pipewells	20.0	70.0
	Sanitation		38.4	73.0
	None	Truckwells	20.3	64.0
	Control	Truckwells	40.0	65.0
Coastal				
	Water	Pipewells	46.4	69.0
	Water & Sanit.		36.6	71.0
	Control	Truckwells	61.4	88.0
Total			38.6	500.0

Appendix 4: Change of Pollution between Storage Tank and Drinking Cup

		E.coli	HH
		percentage points	*N*
Mountain			
	Water	23.3	116
	No Connection	16	50
	Control	22	50
Coast			
	Water	25.6	117
	Control	31	71
Total		24.1	407

Appendix 5: IV Regressions – Children Age 0-5 years

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Outcome	Disease Incidence			Diarrhoea Incidence			Disease Severity		
Region	Mountain		Coastal	Mountain		Coastal	Mountain		Coastal
Treatment	Water	Sanitation	Sanitation	Water	Sanitation	Sanitation	Water	Sanitation	Sanitation
Control group	In-town & out-town	Water	Water	In-town & out-town	Water	Water	In-town & out-town	Water	Water
Water	0.213*			0.155***			0.307**		
	(0.111)			(0.052)			(0.119)		
Sanitation	0.066	0.103	-0.552	-0.024	0.001	-0.187	-0.040	0.158	-0.626
	(0.095)	(0.122)	(0.420)	(0.043)	(0.065)	(0.148)	(0.097)	(0.120)	(0.446)
Primary	0.064	0.223**	0.073	0.014	0.063	0.058	0.107*	0.314***	0.050
	(0.054)	(0.098)	(0.094)	(0.023)	(0.045)	(0.048)	(0.059)	(0.106)	(0.115)
Middle	0.032	0.078	-0.100	0.034	0.046	0.005	0.001	0.061	0.052
	(0.082)	(0.184)	(0.120)	(0.037)	(0.073)	(0.071)	(0.089)	(0.173)	(0.203)
Secondary	0.105	0.213*	0.006	0.034	0.070	0.038	0.026	0.233**	-0.061
	(0.081)	(0.118)	(0.120)	(0.031)	(0.052)	(0.050)	(0.066)	(0.099)	(0.136)
Tertiary	-0.006	0.117	0.113	0.045	0.117*	0.019	0.007	0.175	0.098
	(0.070)	(0.119)	(0.125)	(0.036)	(0.063)	(0.052)	(0.073)	(0.125)	(0.139)
Disease knowledge	-0.033	-0.058	0.070	-0.031	0.003	0.045	0.083*	0.034	0.151**
	(0.048)	(0.082)	(0.066)	(0.020)	(0.036)	(0.032)	(0.046)	(0.080)	(0.075)
Soap	0.082*	0.043	0.072	0.011	-0.029	0.004	0.021	0.024	0.112
	(0.050)	(0.087)	(0.085)	(0.021)	(0.039)	(0.043)	(0.048)	(0.083)	(0.091)
Purification	-0.089	-0.046	-0.023	-0.022	-0.036	0.065	-0.101	-0.105	0.066
	(0.061)	(0.091)	(0.097)	(0.032)	(0.043)	(0.077)	(0.064)	(0.091)	(0.191)
Bad water quality	0.196	0.272	0.051	0.071	0.147**	0.044	0.230*	0.275	0.311
	(0.122)	(0.179)	(0.310)	(0.048)	(0.073)	(0.123)	(0.124)	(0.183)	(0.380)
Sewerage clogging	0.001	0.030	0.032	-0.000	0.018	0.006	0.004	0.017	0.022
	(0.006)	(0.036)	(0.090)	(0.002)	(0.015)	(0.038)	(0.008)	(0.033)	(0.088)
Dependency ratio	-0.040	-0.017	-0.087	-0.037	-0.056	-0.064	-0.150	-0.182	-0.274
	(0.135)	(0.252)	(0.171)	(0.064)	(0.131)	(0.082)	(0.141)	(0.253)	(0.197)
House owned	-0.071	-0.153	0.129	-0.044*	-0.073	0.033	-0.080	-0.081	0.102
	(0.056)	(0.118)	(0.134)	(0.025)	(0.049)	(0.057)	(0.056)	(0.104)	(0.134)
Assets	-0.024	-0.068	0.091**	-0.015	-0.029	0.025	-0.044	-0.135**	0.191***
	(0.037)	(0.071)	(0.043)	(0.014)	(0.029)	(0.021)	(0.036)	(0.064)	(0.071)
Truck	0.126*	0.147*		0.120***	0.132***		0.152**	0.104	
	(0.070)	(0.088)		(0.030)	(0.037)		(0.065)	(0.080)	
Constant	0.148	0.330	0.356	0.021	0.151	0.163*	0.203	0.446*	0.312
	(0.132)	(0.240)	(0.227)	(0.057)	(0.122)	(0.095)	(0.129)	(0.244)	(0.259)
Observations	784	311	411	784	311	411	784	311	411
F-Test stage 1	57.76	34.38	4.938	57.76	34.38	4.938	57.76	34.38	4.938
Prob > F	0.000	0.000	0.00762	0.000	0.000	0.00762	0.000	0.000	0.00762
Hansen P-val	0.795	0.907	0.703	0.645	0.632	0.496	0.557	0.667	0.793
Instruments	Amran			Amran			Amran		
	Rocky Ground	Rocky Ground		Rocky Ground	Rocky Ground		Rocky Ground	Rocky Ground	
	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre	Distance to Centre
	Age of House	Age of House	Age of House	Age of House	Age of House	Age of House	Age of House	Age of House	Age of House

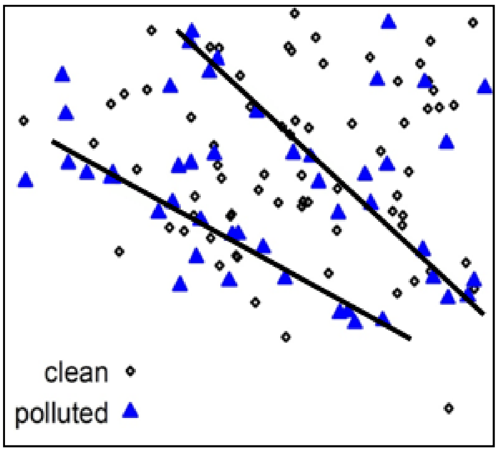
Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix 6: IV Regressions – All ages

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Outcome	Disease Incidence			Diarrhoea Incidence			Disease Severity		
Region	Mountain		Coastal	Mountain		Coastal	Mountain		Coastal
Treatment	Water	Sanitation	Sanitation	Water	Sanitation	Sanitation	Water	Sanitation	Sanitation
Control group	In-town & out-town	Water	Water	In-town & out-town	Water	Water	In-town & out-town	Water	Water
Water	0.072**			0.035			0.067**		
	(0.031)			(0.022)			(0.027)		
Sanitation	-0.012	0.008	-0.152	0.002	0.011	-0.071	-0.022	0.024	-0.079
	(0.025)	(0.028)	(0.122)	(0.017)	(0.021)	(0.096)	(0.022)	(0.026)	(0.083)
Primary	-0.003	0.036*	-0.002	0.010	0.026*	-0.006	-0.004	0.029	-0.010
	(0.012)	(0.021)	(0.016)	(0.008)	(0.014)	(0.010)	(0.011)	(0.019)	(0.013)
Middle	-0.003	-0.034	0.014	0.010	-0.000	0.027	-0.023	-0.029	0.002
	(0.019)	(0.028)	(0.035)	(0.013)	(0.019)	(0.028)	(0.015)	(0.024)	(0.025)
Secondary	0.014	0.038	-0.006	0.023*	0.030	0.009	-0.003	0.028	-0.019
	(0.018)	(0.027)	(0.019)	(0.013)	(0.019)	(0.014)	(0.015)	(0.022)	(0.016)
Tertiary	-0.002	0.023	0.018	0.025	0.047	0.008	-0.011	0.010	-0.003
	(0.021)	(0.039)	(0.023)	(0.016)	(0.031)	(0.017)	(0.018)	(0.032)	(0.019)
Disease knowledge	0.005	-0.005	0.017	0.002	0.014	0.010	0.025***	0.016	0.016*
	(0.011)	(0.018)	(0.012)	(0.008)	(0.013)	(0.008)	(0.009)	(0.015)	(0.010)
Soap	0.014	-0.004	0.036**	0.011	0.001	0.007	0.004	-0.000	0.017
	(0.012)	(0.020)	(0.017)	(0.008)	(0.013)	(0.012)	(0.010)	(0.018)	(0.013)
Purification	-0.006	0.003	0.097	-0.010	-0.011	0.062	-0.010	-0.013	0.058
	(0.015)	(0.022)	(0.060)	(0.011)	(0.016)	(0.045)	(0.012)	(0.018)	(0.046)
Bad water quality	0.042	0.034	0.023	0.030	0.027	0.007	0.040*	0.027	0.048
	(0.026)	(0.035)	(0.041)	(0.021)	(0.028)	(0.037)	(0.021)	(0.028)	(0.039)
Sewerage clogging	0.002	0.008	0.009	0.000	0.010	0.007	0.001	0.001	-0.003
	(0.002)	(0.008)	(0.007)	(0.001)	(0.007)	(0.007)	(0.001)	(0.005)	(0.005)
Dependency ratio	0.121***	0.113*	0.046	0.052**	0.054	0.023	0.100***	0.103*	0.044
	(0.037)	(0.063)	(0.034)	(0.025)	(0.046)	(0.023)	(0.034)	(0.056)	(0.029)
House owned	-0.044***	-0.057*	-0.006	-0.014	-0.031	-0.002	-0.028**	-0.028	0.014
	(0.014)	(0.029)	(0.027)	(0.010)	(0.019)	(0.021)	(0.012)	(0.024)	(0.017)
Assets	-0.009	-0.010	0.019*	-0.004	-0.000	0.016**	-0.013*	-0.018	0.018**
	(0.009)	(0.018)	(0.011)	(0.007)	(0.014)	(0.007)	(0.007)	(0.014)	(0.008)
Truck	0.025	0.025		0.038***	0.044***		0.019	0.021	
	(0.017)	(0.020)		(0.010)	(0.013)		(0.015)	(0.017)	
Constant	0.022	0.077	0.114	-0.026	-0.010	0.043	0.022	0.044	0.038
	(0.030)	(0.057)	(0.073)	(0.023)	(0.046)	(0.056)	(0.026)	(0.048)	(0.050)
Observations	1,072	436	826	1,072	436	826	1,072	436	826
F-Test stage 1	78.71	46.91	3.160	78.71	46.91	3.160	78.71	46.91	3.160
Prob > F	0.000	0.000	0.043	0.000	0.000	0.043	0.000	0.000	0.043
Hansen P-val	0.561	0.887	0.330	0.380	0.335	0.420	0.294	0.518	0.792
Instruments	Amran Rocky Ground Distance to Centre Age of House	Rocky Ground Distance to Centre Age of House	Distance to Centre Age of House	Amran Rocky Ground Distance to Centre Age of House	Rocky Ground Distance to Centre Age of House	Distance to Centre Age of House	Amran Rocky Ground Distance to Centre Age of House	Rocky Ground Distance to Centre Age of House	Distance to Centre Age of House

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Appendix 7: Spatial Distribution of E.coli- polluted Storage Tanks (coastal)



Note: The figure shows spatial distribution of households with E.coli polluted storage tank using GPS coordinates. While some pollution appears random, a pattern seems to exist in the lower half, which is marked by two straight lines which correspond to the roads used for water pipe construction.

Appendix 8: Data Appendix – Variables

Health-related variables

Disease	Household incidence of water-borne symptoms (at least 1 out of 5 symptoms)
Diarrhea	Household incidence of diarrhea (bloody and watery)
Severity	Household incidence of water-related symptoms, which were classified as severe by the respondent
Disease (child)	Same as Disease, limited to children 5 years of age and younger
Diarrhea (child)	Same as Diarrhea, limited to children 5 years of age and younger
Severity (child)	Same as Severity, limited to children 5 years of age and younger
Workdays missed	Number of work days missed due to water-related symptoms limited to working age household members
Schooldays missed	Number of school days missed due to water-related symptoms limited to household members enrolled in school.

Socioeconomic characteristics

Household size	The total number of household members
Dependency ratio	Number of household members younger than 15 or older than 60 by total number of household members
Education (head)	Set of binary variables indicating the educational level of the household head: no education (used as reference category); primary schooling (including madrasa schools and vocational training which provide reading and writing skills); middle schooling; secondary schooling; and tertiary schooling.
House owned	Binary variable indicating whether the house/apartment is owned by the household
Asset	PCA index of reported housing characteristics.

Housing characteristics

Distance to centre	The distance of the dwelling from the city centre in meters
Age of house	The reported age of the dwelling
Rocky ground	Binary variable with value 1 if house is built on rocky ground

Hygiene-related variables

Knowledge (disease)	Binary variable, takes the value 1 if the health knowledge question correctly answered. Test asks about 5 symptoms of water borne diseases
Soap	Binary variable indicating whether soap and/or detergent is used for hand washing
Purification	Binary variable indicating whether water is purified by the household before drinking

Water quality-related variables

Unreliable	Binary variable indicating whether the respondent claimed that the most substantial problem of the main source for drinking water is unreliability
Bad water quality	Binary variable indicating whether the quality of the water from the main source for drinking is „bad“ or „very bad“; self reported
Sewerage clogging	Number of times the toilet of the household was unusable during the past three months
Truck	Binary variable indicating whether household uses trucked water for drinking