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From intermittent to continuous service: Costs, benefits, equity and sustainability of water system reforms in Hubli-Dharwad, India

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ABSTRACT

Urban service provision falls somewhere on the continuum of lower-cost, lower-quality, unreliable and intermittent to higher-cost, higher-quality, reliable and continuous. Piped water services in India are generally in the former category, but efforts are underway in some cities to shift to continuous supply. We use a matched-cohort research design to evaluate one such effort: an upgrade to continuous water service in a pilot zone of Hubli-Dharwad, India, while the rest of the city remained on intermittent services. We conducted a survey of ~4000 households with four rounds of data collection over 15 months. We evaluated the household-level net benefits, the equity of their distribution, and the affordability of water access under continuous supply. We also evaluated the project at the system-level (household and utility), estimating the net present value of the upgrade and the feasibility of scale-up to the entire city. We found positive net benefits for households overall, but uneven distribution of these benefits across socio-economic strata. We also found that the costs of supply augmentation, a necessary step for scale-up, significantly reduced the project net present value. The potential for scale-up is thus unclear.

1. Introduction

Intermittent and unreliable local public services, such as piped water, electricity, public transportation and telecommunications, are "normal" in the cities of many low- and middle-income countries. Unreliable services impose financial, health and psychological costs on ordinary citizens: they wait for water, light lamps in the dark, and arrive stressed out and late for work on a routine basis. States, donors, multi-lateral organizations and service providers therefore aspire to deliver reliable and continuous access to critical urban services (Ramachandran, 2011; Calderón, 2009).

More reliable access calls for investments in piped water, telecommunications, electricity systems and roads. There is often an implicit assumption that, following the pattern of cities in the global North, economies will grow and improved urban services will become the natural order of things. However, in many instances, with rapid urbanization and economic development increasing the competition over land and water (Showers, 2002; Arnold, Kohlin, & Persson, 2006; Bakker, Kooy, Shofiani, & Martijn, 2008), high-quality urban services remain an aspiration. Natural resource depletion and climate change, in turn, are gradually reducing the availability of resources themselves (IPCC, 2014). In many cases, over time, there has been a reversion to less reliable, more restricted, access to urban services (Kaseke & Hosking, 2013).

None of the ingredients needed to provide urban services, whether it be money, bureaucratic capacity, natural resources or urban space, is evenly distributed across the globe. Many of the ingredients are substitutes for one another: drinking water can be made from wastewater with money and energy, for example, or meter readers can be replaced with investments in automation. These tradeoffs create a production curve for each city, constraining the basket of services that it can provide. In this paper, we analyze the complexities of improving piped water services in urban India; the challenges and tradeoffs we uncover are applicable to many service regimes moving along the continuum from low-cost, rationed allocation, to higher-cost, continuous access. We argue that clear and present benefits of continuous water supply notwithstanding, benefits, costs, equity and sustainability are traded off in ways that are not always transparent in the water policy and planning literatures.

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Urban access to piped water is low in many regions of the world: 33% in Sub-Saharan Africa, 51% in South-Eastern Asia, 56% in Southern Asia (WHO/UNICEF, 2015). Piped water access is often available only intermittently, meaning, water flows through sections of the piped network for a few hours a day a few days a week. In 2000 the World Health Organization (WHO) estimated that over one third of the urban water systems in Africa and Latin America and over one half of the systems in Asia operated intermittently (WHO/UNICEF, 2000). At least 309 million people in the world access an intermittent water supply (IWS), according to the International Benchmarking Network (IBNET) database, but the real number could be more than twice this (Kumpel & Nelson, 2016). Many cities in Asia and Africa, India included, are converting, or considering converting, at least some intermittent systems to continuously supplied systems. In India, at least, the conversion to continuous (or "24×7") systems has been controversial; critics have argued that such upgrades will benefit consultants and construction companies but may be unaffordable for the poor.

Although continuous water supply (CWS) is associated with improved water quality (Kumpel & Nelson, 2013) and improved health outcomes (Ercümen et al., 2015) when compared with IWS, the economic impacts of a conversion from IWS to CWS have not previously been assessed in the research literature. We present here a comprehensive socio-economic evaluation of an upgrade from IWS to CWS of a World Bank (WB) financed pilot project in Hubli-Dharwad, India. We focus on users' net benefits in terms of time spent and cash expenses incurred on account of their drinking water supply, as reductions in these are a major reason for proposing such upgrades. We discuss the distribution and affordability of these benefits; we also discuss what these results imply for the potential for scale-up of these benefits. Unaffordable tariff increases for low-income households, disconnection due to non-payment among marginalized groups and insufficient supplies for scaling up the higher levels of service are all possible in demonstration projects that yield overall benefits.

This study is the first that we are aware of to compare the users' costs and benefits, and the distribution of those benefits over socio-economic strata, for an upgrade from IWS to CWS within one urban conglomeration. Our evaluation is based on a matched-cohort quasi-experimental study in which we compared eight CWS wards (administrative units of the city) to eight matched wards that remained on IWS (Section 2). Our methods include direct and participant observations, four rounds of surveys with a panel of ~4000 households over 15 months, and extensive document analysis (Section 3). We conduct simple parametric averaging and econometric modeling of the average changes in household coping costs, water bills and monthly water use after the upgrade to CWS; we also analyze how these changes are distributed across wealth quintiles (Section 4). We estimate the net present value (NPV) of the upgrade to the water system overall and by wealth quintile, to see if the investment costs of the upgrade justified the benefits from the utility's perspective (Section 5). We end with a discussion of what our results imply for continuous water supply in urban India, and potentially beyond.

2. Background

2.1. IWS in India and the decision to upgrade urban piped water services

In India alone, over 150 million people are served by intermittent piped water systems, and no large metropolitan area has completely converted to CWS. Most cities in India report water availability of approximately four hours per day, while several deliver water only once every 5–10 days (Ahluwalia, 2011; McKenzie & Ray, 2009). Households must therefore expend time and money to wait for, collect, store, and possibly treat their water between deliveries; such activities are collectively referred to as 'coping costs.' The very term implies that intermittency is just a temporary infraction, though intermittent and unreliable water services are the norm for the majority of urban Indians.

Improved water services can have a positive economic impact on households through savings in time, money or a combination of the two. In Kathmandu, (Pattanayak, Yang, Whittington, & Bal Kumar, 2005) observed that collecting water was primarily a time expenditure and (according to their estimates) represented 45% of total coping costs, valued at ~1% of household income, on average. They also observed that the highest income quintile had the highest coping costs, but time expenditures as a proportion of total coping costs were much larger in lower-income households (Pattanayak et al., 2005).

Zérah (2000) observed many strategies for coping with unreliable water supply: collecting, pumping, and storing, as well as reusing water, rescheduling activities, household water treatment, complaining to the utility, and even moving to a new location. Her study in Delhi found that coping costs represented up to 15.7% of monthly income in low-income households, and 1.4% in higher income households, indicating that even when absolute costs are lower in low-income households, concerns about the equity of access under IWS remain (Zérah, 1998, 2000).

For an urban water utility, making a major upgrade in order to alleviate coping costs is never a straight-forward decision: net economic benefits, impacts on water quality, health and equity of access across income groups must all be considered. In addition, the sustainability of the upgrades depends on the management of available supplies, given hydrological limits today as well as in the future. Finally, upgrading systems to 24×7 water, as CWS is often called in India, requires heavy upfront investment and a large increase in the operations and maintenance budget of the managing water utility (Vairavamoorthy, Gorantiwar, & Pathirana, 2008; Dutta, Chander, & Srivastava, 2005).

Whether, where, and how to upgrade urban water services to 24×7 is a hotly debated public policy question in India. Proponents argue that decreased coping costs will help all residents, especially the poor, while critics voice concern that increased prices will put up barriers to access, especially for the poor (Dasgupta & Dasgupta, 2004; Saleth & Sastry, 2004; Sangameswaran, Madhav, & D'Rozario, 2008; World Bank & Ministry of Finance, Government of India, 2013). Proponents have also argued that water quality will deteriorate less in a continuously pressurized piped system, and that less water will be wasted because, in an intermittent regime, water is stored between supply days and then thrown away in favor of fresh water (McIntosh, 2003; Galaitsi et al., 2016). Other studies have argued that consumption will increase with higher water availability (Andey & Kelkar, 2009), and that under supply-constrained circumstances very little water, in fact, is thrown away (Kumpel, Woelfle-Erskine, Ray, & Nelson, 2017). These findings add to concerns that upgrades to CWS may not be sustained by the limited water supplies of urban India (Sangameswaran et al., 2008), or by the carrying capacity of its conveyance infrastructure (Jayaramu, Burt, & Manoj Kumar, 2015).

Water utilities and policy makers must make choices along the service quality and affordability frontier, insofar as improved services increase the utility's production costs. Understanding coping costs, and how they might change and for whom they might change after a service upgrade, allows utilities to balance benefits with costs. Time expenditure as a proportion of total coping costs is of particular importance, and assessing the impacts of conversion to CWS is complicated by disagreements on how to account for the value of time (Whittington, Mu, Roches, & STUDlY, 1989;

Pattanayak et al., 2005). Additionally, conversion to CWS may not eliminate the behaviors usually associated with 'coping': inconvenient access points or the continuation of established practices could complicate the assessment of household impacts (Burt & Ray, 2014). On the other hand, (some) evidence suggests that higher-quality service and customer satisfaction lead to higher payment of water bills (Vásquez, 2015; Kayaga, Franceys, & Sansom, 2004).

We evaluate a pilot upgrade from IWS to CWS in urban India, taking into account the household- and utility-level costs and benefits of the conversion, equity of access, and sustainability now and after a planned scale-up. We use the twin cities of Hubli-Dharwad, where we conducted a matched-cohort study from 2010 to 2012, as our empirical case.

2.2. From intermittent to continuous water in Hubli-Dharwad

This section lays out the context of water services in our study site, in both its IWS and CWS zones. We combine data from government documents and non-government sources with our own primary data to portray the water supply conditions under which local residents access and manage their piped water.

Hubli-Dharwad is a mid-sized city in northern Karnataka. It has a population of 943,185, making it the second largest city in the state, after Bangalore (Census of India, 2011). In 2008, 10% of the residents were upgraded to receive CWS under a pilot program largely financed by the World Bank (WB) (World Bank, 2004); the rest of the city continued to receive piped water supplies intermittently (The Times of India, 2017). IWS requires a variety of coping activities, and specific strategies depend on the source, water quality, treatment, conveyance, contamination, access points and delivery methods accessible to the household. All these are moderated by household income. The five categories of coping behaviors identified by (Pattanayak et al., 2005) (collecting, pumping, treating, storing and purchasing water) are all common in IWS areas of Hubli-Dharwad, and are present to a lesser degree in CWS areas (Burt & Ray, 2014).

Residents with piped water fall into three categories of access and storage (Woelfle-Erskine, 2012): 1) households that access water through a shared public tap (or "standpipe"), 2) households with a private tap on their premises but no overhead storage tank, and 3) households with both a private tap and overhead storage on their premises. Above median wealth (AMW) households are more likely to have a private tap and overhead storage and less likely to use standpipes to access their water (see Table 1). Below median wealth (BMW) households are more likely to access water through an unauthorized connection (Burt & Ray, 2014).[1] As a supplement to the piped water supply, electric and handpump-operated borewells[2] are found throughout Hubli-Dharwad.

Our household surveys in the IWS zones (details in Section 3 below) showed that the frequency of water deliveries varied among households and over time, but were generally once in three to five days (see Supplemental Information (SI) S1). These variations can be attributed in part to seasonality, and in part to investments that the utility made in the IWS network during the study period. Delivery frequency did not vary across wealth categories.

Hubli-Dharwad is not an uncommon case in urban India. Most urban water utilities in India are government-controlled; water tariffs are low, and utility budgets are heavily subsidized by the government (Saleth & Sastry, 2004; McKenzie & Ray, 2009). This model of service provision focuses on keeping monthly water affordable for all households. At the same time, due to budget limitations, network expansion is slow, leakage rates are high, intermittency is the norm, and access remains limited for many low-income neighborhoods, resulting in the near-universal adoption of so-called coping behaviors. Water users in many locations frequently become used to low-quality water service and its associated high coping costs.

Using Hubli-Dharwad as an example that they hope to replicate, the WB partially financed a pilot project to upgrade water services: the Karnataka Urban Water and Sanitation Improvement Project (KUWASIP). KUWASIP aimed to provide CWS to 10% of three cities in northern Karnataka: Hubli-Dharwad, Gulbarga and Belgaum. Indian cities are administratively divided into "wards"; out of 67 wards within Hubli-Dharwad, eight were chosen for the demonstration project based on ease of hydraulic isolation within the piped water network. These wards cover a mix of low-, middle- and high-income households, similar in proportion to the rest of Hubli-Dharwad (CMDR, 2006; Sangameswaran et al., 2008). As part of the upgrade from infrequent IWS to CWS, all free public standpipes were removed and nearly all free public borewells were shut down. All household connections were registered with the local utility and put on an increasing block rate tariff structure on top of monthly fixed rate charges. Table 2 shows the tariff structure for CWS relative to IWS zones, arrived at after public protests and KUWASIP-organized meetings reduced the originally planned, even steeper, CWS rates (Burt & Ray, 2014).

Table 1
Water access type by percentage of population and wealth category, Hubli-Dharwad (IWS Zones). Source: Burt & Ray (2014).

	Shared standpipe	Private tap, no overhead tank	Private tap, with overhead tank
BMW	9.8%	82.1%	8.1%
AMW	2.9%	37.6%	59.6%

3. Sample selection & data collection

The data on household costs and benefits presented here were collected as part of a larger study evaluating the CWS demonstration project based on its health, water quality, water consumption, water storage and household economic impacts (Kumpel & Nelson, 2013; Ercümen et al., 2015; Kumpel et al., 2017; Burt & Ray, 2014). Because KUWASIP covered only 10% of the city, we were able estimate the impact of the demonstration project through direct comparison of matched wards from within the same city.

Table 2
Comparison of the Monthly Tariff Structures for CWS and IWS zones (source: Hubli-Dharwad Municipal Corporation). ₹45.24 = $US 1 (World Bank, 2004). See Fig. S2 for an example bill calculation and picture of an example bill.

	CWS		IWS	
Flat Rate	₹48		₹90*	
Meter Charge	₹30		(none)	
	Volume (kL)	Tariff (₹/kL)	Volume (kL)	Tariff (₹/kL)
Volumetric Rate	8–15	10	>15	5.8
	15–25	15		
	>25	20		

*Some houses that were not metered were charged ₹180 (2 × ₹90) if they were likely to be using more than 15 kL/month.

[1] An unauthorized connection is any connection to the piped water network that has not been officially registered with the utility. Most such connections at our study site were simply intentional holes hacked into the pipes.

[2] A borewell is a well dug through a mechanical bore. They are usually deeper than hand-dug wells. Pumping mechanisms found in Hubli-Dharwad include mechanical handpumps and electrical motorized pumps. Handpumps operate entirely on human power, and may need considerable effort for operation. For the motorized pumps, the electricity is paid for by the Hubli-Dharwad Municipal Corporation.

3.1. Sample selection

We investigated the impact of CWS in the pilot project zones through the quasi-experimental approach of multivariate matching to allow unbiased comparison of the intermittent and continuous zones of Hubli-Dharwad. We used an evolutionary machine learning algorithm called genetic matching to select control (IWS) units that minimized the difference with treated (CWS) units across specified covariates (Sekhon, 2009; Diamond & Sekhon, 2013). Quasi-experimental methods using propensity score matching have been used to evaluate water and sanitation interventions (Pattanayak, Poulos, Yang, & Patil, 2010), but our study is the first instance of genetic matching being used to evaluate such an intervention. We chose eight control wards (from the 59 IWS wards) as pair-wise matches for the eight intervention wards, based on a 15,000 household survey conducted by the Center for Multi-Disciplinary Development Research prior to the implementation of the CWS upgrade (CMDR, 2006). The wards were matched on ward-level economic indicators (proportion of slum households, low-income households, material used to construct the house, houses with only one room), demographic indicators (proportion of illiterate females), water and sanitation conditions (presence of household tap and latrine, garbage disposal and collection, pre-CWS water delivery frequency) and health costs (pre-intervention monthly health expenditures).

Approximately 250 participants were systematically enrolled from each of eight intervention and eight control wards (n = 1969 in CWS zones, and n = 1953 in IWS zones). We selected the households by identifying a specific starting point (often a landmark such as a temple), assigning a different direction to each enumerator, and instructing them to approach the nearest household and then the next nearest household etc., enrolling any that met the eligibility criterion of having a child under the age of five, until the targeted number of households per ward was reached[3]. Every house was geo-coded to enable ease of return in subsequent survey rounds. Post-survey comparisons of socio-economic status (SES) and access to water and sanitation infrastructure indicated an extremely close match between participants in CWS and selected IWS wards (see SI Table S3).

3.2. Data collection

We conducted four rounds of household surveys over 15 months (November 2010 – February 2012). We prepared the survey instrument in English, translated it into Kannada, and piloted it iteratively to ensure that it reflected the specific ways in which people collected, stored, used, and paid for water in Hubli-Dharwad. We tracked all local sources of domestic water: piped surface water provided by the utility (the primary source evaluated in our study), piped borewell water provided through a neighborhood network, borewell water from a public tank, a hand-pump, or a private well, trucked water and bottled water.

Indicators of SES were not likely to change significantly for the majority of households over the course this study. As a verification step, however, we collected SES data, such as presence of rooftop water tanks or type of building material, for two survey rounds. As expected, these were largely stable. Stated income in surveys is often an incomplete proxy for household wealth; we therefore estimated a relative wealth score using a principal component analysis of observed housing materials and reported household assets (Vyas & Kumaranayake, 2006). All participant households were categorized into wealth quintiles based on their score.

We collected monthly water bill data from the households. We asked to see their most recent bill, but if one was not produced, we recorded the most recent billed amount as reported by the household.[4] We also collected detailed information on any and all coping costs. Coping costs included expenditure of money or time in travelling to, waiting for, collecting, hauling, storing and possibly treating, water from any of the reported sources. We tracked frequency and duration of water supplies, and any household-level equipment used (e.g., pumps, storage containers, water filters). Although we collected detailed data on health incidence, medical expenses and time spent on account of illness or care-taking for an ill family member, we did not include these in our analysis. Reported cash expenditures and time spent were too small to lead to detectable changes between IWS and CWS households over the survey period.[5]

Monetary expenses on water included ongoing expenditures (such as borewell maintenance, utility bills or purchased water) and investments in either household-level infrastructure (such as overhead tanks or private borewells) or other durable equipment (such as water filters, buckets and barrels). The water bills in our study were official bills; they did not include any side payments for utility employees or frontline workers who read meters or turned water valves on and off in the IWS zones. Our investigations indicated that these payments existed but were small; previous research has shown that they are quite common in India (e.g. Connors, 2005) but also vary widely within one city (e.g. Hyun, Post, & Ray, 2018). We collected data from all participating households on the size and materials of permanently installed household-level infrastructure to estimate investment costs. We collected data on meter installation from utility records, and averaged the total cost of new meter installation across all CWS households. Likewise, we collected information on all ongoing water-related expenses. As a cross-check against household reports, we also collected retail prices for a range of popular water filters, natural gas tanks (used for boiling), storage tanks (including installation costs), barrels, trucked water and bottled water, via a comprehensive local market survey.

We conducted detailed observations of household water storage containers in a subset of 707 households, chosen as a systematic sample (Table S4). In this survey we detailed the materials and dimensions of each and every water storage container in regular use in the household. These data were used to estimate the volumes and material substances of all small storage equipment; volumes and materials were converted to cost via price information collected in the local market survey. We averaged the costs for small storage equipment for each wealth quintile in IWS zones and each wealth quintile in CWS zones; we used this average value for all households within a wealth quintile that were directly observed to be practicing in-home storage.

We trained our field staff to conduct the household survey and container observations using the Open Data Kit (ODK) software, run on Android phones. The individual forms were downloaded onto a single designated computer at the end of each day of

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[3] The same household surveys were used to evaluate the social and economic impacts, as well as the health impacts, of the conversion to CWS. For the health study, only households with children under the age of 5 were relevant; therefore, we restricted the entire survey to such households. Unless the introduction of CWS had a disproportionate impact on households with (very) young children relative to those without, we would not expect this selection criterion to bias our outcome of interest, i.e. differences in time or money spent on domestic water in IWS and CWS households.

[4] Reported bills are subject to recall bias, but we have no reason to believe that this bias leads systematically to higher or lower reports than the actual value. Lower-SES households were more likely not to have their utility bills; sometimes this was because they paid their landlords rather than the utility, and sometimes this was because these households in IWS zones often did not have meters. Our water bill estimates for lower-SES households were therefore, on average, less reliable than those for higher-SES households.

[5] We also did not include psycho-social costs, such as anger or frustration while waiting, in our assessment of impacts. These are important, but they are difficult to measure and aggregate.

fieldwork, and aggregated into a single csv database using the ODK Aggregate software (Hartung et al., 2010). We performed checks on the aggregated data on a daily basis. Once data collection was completed, we used R (R Core Team, 2012) and its Stargazer package (Hlavac, 2015) to analyze the data and produce all data tables and figures.

4. Household-level benefits

In this section we present our data analysis methods, with both simple parametric averages and econometric models, and our results, for household-level net benefits, distribution of benefits and water use after the CWS upgrade. Unless otherwise noted, the results reported below were estimated using data collected in Round 2 of our survey.[6]

4.1. Data analysis and model: net benefits, equity and water use

We conducted several different analyses in order to derive the many different ways in which households were impacted by the upgrade to CWS, as well as the variation in impacts across households. First, using our sampling frame to control for covariates, we present simple parametric averages for CWS and IWS households for our three central variables: (1) monthly ongoing expenditures of money, (2) the amortized value of durable investments and (3) expenditures of time.[7] Monthly expenditures included the monthly bill, but also any other regular expense related directly, or indirectly, to water use (as described in Section 2.2). Investments included durable items (any pieces of equipment or household-level infrastructure, as described in Section 2.2). Our amortization method included a discount rate of 12%, in line with the World Bank's NPV calculations for KUWASIP, and the estimated expected lifetimes for each item (for expected lifetimes see Table S5).

Building on this, we constructed an econometric model with these three outcomes as the dependent variables, explicitly controlling for presence of CWS, household size and proxies of socio-economic status (SES), such as our wealth score, materials used to construct the home, education level, and religion. For individual household i, expenditure of money (m_i), was a composite variable:

$$\mathbf{m_i} = \boldsymbol{\beta}'\mathbf{x_i} + \boldsymbol{\alpha}\mathbf{s_i} + \boldsymbol{\varepsilon}_\mathbf{i} \quad (1)$$

where, for i = 1…N, $\mathbf{s_i}$ was the level of service (s_i = 1 for CWS, 0 for IWS) and $\mathbf{x_i}$ represented indicators of socio-economic status. The coefficient for s_i represented the impact of the upgrade on CWS households against the reference of IWS households, where s_i could be positive, negative or zero. The same model was applied to amortized value of investments (a_i) and expenditure of time (t_i).

To evaluate the distribution of benefits, we calculated per-quintile simple averages as well as econometric models, with these same three outcomes/dependent variables, following the same process for these subsets as we did for the total sample. As a second measure of equity, we compared the average monthly water bill for each wealth quintile in IWS and CWS zones as a percentage of estimated household income.

Finally, to address the debate on whether IWS regimes encourage water waste because domestic chores are carried out under running taps and stored water is thrown away in favor of "fresh" water, we calculated average monthly usage across our study households, over all four survey rounds, in CWS and IWS zones, for the full sample and for each wealth quintile. These data were necessarily partial, as they came only from households that both had a meter and showed our research team their most recent utility bill or reported their most recent bill amount.

4.2. Results: net benefits, equity and water use

Averaging the costs of water services across the full sample showed that the upgrade to CWS represented a near-doubling of monthly monetary expenditures (Table 3). This increase was almost entirely due to higher water bills (Fig. 1). It is hard to say how much of the increase in bills was due to higher tariffs versus increased water usage, as we do not have data on meter coverage in CWS areas before CWS was implemented, and non-metered households would have paid a flat rate. A comparison of the average amortized investments in storage equipment showed that the upgrade represented a significant decrease in such investments (Table 3; Fig. 1). We found a difference of 22.5 h per month (on average) time savings among CWS households compared to IWS households (Table 3); most of the savings came from no longer needing to wait for water when deliveries came later than scheduled (Fig. 1).[8]

Overall, savings from amortized investments more than offset the increase in costs from the monthly ongoing expenditures. Summing ongoing expenditures and amortized investments, CWS households saved on average ₹69 per month in total monetary expenditures (see Table 3). All these results were robust and statistically significant under econometric modeling controlling for socio-economic factors, evidence that our study design had adequately controlled for confounding variables (Table 4).

The results for average household savings in the full sample were robust across wealth quintiles; all quintiles saw increased monthly bills, decreased coping costs and substantial time savings.[9] The monthly ongoing expenditure and amortized investments were correlated with wealth categories; lower quintile households saw smaller decreases in coping costs and smaller increases in monthly expenditures (See SI S7 and S8). Time saved was not significantly different across wealth quintiles (Fig. 2). These patterns were robust when controlling for indicators of SES, including household size, material of home construction, mother's education, religion, home ownership and wealth index score (see SI Tables S9–S11) (Fig. 3).

Turning to average utility bills as a percentage of reported income, we observed that lower-SES households paid a larger percentage of their income under CWS than higher SES households. The two lower wealth quintiles paid, on average, just over 3% of their reported household income in CWS zones. This is much larger than the equivalent in IWS areas where the lowest wealth quintile paid just over 1% of reported household income. The same metric in the highest wealth quintile did not have a statistically significant

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6 In every case where data from only one survey round was used, robustness checks showed that the value of the outcome variables, and our results, remained unaffected whether we used one round of data or all data rounds. In order to keep our analysis and its explanation simple, therefore, we elected to use only Round 2 data for most of the household-level calculations presented here. The full set of data on socio-economic variables (such as presence of a rooftop tank, or building materials of the house) was collected in Rounds 1 and 2; thus Round 2 offered a complete dataset for all variables.

7 Low-income households used water for bathing children, washing dishes, etc., directly from the tap or attached hose during the water delivery period itself (Kumpel, Woelfle-Erskine, Ray, & Nelson, 2017). We did not include this time in our calculations as it is time spent using water rather than waiting and collecting to cope with intermittency.

8 Delivery schedules within each ward were published weekly, and updated regularly, in the local newspapers at the time of our study.

9 Our water bill data (SI Fig. S7) contradicted the Indian Ministry of Finance – World Bank joint report conclusion that "20 percent of customers in Hubli…[and] 24 percent in Dharwad…were paying the lifeline tariff of 48 per month" (World Bank, 2013; p 8). This claim also appears in the WSP assessment: "One quarter of connections are using the minimum consumption of 0 – 8 KL per month at a cost of Rs 48" (Franceys and Jalakam 2010: p 14). See also Fig. 6 below for per-quintile billed volumes.

Table 3
Mean and 95% confidence intervals for monthly ongoing expenditures; monthly amortized investments in any durable equipment and household-level infrastructure; total monetary expenditures (including ongoing expenditures and amortized investments) and hours spent managing water.

	CWS		IWS	
	Mean	(95% CI)	Mean	(95% CI)
Ongoing Expenditures	₹204	(186.6–220.3)	₹96	(81.9–111.2)
Amortized Investment	₹115	(109.6–120.4)	₹251	(240.8–261.2)
Total Monetary Expenditures	₹310	(292.5–327.5)	₹354	(334.3–374.2)
Time (Hours)	7.4	(7.1–7.7)	29.9	(28.5–31.2)

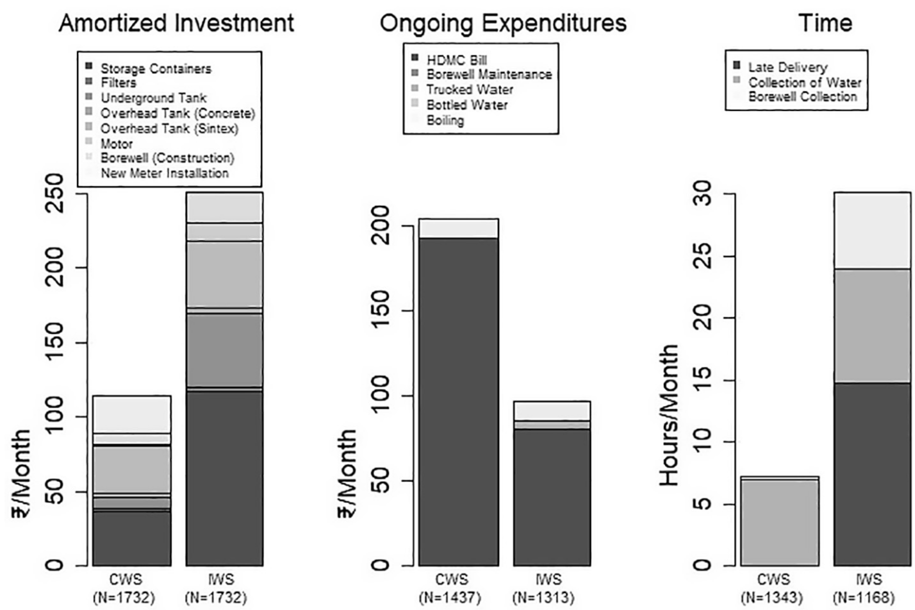


Fig. 1. Breakdown of expenditures by type of expenditure, average per household, in CWS and IWS zones. From left to right, monthly ongoing expenditures, amortized investments and time expenditure.

Table 4
Regression results on household socio-economic status SES of (1) monthly ongoing expenditures; (2) monthly amortized investments in any durable equipment and household level infrastructure; (3) total monetary costs (i.e. Columns 1 + 2); and (4) hours spent managing water. (See SI Table S6 for regression results with all covariates).

	Regression results Dependent variable:			
	Ongoing Expenditures (₹/Month) (1)	Amortized Investment (₹/Month) (2)	Total Monetary Costs (₹/Month) (3)	Time (Hours/Month) (4)
CWS	111.679*** (11.385)	−133.644*** (4.875)	−32.633*** (12.330)	−22.632*** (0.683)
Cement Walls	14.334 (13.327)	43.668*** (5.705)	55.146*** (14.356)	−3.892*** (0.793)
Household Size	6.471*** (1.817)	−1.265* (0.766)	3.378* (1.969)	0.320*** (0.107)
Illiterate Mother	−8.238 (21.093)	10.423 (8.650)	1.977 (22.624)	2.121* (1.196)
Hindu	−4.945 (12.627)	41.446*** (5.366)	40.114*** (13.620)	−0.415 (0.746)
Own their Home	13.173 (12.911)	8.085 (5.531)	23.230* (14.032)	−0.193 (0.762)
Wealth Index Score	23.982*** (3.538)	42.143*** (1.502)	64.680*** (3.839)	0.658*** (0.211)
Constant	38.290* (20.103)	198.843*** (8.674)	251.921*** (21.748)	30.346*** (1.212)
Observations	2,739	3,453	2,688	3,078
R^2	0.071	0.452	0.193	0.272
Adjusted R^2	0.069	0.451	0.191	0.271

Note: $^{*}p < 0.10$ $^{**}p < 0.05$ $^{***}p < 0.01$.
Note: All SES variables collected in our sample were included in a larger model (see SI, Table S6). The above variables, a subset of the total set, represented categories that the political economy literature considers important proxies for SES. These included religion, assets, size of household and materials used to construct the home. All possible variables considered for inclusion in equation (1) were checked for collinearity. The variables included in Table 4 all had low measures of collinearity. The full models included variables that exhibited collinearity (Table S6).
Note: Results displayed are: estimated coefficient (standard errors in parentheses).

difference between CWS and IWS zones (Fig. 4). Even if reported income is an unreliable metric, the same denominator was used for both CWS and IWS households within a given wealth quintile; therefore, the relative difference between IWS and CWS zones within a given wealth category should have been robust.

The water bill as a percentage of income (Fig. 4) did not account for the volumes of water consumed; if lower SES households were also relatively high consumers, then this might partially explain the higher fraction of their incomes going to water. Fig. 5 shows the estimated monthly water use of CWS and IWS households.

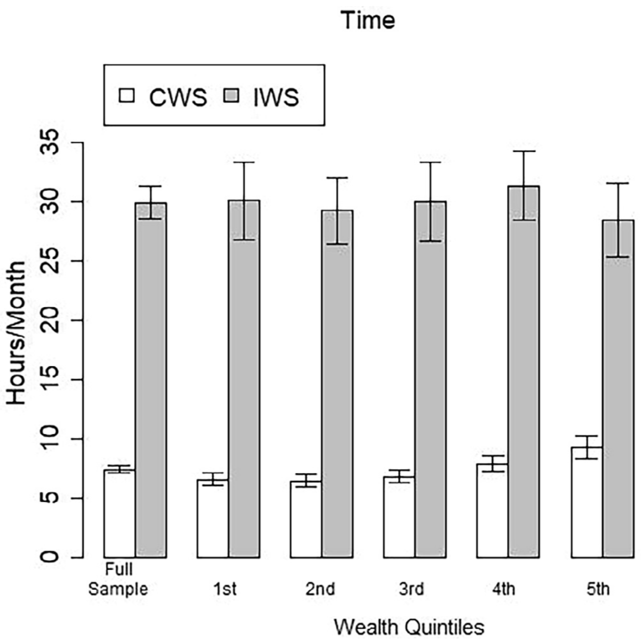


Fig. 2. Monthly water-related time expenditure in CWS and IWS zones, across wealth quintiles.

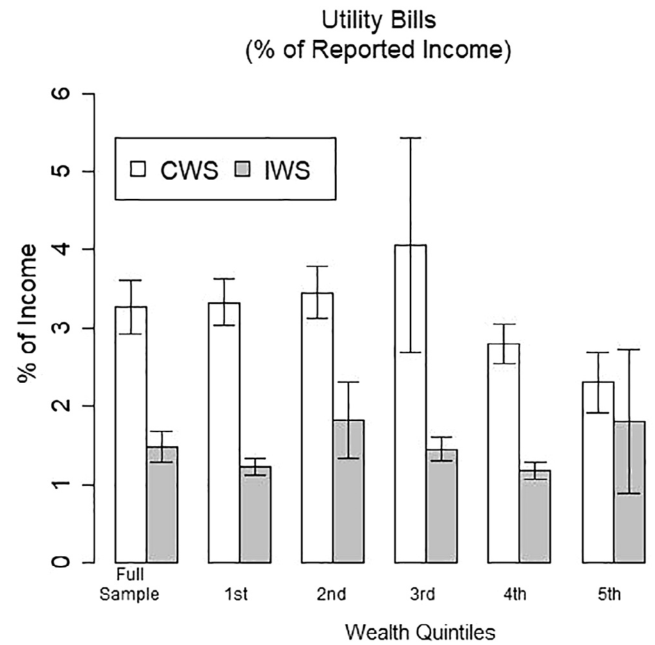


Fig. 4. Average Utility Bills, as a percentage of reported income (Y-Axis), for the full sample as well as by wealth quintile.

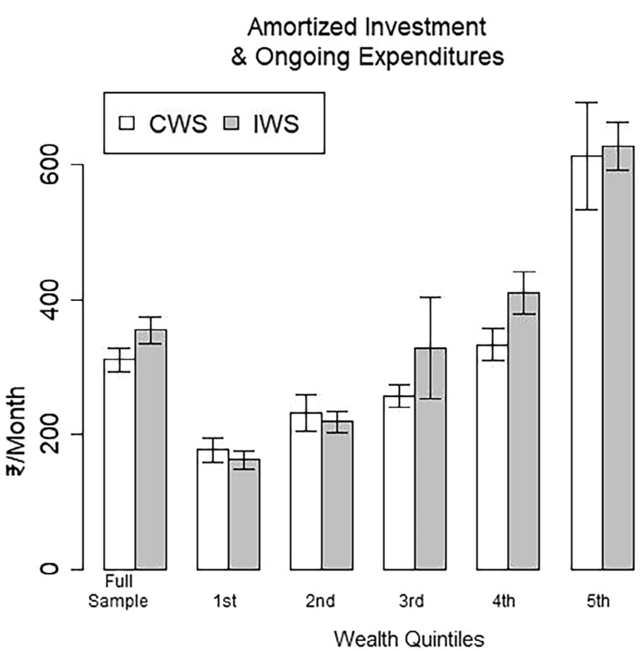
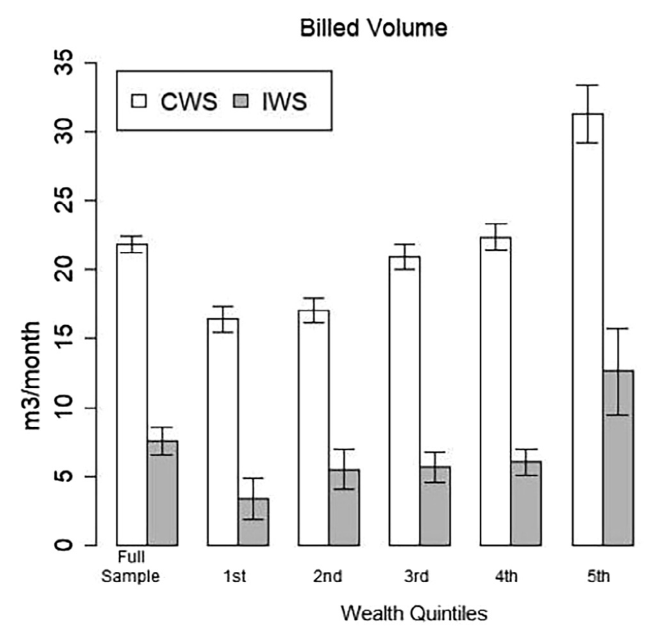


Fig. 3. Total Monetary Costs (monthly ongoing expenditures + amortized investments) in CWS and IWS zones, across wealth quintiles.



Percent of all households that showed their bill to us at least once

	AllHH	WQ1	WQ2	WQ3	WQ4	WQ5
IWS	20%	9%	17%	21%	27%	27%
CWS	46%	35%	44%	52%	54%	43%

Fig. 5. Average Billed Volumes from utility bills, for IWS and CWS zones, across the full sample and each wealth quintile. The table below the figure shows the percentage of households reporting data in the full sample and each wealth quintile.

The sub-sample number for those with meters and current utility bills was smaller for IWS households, and also for households in the lowest wealth quintile; we note the number of households contributing to each quintile at the bottom of Fig. 5. The pattern in our billed volume data is clear: there was a significant increase in monthly billed volume, across all wealth quintiles, in CWS households compared with IWS households. For the full sample, the billed volume in IWS areas was 34–79% of that in CWS areas. In both CWS and IWS regimes, the consumption of the two lower-wealth quintile households was significantly lower than that of the highest quintile.

Finally, private borewell usage in CWS areas was roughly half of what we observed in IWS areas, but there was a dramatic drop off in the use of (free) standpipes and borewells in CWS zones. This was due, at least in part, to the utility closing off many public sources in an effort to eliminate "non-revenue water" (Fig. 6).

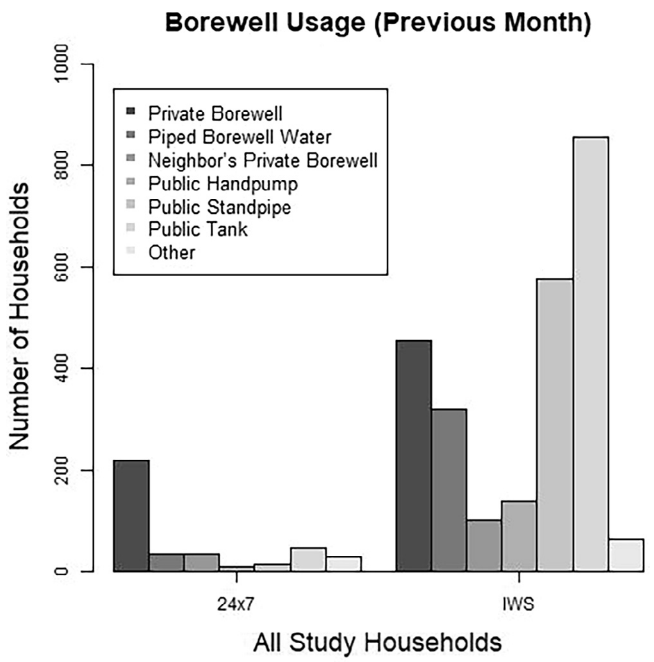


Fig. 6. Borewell and standpipe usage during the previous month (reported by survey respondents).

5. System-level net present value

In this section we present the data analysis and results for system-level net present value of costs and benefits. This incorporates both the household-level NPV of savings and the utility-level NPV of costs and benefits, calculated on a per-capita basis, of the upgrade from IWS to CWS. We draw from project documents for the utility-level analyses and from our own survey for the household-level analyses.

Finding accurate cost estimates for supply augmentation and demo implementation was difficult due to the inconsistent reporting of the WB and WSP documentation. One estimate of the total cost of the KUWASIP investment was reported in WB documents made public on their website (World Bank, 2004; World Bank, 2011). In addition, we took some cost data and local population data from a report by the Water and Sanitation Program (WSP), a multi-donor partnership administered by the WB (Franceys & Jalakam, 2010). The costs for KUWASIP consisted of several parts; we binned them in roughly the same three funding categories as the World Bank documents did: (1) to help strengthen the urban water sector in Karnataka, and administer KUWASIP (we call this 'capacity building'); (2) to augment the water supplies and increase the production efficiency of each city (or 'supply augmentation'); and (3) to implement the demonstration project itself, including investments in the distribution networks and the initial costs of operations and maintenance (or 'demo implementation')[10]. In what follows, we ignored capacity building (with its total cost of US $ 3.94 million) and focused on the two larger cost components.

In order to be transparent in the face of multiple official cost estimates and categories, we conducted separate cost-benefit analyses based on five different available cost totals, by source of citation and cost category inclusion. The first three costs were those stated in the WSP report (US$10.92 million), the cost-benefit analysis in the WB Project Appraisal (US$18.21), and the actual sum loaned by the World Bank (US $ 19.57 million); all three refer to the cost of demo implementation in all three cities (Hubli-Dharwad, Belgaum and Gulbarga).[11] The last two measures included the cost of supply augmentation, taken from the WB Project Appraisal (US$5.97 million), and the actual sum loaned by the World Bank (US $ 27.63 million); the former for Hubli-Dharwad alone and the latter for all three cities (World Bank, 2004; p34–44). We used the exchange rate adopted by the WB Project Appraisal (₹45.24/US $) (Franceys & Jalakam, 2010, p. 7; World Bank, 2004).

To estimate system-level costs, we added all direct costs observed at the household-level to the (five) estimates of project-level costs. We excluded monthly water bills as these are just a transfer within the system (a cost to households but a benefit to the utility). To keep our calculations tractable, we assumed that household-level costs would stay the same (in real terms) and we did not include costs (or benefits) external to households or the utility, such as impacts to the local ecosystem or to groundwater supplies outside of the municipal system.

5.1. Data analysis

In order to calculate the NPV of per capita costs and benefits at the utility-level (U_l^{pc}, where the l indicated which of the five utility level cost estimates were being calculated), we first calculated the NPV of benefits (B):

$$B = \text{NPV}(b_L, b_E) = \sum_{t=1}^{T} \left[\frac{b_L + b_E}{(1+r)^t} \right] \quad (2)$$

where b_L was the expected annual benefit accruing to the utility in Hubli-Dharwad from leak reduction, b_E was the expected annual benefit from process improvements leading to increased energy efficiency in Hubli-Dharwad, r was the discount rate, t was the year and T was the total number of years. In line with WB estimates, we used a 15-year time period (T = 15) and a discount rate of 12% (r = 0.12) (World Bank, 2004). We took b_L and b_E from the WB Project Appraisal, where they were assumed to be constant over the time period and were a result of supply augmentation investments (World Bank, 2004).

To calculate U_l^{pc} we used the following equations:

$$\text{For } l = 1\text{-}3: \quad U_l^{pc} = \frac{C_D}{P_3^{DZ}} \quad (3)$$

$$\text{For } l = 4: \quad U_l^{pc} = \frac{B}{P_1} - \frac{C_D}{P_3^{DZ}} - \frac{C_S}{P_3} \quad (4)$$

$$\text{For } l = 5: \quad U_l^{pc} = \frac{B}{P_1^{DZ}} - \frac{C_D}{P_3^{DZ}} - \frac{C_S}{P_3^{DZ}} \quad (5)$$

where C_D was one of the three cost totals attributed to the demo implementation (US$10.92, US$18.21 or US$ 19.57 million), C_S was the total cost of supply augmentation in all three cities (US $27.63 million),[12] P_1^{DZ} was the population of the demo zone in Hubli-Dharwad, P_3^{DZ} was the population of the demo zones in all three cities, P_1 was the population of Hubli-Dharwad, and P_3 was the population of all three cities. For l = 1–3, only the costs of demo implementation were considered and Eq. (3) was used. For l = 4, the

[10] In Annex 2 of the Project Appraisal document (p 34–44), there is a list of cost categories. We included project component A – 'Sector Development and Technical Assistance' and component C – 'Project Implementation' in our 'capacity building' category; project component B1 – 'Priority Investments' in our 'supply augmentation' category; and project components B2 – 'Works in city distribution networks' and B3 – 'demonstration projects' in our 'demo implementation' category.

[11] Demo implementation costs disaggregated by city were not available.

[12] See SI S12 for a similar analysis, using the cost estimate for the supply augmentation in Hubli-Dharwad that was used in the WB cost-benefit analysis found in the Project Appraisal, p 48 (US$5.97 million).

costs and benefits of supply augmentation were added to the costs of demo implementation, and attributed to the total population of the cities, as indicated in Eq. (4). For $l = 5$, the same costs and benefits were considered as in Eq. (4), but they were attributed to the population of the demo zones only, as indicated in Eq. (5). For each NPV calculation, the costs and benefits were assumed to be equal per capita from the perspective of the utility.

For the household level, we calculated the NPVs of costs and benefits for our three composite variables. For the total ongoing monthly expenditure for each household (m_i):

$$m_i = \frac{\sum_{j=1}^{4}\sum_{k=1}^{K} m_{ijk}}{J_i} \tag{6}$$

We calculated the average m_i for each household by summing all m_{ijk} across all data collection rounds (j) and all expenditure types (k), and dividing by the number of rounds of data collected from the i^{th} household (J_i). In most cases $J_i = 4$. We assumed these expenditures to be constant from year to year, and calculated NPV of m_i (M_i):

$$M_i = \text{NPV}(m_i) = \sum_{t=1}^{T}\left[\frac{m_i}{(1+r)^t}\right] \tag{7}$$

where, as in Eq. (2), T = 15 years and r = 0.12. For all household durable investments, we first calculated the average amount invested for each type of investment at the household level (a_{ik}):

$$a_{ik} = \frac{\sum_{j=1}^{4} a_{ijk}}{J_i} \tag{8}$$

where i, j, and J have the same definitions as in eq. 3, and k here referred to investment types. For the NPV of a_i (A_i),

$$A_i = \text{NPV}(a_i) = \sum_{k=1}^{K}\left[\frac{a_{ik}}{(1+r)^{(0.5)T_k}}\right] \tag{9}$$

where, as before, r = 0.12; T_k was the expected useful life of item k (with k referring to a given investment type; see SI Table S5). We assumed that each investment was half-way through its useful life (T_k) at the time of our survey, and would be replaced at the end of it.

To estimate a system-level NPV of costs and benefits with a single unit of measurement, we needed to monetize the value of time. We used the reported income data from our survey as the basis for approximating the hourly (market) value of time spent on water-related chores. We monetized the value of an hour of time spent waiting for, collecting and treating water at 50% of the reported hourly earnings, following (Pattanayak et al., 2005). Starting with the reported total household income, we divided the monthly income across all (paid) working adults within each household. For each wealth quintile, we calculated the average monthly earning per worker. We converted these estimates into hourly earnings by assuming a 40-h work week and 52 weeks of work, and, finally, we multiplied the per-quintile estimates by 0.5.[13]

For the total time expenditure used each month on waiting for, collecting and treating water for each household (h_i):

$$h_i = \frac{\sum_{j=1}^{4}\sum_{k=1}^{K} h_{ijk}}{J_i} \tag{10}$$

where h_{ijk} was each type of time expenditure, across all data collection rounds (j) and all expenditure types (k). As before, in most cases $J_i = 4$. Using the resulting order-of-magnitude estimates for the hourly value of time for each wealth quintile, we converted time expenditures per month (h_i) to rupees per month (r_i), for each household in our sample. We assumed these time expenditures to be constant from year to year, and calculated the NPV of r_i (R_i):

$$R_i = \text{NPV}(r_i) = \sum_{t=1}^{T}\left[\frac{r_i}{(1+r)^t}\right] \tag{11}$$

We estimated the total NPV of all three cost categories for each household (T_i), and divided by household size (H_i), to get NPV of costs per capita for each household (T_i^{pc}):[14]

$$T_i = M_i + A_i + R_i \tag{12}$$

$$T_i^{pc} = T_i / H_i \tag{13}$$

We then calculated the average NPV of savings due to the pilot project in each wealth quintile (S_w^{pc}):

$$S_w^{pc} = \frac{\sum_{i=1}^{V_{IWS}} T_i^{pc}}{V_{IWS}} - \frac{\sum_{i=1}^{V_{CWS}} T_i^{pc}}{V_{CWS}} \tag{14}$$

where V_{IWS} and V_{CWS} were the number of households receiving intermittent and continuous water supply, respectively, in that wealth quintile.

To estimate system-level NPV of costs and benefits for each estimate of utility cost for each wealth quintile, ($SYS_{l,w}^{pc}$):

$$SYS_{l,w}^{pc} = U_l^{pc} + S_w^{pc} \tag{15}$$

where U_l^{pc} was the per capita NPV of costs and benefits at the utility level for cost level l, and S_w^{pc} was the average net savings per capita for wealth quintile w attributable to the conversion to CWS. A positive U_l^{pc} indicated a net benefit, and negative U_l^{pc} a net cost.

5.2. Results

The results of our system-level analysis of the per capita NPV of the costs and benefits for the full sample and for each wealth quintile ($SYS_{l,w}^{pc}$ for l = 1…5 and w = 1…5) were shown in Table 5. Table 5 also shows the NPV of savings at the household level and the NPV of costs and benefits at the utility level, to clarify how each contributes to the results. We found that if (i) the cost of supply augmentation is included and attributed to the demo implementation alone; (ii) the full cost of the upgrade is recovered over 15 years from user charges; and (iii) these charges are equally allocated per capita, then the NPV of costs and benefits at the system-level, and for four of five wealth quintiles, is negative. If, however, the cost of new supplies is divided over the entire population of the three pilot cities – those with CWS and IWS – then the system-level NPV for the top two quintiles becomes positive. The assumed value of time significantly influenced these results; to see a sensitivity analysis with time valued at 25% rather than 50% of the average within-quintile wage, see SI Table S13–S14.

6. Discussion and conclusion

KUWASIP was an ambitious pilot program. It broke new ground for urban water provision in India despite heated controversy. From our ~4000 household study comparing CWS to IWS zones, it appears that most CWS households have experienced a net economic benefit from KUWASIP's operations and rate structure in Hubli-Dharwad. This benefit is largely due to time savings relative to IWS households; the time savings were not correlated with SES. The decoupling of time savings from SES, while initially surprising,

[13] A simpler option would have been to value one hour of time at 25% of the average wage (as in Kremer et al. 2009). This would have given the same hourly "wage" across all wealth quintiles. Our method acknowledges the earnings differences across quintiles, though the incomes reported are likely to be underestimates.

[14] We knew how many members were in each household from our survey data.

Table 5
NPV of savings at the Household-Level for the Full Sample and all Wealth Quintiles; NPV of Costs and Benefits at the Utility-Level for each of the five cost levels; and the NPV of Costs and Benefits at each cost level and wealth category. All amounts are in average Rupees per capita (US$1 = ₹45.24).

Net Costs - Utility Level	Project Cost Assumption		Full Sample	Wealth Quintile 1	2	3	4	5
	Net Savings - Household Level		4723	2977	2785	3988	6038	7986
−2704	Demo Implementation	WSP Report	2019	273	81	1283	3333	5282
−4510		WB CBA	213	−1533	−1725	−522	1528	3476
−4847		WB Loan Amount	−124	−1870	−2062	−859	1191	3139
−5092	Demo Implementation + Supply Augmentation	WB Loan Amount, Total Population, 3 pilot cities	−368	−2115	−2306	−1104	946	2894
−6741		WB Loan Amount, Demo Population, 3 pilot cities	−2018	−3764	−3956	−2753	−703	1245

Note: The per capita NPV of new meters was ₹431 overall, and ranged from ₹395 for the highest wealth quintile to ₹503 for the lowest wealth quintile. Since meter costs were assigned as an average for the entire population at the household level, actual per capita costs for households that received a subsidized installation may have been slightly lower.

could be because almost all households, regardless of SES, collect drinking water directly from the tap, while the overhead systems in many wealthier households passively collect non-drinking water. Alternatively, it could be because low-income households often share taps (Kumpel et al., 2017); they may have wished to collect more water, but could not, in their limited time. We found savings on account of lower investment costs across wealth quintiles, and these *were* correlated with SES. In the lower quintiles the savings were nearly offset by the increased monthly water bill; in the two highest quintiles the net savings were significant.

Looking at current costs and benefits from the perspective of the households, we might conclude that utilities should, whenever possible, upgrade to CWS. No urban piped water system is actually designed for IWS (Galaitsi et al., 2016); upgrading to CWS may therefore seem an uncontroversial goal.

Our analysis does not find fault with any of KUWASIP's successes; it does, however highlight current and future challenges. We find that the impacts of upgrading to CWS go beyond the initial capital investment costs or subsequent ongoing costs; the sustainability of water resources and the equity of water access can and do shift with this service upgrade. Based on our findings, we would argue that any large-scale water system upgrade must take into account potential trade-offs amongst the equity of benefits, the affordability of water, and the maintenance of, or improvement towards, the sustainability of supplies.

Our work indicates that if the burden of full cost recovery falls on the users, and is equally allocated over the relevant population of users, then the net benefits of the project would be unevenly distributed across socio-economic strata. With the exception of the lowest of our five project cost estimates, the households in the lower three wealth quintiles would have had negative NPV from the project. Moreover, our estimates for the overall project-level NPV are positive only if the cost of bringing in new supplies is not included; yet the project would likely not have been possible without supply augmentation. Therefore, the planned scale-up of CWS beyond the demonstration zones is not assured; scaling up CWS will be especially challenging given that consumption in the CWS zones appears to have gone up (see Fig. 5). If capacity or capital constraints prevent scaling CWS up to the entire city, then the upgrade cannot be seen as equitable.

We note that our system-level NPV calculations were sensitive to the assumed value of waiting times. How (or even whether) to monetize time is an ongoing debate in development studies, though unpaid time clearly has an opportunity cost. Different scholars have taken different approaches to monetization; examples include choice of water source as a proxy for the value of time (Whittington et al., 1989); (Kremer, Leino, Miguel, & Zwane, 2009), or valuing time at a fraction of the going wage (Pattanayak et al., 2005), or valuing time by the replacement cost of the service or product of that time (Reid, 1934), cited in (Eisner, 1996). No one in our sample dedicated their full attention to waiting for water; they performed other chores while waiting. But while people (usually women) wait, they are limited in their actions, and constrained to stay near the home. They may miss important social and family events or be late for paid work. We followed the procedure used by (Pattanayak et al., 2005) and valued an hour spent waiting for water at less than the full hourly wage, but we adjusted the 'wage' to reflect earnings differentials by wealth quintile. Our method, therefore, assigns a higher market value to an hour of unpaid labor at the upper-income bracket than to that same hour at a lower one.

This project was in part justified by the hypothetical benefits it would bring to low-income households; we find that low-SES households did benefit under the current rate structure, but less than higher-SES households. The distribution of benefits was strongly correlated with SES; the lowest wealth quintile saved roughly one-fifth of the amount saved by the highest wealth quintile on monthly amortized investments. Likewise, water consumption, which increased in all quintiles, was strongly correlated with wealth, while the water bills as a percentage of reported income were negatively correlated with wealth. All of this indicates that while proponents claimed that this pilot "...revolutionizes service to the poor" (Franceys & Jalakam, 2010), it may have exacerbated social inequity to some extent.

From the equity and affordability perspective, it should give pause that the largest tariff increase, in terms of the proportion of (reported) income, was felt by those least able to shoulder the increase.[15] There is no accepted definition of what is "affordable" and no widely acknowledged guideline for the percentage of household income that should be allocated to the water bill. Affordability studies recommend no more than 3% to 6% of household income for water and sanitation (Amrose, Burt, & Ray, 2015); the US Environmental Protection Agency considers water costs above 2% of income to be unaffordable (Glaze & Stavins, 2002). Although hovering around 3% of income for the lowest wealth quintiles in the CWS zones, this distribution of costs increases the risk that some house-

[15] Household surveys are generally believed to under-report income in India, therefore our ratios of water bills to reported income may be skewed upwards. However, research consistently shows that survey-based incomes and expenditures are more heavily underreported in upper-income households (e.g. (Asian Development Bank, 2007); (Basole, 2014). Our analysis, therefore, could underestimate the relatively higher burden of water tariffs under CWS on the lowest-income quintiles.

holds will, at least sometimes, find the new tariffs unaffordable. An early critique of KUWASIP was that increased prices in the wake of CWS would be a barrier to access for low-income customers, and that unpaid bills would eventually lead to disconnection (Burt & Ray, 2014). So far, this has not been the case, but if drinking water access is a human right (UN Human Rights Council, 2010), then protecting access may require more than adopting threshold affordability criteria. In Hubli-Dharwad, continued access to free public borewells and standpipes would have been a protective, pro-poor measure (see also (Connors, 2005)).

Public water sources were, in fact, largely de-commissioned in the CWS wards. This policy represents a change in water security: free public borewells are backup sources when pipes fail, whether through utility disconnection or insufficient supplies. About half of the households with continuous supply in our study reported at least one interruption in water service during the 15-month study period; of these, 42% lasted 1–6 h. Furthermore, those households who had access to private borewells continued to use them despite access to CWS, albeit at lower rates than in IWS zones, indicating that such sources held value for households in Hubli-Dharwad.

Closing the borewells did not just shift water access, it shifted the resilience of the water system as well. Shutting off free public sources in a bid to maximize cost-recovery could make the poorest households more vulnerable. If, in the future, low income households find KUWASIP's new water charges unaffordable, and no longer have recourse to a free back-up source, they may resort to behaviors commonly practiced in the past; they could hack into pipes and create new informal connections of their own making (Burt & Ray, 2014). This would, in turn, have a negative impact on many of the system-level benefits of the pilot project, including the NPV, reduced leakage, and reduced non-revenue water. Furthermore, diversification of sources is one of the hallmarks of more resilient water systems, especially for a city where municipal supplies are constrained.

The WSP has stated that converting to CWS saved on water resources by reducing wasted water in the household and repairing leaks in the piped network (Franceys & Jalakam, 2010). The claim that households waste water by letting taps run unattended, or discarding remaining stored water when new water is delivered, was not upheld by previous research (Kumpel et al., 2017). Our work found consistent increases in billed volumes in CWS zones compared to IWS areas. This is perhaps not surprising because continuous access to water at the tap is very convenient. CWS proponents, however, had argued that consumption would actually fall, and official appraisals continue to claim (without showing data) that "People tended to conserve water when they were sure of reliable supply" (World Bank, 2013).

The World Bank reports that "technical losses" (i.e., leakages in the pipe network) in KUWASIP-managed CWS zones averaged 7%[16] (World Bank, 2013; p 8); if households are not, to any appreciable extent, discarding old water or letting taps run, then leakage in IWS zones would have had to be 27–73% (20–66% saved due to the upgrade + 7% leakage in CWS zones) to balance the billed volume increases that we observed. Leakage rates in previously IWS zones are not known but the WB estimates that they were "about 50%"; in a benchmarking exercise, the average leakage across 28 Indian cities was 44.1% (World Bank, 2004). This suggests that, three years into the CWS upgrade, there were at most 17%, and possibly no, net savings of water resources.

Without new supplies, whether or not a CWS upgrade can be sustained will clearly depend on the local balance between reductions in non-revenue water and increased demand due to increased access under CWS. The World Bank Project Appraisal document has argued that both CWS and IWS zones in the three pilot cities benefitted from supply augmentation, and therefore these investments costs should not be applied to the demo-zone cost-benefit analysis. Our results do not support this argument.

We argue that most, if not all, of the supply augmentation costs should be attributed directly to the demonstration project. This is because (i) the CWS upgrade appears to have caused an increase in water consumption, beyond the water savings from repairing leaks; (ii) our CMDR colleagues report that many of the intermittent zones, as of this writing, have reverted to a delivery frequency of once a week or less, and this suggests that most of the new supplies are not flowing to the IWS wards; and (iii) our research team's previous work indicates that current planned water system capacity, going forward, may not support scale 24×7 up to the rest of Hubli-Dharwad (Jayaramu et al., 2015).

The analysis thus far does not account for any increase in demand going forward. If water consumption patterns observed in the CWS zones are replicated throughout the city after scale-up, then the installed supply capacity will be quickly overwhelmed (Jayaramu et al., 2015). Scale-up may not be successful without further investments in supply augmentation, in which case the positive net benefits observed in the pilot may not be sustained. A partial service upgrade that provides benefits today is not favorable if the benefits are not maintained, nor equitable if it is not scaled to the entire city. We conclude that if CWS is not scaled up to the rest of Hubli-Dharwad, either on account of capacity constraints or capital constraints, then positive net benefits of the current pilot cannot justify the city-wide project, and the upgrade may come to be seen as highly inequitable. Furthermore, as most Indian cities do, Hubli-Dharwad is expanding beyond its current boundaries into what are now its un-piped, un-sewered, peri-urban areas. Continuous piped water to some parts of the city, if new supplies are unavailable or unaffordable, may undermine the prospects for even intermittent piped water to such areas. All these caveats must moderate our findings on the success of continuous supply within the confines of the demonstration zones.

Continuous piped water service is a boon for those who enjoy its benefits, and there are good reasons for why it is the internationally accepted benchmark for water utilities. We are in no way arguing against it. We are, instead, advocating that its viability be evaluated case-by-case, based on four criteria that are central concerns in the public policy debate in India, and that are likely to be of concern for utilities in many low- and middle-income countries: net benefits, equity, affordability and sustainability. Our study reveals some of the basic policy trade-offs regarding urban water provision that will be at the heart of future upgrades in any resource-constrained country. Our research design results can help water resource managers, urban planners and development financiers to decide whether or not a CWS upgrade program meets all of their needs as well as the needs of all.

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[16] Technical losses of 7% are low compared to other well-run water systems, but new pipes have little leakage, and the CWS zone pipes had been completely replaced.

Ethics

Enumerators explained the details of the study to all respondents, and obtained informed verbal consent from each respondent prior to inclusion in the study. Our research protocol was approved for ethical compliance by both the University of California at Berkeley's Office for the Protection of Human Subjects and the Center for Multi-Disciplinary Development Research, Dharwad, India.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.worlddev.2018.04.011.

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