INTERMITTENT VS. CONTINUOUS WATER SUPPLY: WHAT BENEFITS DO HOUSEHOLDS ACTUALLY RECEIVE? EVIDENCE FROM TWO CITIES IN INDIA

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ABSTRACT

Kyle S. Onda: Intermittent vs. Continuous Water Supply: What benefits do households actually receive? Evidence from two cities in India
(Under the direction of Jamie Bartram and Meenu Tewari)

Almost all urban water systems in South Asia provide intermittent water supply. Intermittent supply can impair water quality and cause users waste water and to adopt costly coping mechanisms such as storage, treatment, pumping, and collection of water from alternate sources. This study implemented a mixed-methods approach that used a billing panel dataset as well as household interviews in two Indian cities undergoing continuous water supply interventions. Continuous water supply did not generally lead to more efficient water consumption among higher income groups, although the poorest households did increase their consumption from very low levels. Moreover, consumers generally continued to incur coping costs under the improved service. There was some evidence for wasteful water use under continuous water supply without volumetric tariffs, especially in slum households. Evaluation of continuous water supply interventions should consider the probability and timing with which household coping behaviors might change. Where continuous water supply is implemented, water demand management strategies should be developed that reconcile conservation goals with affordability goals for the poorest.

To my family and friends, whom I could not have done this without.
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24x7	24 hours per day, 7 days per week
CWS	Continuous Water Supply
CPHEEO	Central Public Health and Environmental Engineering Organization (Government of India)
DMA	District Meter Area
IBT	Increasing Block Tariff
IRB	Institutional Review Board
IWS	Intermittent Water Supply
JNNURM	Jawaharal Nehru National Urban Renewal Mission
LPCD	Liters per capita per day
MJP	Maharashtra Jeeven Pradhikaran (State Water Board)
MLD	Million Liters per Day
NESL	Nagpur Environmental Services Ltd. (Nagpur Water Regulator)
NRW	Non-revenue Water
OCW	Orange City Water (Nagpur Private Water Utility Operator)
PSM	Propensity Score Matching
SLB	Service Level Benchmarks (Government of India)
UNICEF	United Nations Children’s Fund
WaSH	Water, Sanitation, and Hygiene
WHO	World Health Organization

1 Introduction

1.1 Background

Worldwide, 4.2% of deaths are attributable to deficiencies in water supply, sanitation, and hygiene practices (Prüss-Üstün et al., 2008). Thus, supplying safe water is a major priority for developing countries and international organizations. In 1990, 71% of the urban population in low and middle-income countries were estimated to have access to water piped to their house plot or inside the house. By 2010, estimated piped water coverage increased to 73%, meaning that new water connections generally kept pace with population growth (UNICEF and WHO, 2012). Moreover, access to piped water does not by itself guarantee access to water that is safe, microbiologically or chemically clean, available in adequate quantities, or supplied reliably and predictably (Onda et al., 2012). A major reason for this discrepancy is intermittent supply of water, even when delivered through piped connections. The practice of non-continuous or intermittent water supply (IWS) (supplying water to the distribution system for less than 24 hours per day, every day) is widely recognized as a significant risk factor for drinking water contamination (Besner et al., 2011; EPA, 2001; Karim et al., 2003; Lehtola et al., 2004; Telgmann et al., 2004), and for pressure transients that can damage a water system over time (Lee and Schwab, 2005). Intermittent supply is also a driver for costly coping mechanisms that in turn decrease service quality for other users. For instance, construction of storage tanks and operation of booster pumping mechanisms not only burden the implementing households directly in the form of time and monetary expenditure, but can lower service pressures and water quantity for other users and introduce further uncertainty in the hydraulics of the system, leading to inequitable distribution of water (Pattanayak et al., 2005; Lee and Schwab, 2005). Estimates from international surveys of water utilities indicate that up to one third of Latin American and African water utilities, and the majority of water utilities in South Asia operate their networks intermittently (van den Berg and Danilenko, 2011).

In light of the efforts to meet the Millennium Development Goals and growing concern about public health problems due to water contamination, the high coping costs to consumers of dealing with unpredictable water supply, and the administrative burden of dealing with system-wide degradation as a result of IWS, water providers for many cities in developing countries have made efforts to improve service delivery, including upgrading from intermittent to continuous water supply (CWS). Recent examples of service delivery reforms and associated network rehabilitation programs include the utilities responsible for: Colombo, Sri Lanka;

Nairobi, Kenya; Manila, Philippines; Dakar, Senegal; and the nation of Burkina Faso (Water and Sanitation Program-Africa, 2009; Chiplunkar et al., 2012). They have made these efforts at considerable expense, generally requiring capital expenditure grants and loans from central governments and/or international donors (Chiplunkar et al., 2012; Water and Sanitation Program-Africa, 2009). Such expenditures for more recent CWS upgrades in India have been justified under the explicit assumption that the intervention will produce benefits to households in the form of better quality water, improved health, and lowered per capita expenditures on water storage, pumping, and treatment (World Bank, 2010). However, does it follow that upgrading water supply from IWS to CWS will automatically ensure that customers will actually experience reductions in the adverse consequences of IWS? What does it take for the assumed benefits of 24x7 service hours? There is little evidence as to whether, under what conditions, and what categories of households actually receive the purported benefits of converting from intermittent to continuous water supply. This paper attempts to provide grounded primary evidence in the urban Indian context to begin to address this gap in the literature between assumptions of CWS supply and the realization of benefits by consumers.

This technical report is organized as follows: It reviews the debate on the merits of continuous water supply; then uses the terms of the debate to build the conceptual framework used to link continuous water supply to potential benefits for domestic consumers, and the research questions that guide the rest of the paper; follows with a description of the methods in terms of study sites, study design, and data collection and analysis; and concludes by analyzing the results in light of the existing literature on water service quality, discussing the policy implications of the findings, and providing perspectives on avenues for further research.

1.2 Converting from Intermittent to Continuous Water Supply: Debates in the Literature

This section provides a background of IWS and CWS and an overview of the debates in the literature about the merits of the introduction of CWS in a formerly IWS network. First, it explains common causes or motivations of IWS system operation. The main criticisms of IWS are outlined, and finally, it summarizes the purported benefits of CWS currently being used to justify large-scale interventions in Indian and international water policy and engineering fields.

1.2.1 Causes of Intermittent Water Supply

Piped water systems are generally designed to deliver a continuous supply of safe water. However, deficiencies in the design, construction, operation, and maintenance of piped water supplies have all contributed in varying degrees to drinking water contamination at the point of use as well as waterborne disease outbreaks (Geldreich, 1996; Lee and Schwab, 2005; Semenza et al., 1998). One commonly cited deficiency is the practice of intermittent water supply. Generally a water utility either adopts intermittent supply or passively lets its network degrade and operate intermittently due to a variety of constraints–of water availability, financial resources, managerial capacity, or all three (Lee and Schwab, 2005). For instance, a utility may be compelled to provide intermittent water supply due to rapid population growth and a lack of concurrent water distribution capacity expansion. Or given water shortages, a water utility might ration the water, supplying water to certain areas during certain time periods (World Bank, 2003). In addition, it is common for water systems to be unintentionally operated intermittently due to leakages and breaks in insufficiently maintained pipes and valves and unplanned withdrawals from illegal connections (World Health Organization, 2003).

1.2.2 Deficiencies of Intermittent Water Supply

There are generally four main reasons for why intermittent supply is considered deficient:

1. Intermittent supply increases the risk for contamination of drinking water in the distribution system and at the point of use in the absence of safe household water treatment and storage.
2. Intermittent supply increases the risk for water-related diseases to be transmitted in the home due to: contamination of drinking water in the home due to a combination of unsafe storage and inadequate treatment, and inadequate quantity and/or convenience of clean water to be used for hygiene behaviors such as handwashing.
3. Intermittent water supply tends to accelerate the deterioration of distribution networks, causing leaks that can prevent the efficient management of water resources and damage that can increase operations and maintenance costs.
4. Intermittent supply burdens households (and disproportionately the poorest households) with various coping costs associated with uncertainty in the quality, quantity and timing of water supply.

These four criticisms are elaborated below:

(i) Drinking water contamination in the network Theoretically, an intermittent water supply is more likely to have contamination introduced into the system than a continuous supply due to a variety of physical reasons. When pipes are empty or at low pressure, contamination from outside the pipes can enter the network through intrusion directly through pipe walls or backflow through cross-connections and leakage points

(Besner et al., 2011; EPA, 2001; Karim et al., 2003). In addition, repressurization of pipes can dislodge bacteria from biofilms or corrosion present in pipe walls (Lehtola et al., 2004; Telgmann et al., 2004). Many studies have provided empirical evidence for impaired water quality in water systems with intermittent supply (Ayoub and Malaeb, 2006; Elala et al., 2011; Kumpel and Nelson, 2013; Raman et al., 1978; Tokajian and Hashwa, 2003).

(ii) Drinking water contamination and hygiene behavior in the home A notable consequence of intermittent water supply is the necessity of storing water in external storage tanks or within the home. Evidence suggests that household water storage creates significant opportunities for contamination of water that is delivered clean at the tap, to the extent of possibly negating any benefits of investments in household of improved water quality in the distribution system (Coelho et al., 2003; Elala et al., 2011; Kumpel and Nelson, 2013; Yassin et al., 2006). A meta-analysis of 57 studies showed that contamination of water between the source (including residential taps of piped water supplies) and the point and time of use is widespread and statistically significant in many contexts worldwide (Wright et al., 2004). In addition, intermittent supply and associated inconvenience to water collection relative to continuous supply can have the effect of reducing water use volumes that could otherwise be used for hygiene behaviors such as handwashing, food hygiene, bathing, and sanitation-related activities (Howard and Bartram, 2003). In a recent study of water consumption patterns under different water service levels in rural communities in the Wei River Basin in China, households with intermittent water supply piped to the home and those relying on public taps had similar water use allocations to hygiene behaviors, while households with continuous water piped to the home demonstrated relatively more frequent water usage for hygiene purposes (Fan et al., 2013).

(iii) Water system management Intermittent supply makes managing the supply and demand of water in the distribution network difficult. This is because traditional engineering modeling techniques assume continuous supply. Thus, in an intermittent supply network, water utility managers are uncertain as to the flows and pressures that different parts of the network are undergoing at any given time, leading to difficulties in detecting the magnitude and location of leakages and often resulting in potential wastage of water. In the context of aging water networks that are not systematically metered, this can lead to inequitable water volumes and pressures being delivered to different parts of the network, leaving the water demanded in undersupplied areas almost impossible to estimate, let alone deliver (Vairavamoorthy and Elango, 2002). Moreover, the operation of an intermittent network also introduces significant wear and tear on water infrastructure as valves and pumps must be operated more frequently, which can lead to more leaks, higher maintenance costs, and higher long-term capital costs as parts of the network need to be replaced more frequently (Lee and Schwab, 2005; World Bank, 2003).

(iv) Household coping costs Intermittent water supply often leads consumers to adopt expensive coping techniques. These include pumping, storage and treatment of unreliable or unclean piped water, and the collection or purchase of water from alternative sources if the intermittent supply does not allow for the collection of sufficient water (Altaf, 1994). There are few empirical studies of coping costs associated with unreliable water supply in South Asian, let alone in the Indian context. Zerah (2000) found an association between the practice of household water storage and hours of supply, income, land tenure, and home ownership in Delhi. Pattanayak et al. (2005) identified and evaluated the monetary value of five major coping behaviors in Kathmandu, Nepal using direct inquiry and time-cost wage-conversion techniques:

1. Collection time costs of walking and waiting at alternative water sources.
2. Monetary pumping and drawing costs associated with constructing on-plot private borewells and pumping from them.
3. Treatment costs associated with boiling and filtering water.
4. Storage costs associated with the capital and maintenance (imputed rental value) of storage tanks.
5. Purchase costs of obtaining water from alternative vendors and tanker trucks.

They found that the sum of these coping costs could total up to 1% of monthly household income, and can exceed twice the amount of actual water bills. Using contingent valuation techniques, they found that willingness to pay for a hypothetical water service improvement that would eliminate these coping costs was greater than the coping costs themselves, although the difference between them was greater for non-poor than poor households. This study demonstrated that coping costs can be substantial, and gives evidence to support the notion that converting intermittent to continuous water supply could provide benefits valued by consumers even in excess of prior coping costs.

1.2.3 Benefits of converting to Continuous Water Supply

Given these deficiencies, many water engineers and policy makers in the water sector recommend conversion of intermittent systems to continuous or "24x7" systems in order to realize the following benefits (CPHEEO, 1999; Rana, 2013; World Bank, 2003, 2010):

1. 24x7 supply delivers better quality water for public health, due primarily to complete pressurization of the pipes.
2. 24x7 supply delivers improved efficiency through the reduced maintenance needs and the conversion of valve operations staff to water meter reading and customer service.
3. 24x7 supply will reduce overall stresses on water resources by reducing water wasted through leaks, overflowing household storage systems, and water hoarding by uncertain customers.
4. 24x7 supply is an improvement in service quality to customers, who will have water supplied at better quality, pressure, convenience, and quantity.
5. 24x7 water supply will disproportionately help the poor, who will benefit the most from reduced coping costs and waiting times, and reallocate their time and money productively.
6. 24x7 water supply will eliminate the need for in-home storage, removing a common pathway for contamination.
7. 24x7 supply will convert the coping costs of consumers into revenue for the water utility as they will abandon coping behaviors and be willing to pay higher tariffs for better service.

In sum, there is a strong political, economic and technical case for water utilities transitioning to CWS. While the case exists in theory, in practice, the costs of this transition, and the distribution of the benefits, are less well understood. In addition, there is a lack of grounded understanding of how the claims that continuous water supply consistently leads to more efficient water management by, and elimination of coping costs for, consumers bear out in practice or depend on context and implementation.

1.3 Purpose of Study

This section uses the proposed benefits of CWS described in the literature to construct the two primary, but interdependent, components of the research: water consumption and coping behaviors. Then, the research questions are presented.

1.3.1 Component 1: Effect of Introducing Continuous Water Supply on Water Consumption

A fundamental response that this paper investigates is the impact of CWS on water consumption. As shown above, among the justifications for CWS interventions are that poor households will substitute away from alternative sources due to the increased convenience and a reduction of the problems of low pressure and reliability of the piped water supply, and so will *increase* water consumption from the piped network. At the same time, replacing IWS with CWS is said to *reduce* consumption among non-poor households, as they will no longer have a reason to hoard water, and they will face a greater incentive to fix leaks and close taps when not needed to lower water bills (World Bank, 2010). While these are the most commonly cited benefits of CWS, major criticisms of CWS are, first, that the increased convenience of water access can lead to unsustainably high levels of consumption, especially when water prices faced by consumers do not reflect the social cost of the abstraction and delivery of water. Second, continuous pressurization can lead to higher water losses through leaks in residential plumbing, since any undetected leaks will leak continuously under CWS. It is also possible that CWS only affects consumption if the water quantity supplied under IWS is below a household's adequacy threshold (Andey and Kelkar, 2009). Finally, a major confounder of the effect of CWS on water consumption is the price increase in water that often accompanies CWS projects, and did so in the study sites.

1.3.2 Component 2: Comparing Coping Behaviors under Intermittent and Continuous Supply and across Implementations

Along with water consumption, the reduction of coping behaviors such as those enumerated and evaluated by Pattanayak et al. (2005) is often cited as a direct benefit of CWS to households (World Bank, 2010; Rana, 2013). In addition, the mechanisms by which CWS results in beneficial effects on domestic water consumption as described in Section 1.3.1 all depend on changes in coping behaviors. However, there are many possible factors that may prevent changes in coping behaviors by households faced with a change from IWS to CWS. For example, 94% of households provided with CWS service in an upgrade in Hubli-Dharwad, India still stored water up to three years after the service improvement for unspecified reasons (Burt and Ray, 2014). Given the dual importance of coping behaviors, the effect of CWS on coping behaviors should be investigated both in its own right, as well as in terms of how this effect relates to water demand. Since coping behaviors vary by context, the list of particular coping behaviors investigated in this study was generated as part of preliminary research activities described in Section 2.3.1.

1.3.3 Research Questions

In light of the two major concepts elaborated above, the main and secondary research questions guiding this study are as follows:

1. How does changing to CWS affect domestic water demand?
   (a) Does the magnitude and/or direction of this effect vary over domestic water storage infrastructure?
   (b) Does the magnitude and/or direction of this effect vary over the availability of alternative domestic water sources?
   (c) Does the magnitude and/or direction of this effect vary over socioeconomic status?
   (d) Does the magnitude and/or direction of this effect vary over initial water demand levels under IWS conditions?
2. To what extent does changing to CWS cause a reduction in coping behaviors?
3. How does the effect of CWS on coping behaviors depend on how CWS is implemented?

Research questions 1, 1(a), 1(b), 1(c), and 1(d) were investigated using econometric methods applied to administrative data collected by a water utility implementing CWS upgrading in part of its network. Research questions 2 and 3 were investigated using a comparative case study based on primary interviews of water customers in two cities implementing CWS upgrading under different institutional frameworks and with different strategies.

2 Methods

This section describes the study sites, and then the research design, data collection, and data analysis methods used for each of two major research components described above.

2.1 Study Sites

While the issue of continuous water supply has global relevance, this study focuses on two particular cases of cities currently upgrading their water supplies from IWS to CWS to examine in detail the context-dependent relationships between water supply mode and water consumption behavior.

2.1.1 The Indian Context

India is an interesting setting to study these questions due to its size, its resource constraints, and the relative importance of the water access issue. India, like many countries in Asia, Latin America, and Sub-Saharan Africa that struggle with issues of urban water supply, faces severe capacity and resource constraints that influence the types of interventions that are possible in its urban water sector. Nearly 99% of India's piped water supplies, in urban and rural areas both, are operated intermittently. While currently, no major city in India has continuous water supply (McKenzie and Ray, 2009), there has been a state of recent experiments with 24x7 water supply reform. These reforms have have been driven by a recent emphasis at the level of the central government to upgrade urban services by setting Service Level Benchmarks (SLBs) for urban infrastructure. For the water sector, one benchmark is delivering at least 135 liters per capita per day (lpcd) of drinking water, and another benchmark is delivering water 24 hours per day (CPHEEO, 1999; World Bank, 2003). This push for higher service delivery standards has been associated with a number of pilot projects throughout the country to experiment with converting intermittent water supplies to continuous water supplies (World Bank, 2010).

Two such projects are currently underway in the cities of Amravati and Nagpur. While Nagpur is a larger city than Amravati, they are both classified as Municipal Corporations, and are the two largest cities in the Vidarbha region of Maharashtra state (see Figure 1).

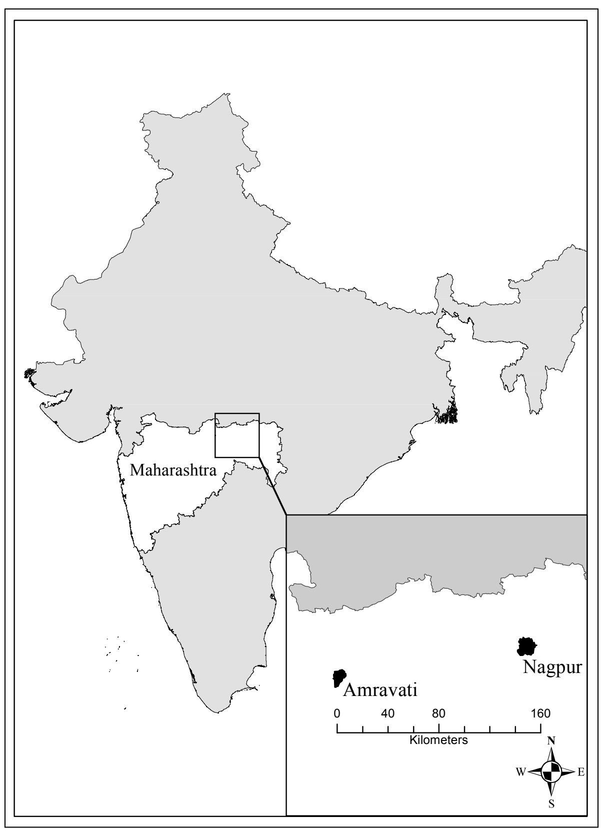


Figure 1: Location map of study sites

Both are major trade and administrative centers for their respective districts. The cities are only 160km apart and their districts share a common border. They have similar climates and face similar water resource constraints. They also embarked on their continuous water supply projects contemporanesouly. However, Nagpur chose a public-private route for implementation, while Amravati implemented the project through a state-level public sector agency. These institutional differences allow for meaningful comparisons between impacts of CWS in both settings that could be attributable to the differences in implementation.

2.1.2 Cases

This section describes the water systems in place in both cities, and then compares their overall water supply situations on commonly accepted water service indicators and the Government of India service level benchmarks to contextualize the differences in the CWS interventions.

Amravati Amravati has a population of 700,000. It relied on a system of borewells for its water supply until 1994, when it constructed a new piped network sourced from a new surface water reservoir at the Upper Wardha dam 55km away. A local office of the Maharashtra Jeevan Pradhikaran (MJP), the state-level water board, administers Amravati's water supply. MJP is headquartered in the state capital of Mumbai, and operates 25 urban water utilities as well as several rural water supply schemes throughout Maharashtra. MJP does not have a meaningful interaction with the Amravati Municipal Corporation in terms of its water pricing and management, although the two bodies do interact occasionally to coordinate network extension with new developments and building activity. As of 2010, MJP supplies about 82 million liters of water per day (MLD) to the city. This water is transported through a transmission main to a single ground storage tank, where it is then transported to a treatment plant, and then transmitted by gravity or pump to one of 16 elevated and ground storage tanks throughout the city. Each storage tank then supplies water by gravity flow to an isolated one of 16 "command areas", which is further subdivided into isolated and distinctly-operated District Meter Areas (DMAs) which distribute water to commercial and institutional users, households, and public standpipes. Roughly 50% of potential customers are connected to the network. The remainder depend on private borewells or public standpipes.

All connections except for standpipes are metered, with roughly 75% of meters functioning at any given time. Water from standpipes is provided free of charge to consumers, and operated in exchange for a monthly fee paid by the Amravati Municipal Corporation. All other connections are charged a bimonthly volumetric tariff based on meter size, or a flat rate if the meter is not functional for a given billing period. Since 2010, all domestic connections are charged according to a volumetric, increasing block tariff (IBT) if their meters are functional. Increasing block tariffs charge increasing prices for water as consumption of water increases, generally in an effort to encourage water conservation. New connections are offered on demand for a connection charge. All water-related charges are set by the MJP head office, and are uniform across its 25 urban water utilities across the state.

In mid-2010, the MJP rehabilitated command areas served by two of the storage tanks to enable CWS. In mid-2011, two more command areas began CWS service. In late 2012, one of these command areas suffered distribution main break and is no longer operating continuously. A total of about 12,000 out of 71,000 (17%) households with piped water connections thus received CWS for some time over the past three years. The vast majority of the other connections in the city receive water two hours in the morning and/or two hours in the evening every day.

Nagpur Nagpur has a population of 2.5 million. Its drinking water supply includes treated water from Gorewada lake outside the city, an intake well system on the Kanhan river 15km away, and the Pench reservoir 50km away. The local groundwater is contaminated and not used as a potable water source by the water utility, but is accessed by those without connections through unregulated borewells and handpumps. After treatment, the water is transmitted to one of 57 elevated or underground service reservoirs from which water is distributed to customers. Work is currently in progress to divide the network into command areas and DMAs as in the Amravati network.

Until 2012, the municipal water works department managed the network. The distribution network is generally in a state of disrepair. While an estimated 85% of households are connected, service hours are highly variable and unpredictable, and some areas receive 0.5 hours per two days. In 2008, the municipal corporation entered into a management contract with Veolia, a French water company, and handed over the waterworks (including storage facilities and the distribution network) in the Dharampeth zone, the administrative heart of the city that includes the central business district, several high-income neighborhoods, and many slum settlements, for the company to administer. Veolia pledged to connect 5,000 slum households and convert the Dharampeth network and its 15,000 connections to CWS. The Nagpur Municipal Corporation (NMC) financed this initiative with funding from JNNURM, an infrastructure capital grant program administrated by the Ministry of Urban Development in the central government. In 2012, Veolia entered a joint-venture agreement with a local civil engineering firm, creating a private operating company called Orange City Water, Ltd. (OCW). The Nagpur Water Works Department was ring-fenced and reorganized as the management company Nagpur Environmental Services, Ltd (NESL). NMC charged NESL with contracting water services management to OCW, which is in turn charged with using JNNURM funds to repair, rationalize, and upgrade the network and to convert the entire city to CWS over the next 25 years.

2.2 Research Design

This study has two components. The first component aims to quantify the impacts of CWS on residential water demand in Amravati, and the second aims to explore the differences in coping behaviors conducted by households with and without CWS in both cities. Both components make use quasi-experimental designs making use of "treatment" groups of households in areas that were upgraded to CWS, and "control" groups of households in areas that remained served by IWS throughout the study period. However, the first component is entirely quantitative

2.2.1 Quantifying the impact of continuous water supply on residential water demand in Amravati

This component, designed to address research questions 1, 1(a), 1(b), 1(c), and 1(d), uses a prospective, longitudinal panel design, for which suitable data was available from Amravati, but not Nagpur. The Amravati CWS intervention can be conceptualized as a natural experiment, in which the 17% of households connected to the piped network in the command areas that MJP upgraded to CWS were "treated", and the remaining connected households composed a "control" group. By using household-level water consumption measures over a period of time before and after CWS service was initiated, this design follows the same households in a panel, and so should control for any time-invariant unobserved household differences that could affect water consumption. Systematic differences in households in the zones selected by MJP for CWS can be doubly controlled for by measuring before-after changes in consumption within each household over time, and by controlling for observed characteristics.

2.2.2 Comparative Case Studies of Amravati and Nagpur: Impacts of continuous water supply on coping behavior

This component, designed to address research questions 2 and 3, uses a two-way posttest-only qualitative comparative case study. This design takes advantage of policy discontinuities across city borders.

In Amravati, the public water utility divided its service area into 16 zones, and took the lead in providing continuous water supply in four of these zones since 2010. In Nagpur, the municipal water works department entered into a public-private partnership and signed a private concession agreement in 2008, where the partnership has provided continuous water supply in a pilot area since 2009 and is now in the process of upgrading it to the entire city.

This design compares water coping behaviors in treatment households receiving CWS and control households receiving IWS, and comparing experiences of treatment and control households under the different implementations of water supply in Nagpur and Amravati. Any differences in coping behaviors between CWS and IWS households within cities are attributed to the treatment in such a design. A serious threat to internal validity would be systematic differences between households with CWS and households without CWS. This deficiency was addressed through purposive sampling of clusters of households in slum settlements and middle and upper-income neighborhoods in CWS and IWS zones as described in Section 2.3.3.

2.3 Data Collection

Approval to conduct this research was obtained from the University of North Carolina at Chapel Hill Institutional Review Board (IRB). The IRB determined that this study (# 13-2186) was exempt from further review. Consent for participation in interviews was provided verbally after participants were informed of the purpose of the study, that their responses would be kept and reported deidentified, and that they could refuse to answer any question or end the interview for any reason.

This section describes the data collection methods of this study. It begins by describing the preliminary research activities that provided essential context, ascertained secondary data availability and informed instrument development. Then the secondary data used for the first (quantitative) major research component are described, followed by the primary data collection method followed for the second major component (comparative case study).

2.3.1 Preliminary Research

This section describes the preliminary research conducted at each site that was essential to the study, followed by the results that informed interview guide development.

Unstructured interviews were conducted with water utility staff members (eight in Nagpur, ten in Amravati) and a convenience sample of eleven households with piped water connections. Interviews and ongoing interactions including field visits to water infrastructure with water utility staff on both individual bases and in groups served to contextualize CWS in each city. These conversations concerned the historical development of and justification for the CWS projects, their CWS implementation strategies, the nature of day-to-day operations, common customer behaviors (including coping behaviors), and notable difficulties encountered and responses made to them over the course of ongoing reforms. This information provided the context which can help to explain any differences in impacts of CWS between the two cities. Access to available administrative data was also negotiated with the responsible parties.

In Nagpur, a neighborhood in the pilot CWS command area was chosen at random, and five households in close proximity were approached and queried informally about their water sources, their memory of water service quality before the CWS intervention and opinions about current water service, their interactions with the water utility, and exactly how they procured water and interacted with it in the home. In Amravati, MJP staff guided the researcher to a convenience sample of three households with CWS and three households with IWS with whom similar conversations were had.

In addition to contextualizing the CWS projects in each city, these interactions provided a grounded preliminary assessment of predominant local water-related coping behaviors that were used to develop the semi-structured interviews that would focus on them. This was necessary because Pattanayak et al. (2005) provide the only comprehensive overview of coping behaviors in a South Asian context, and Kathmandu cannot be assumed to be similar in all relevant ways to Nagpur and Amravati. In order to develop complete and relevant interview guides to investigate coping behaviors, the predominant coping behaviors in Amravati and Nagpur needed to be determined.

Interviews with water utility staff and the preliminary sample of households within each city revealed the most common coping behaviors and associated burdens that exist in households with piped water supply. These behaviors were consistent in both cities, and included the following :

1. Storage in overhead, and in some cases, underground storage tanks (sumps), incurring contamination risk, rental costs for capital, and time costs for cleaning.
2. Storage of water for drinking and cooking in vessels inside the kitchen or elsewhere in the home (this was reported to be near-universal, but was characterized as a cultural practice rather than a coping behavior).

3. Use of booster pumps to extract water from system or to transfer water from an underground to overhead tank, incurring electricity charges.
4. Treating water for drinking and cooking before consumption, including boiling, cloth filters, alum, manual chlorination, or RO/UV/Chemical treatment devices, incurring a variety of costs including purchase, maintenance, and energy.
5. Supplementing supply with a private borewell with a pump or a dug well or a public source, incurring electricity and/or time costs.

Table 1 summarizes the hypothesized effects of CWS on these outcomes, which were evaluated by the research methods described in the following sections.

Table 1: Potential impacts of continuous water supply

Outcome	Hypothesized effect of CWS
Water consumption	Increase in low-end consumers; Reduction in high-end consumers
Water Storage (external)	Reduction; Elimination in new houses
Water storage (internal)	Elimination
Pumping	Reduction
Treatment	Reduction
Alternative source use	Reduction

2.3.2 Component 1: Amravati Administrative Data

Beginning in 2009 in anticipation of the CWS intervention, MJP created a computerized billing system and began conducting what it termed a "consumer survey". The consumer survey was a census administered to the head of household or building manager of every building and slum tenement in the city, whether connected to MJP's water network or not. It was first administered in mid-2009, and is updated weekly with the construction and occupation of new buildings or changes in occupation of existing buildings added to the database. There were 133,948 records in the database as of June 2013. Each record includes information on household or building-level social and demographic characteristics, water infrastructure, and the water system operating zone it is located in. The instrument used is shown in Appendix A.

The billing database contains MJP's records for bimonthly periods for all current and disconnected customers beginning in October of 2009. By September 2010 24x7 water supply was introduced in two of the 16 zones of the city (called Arjun Nagar and Sai Nagar) by September 2010, and expanded to two more zones (called HSR and Maya Nagar) by August 2011. Water tariffs were revised significantly in October 2010 and July 2012 (see Table 9). The billing database includes the following data for each bimonthly billing period:

- Existing debt on water account
- Status of water meter (unreadable, broken, disconnected, newly installed, normal function)
- Water consumption in liters
- Current bill
- Amount paid on bill
- Date of bill payment

An important aspect of this consumer survey is that each building was assigned a unique numeric ID that can be matched to corresponding records in the billing database. Thus a longitudinal panel dataset of metered water demand with a rich set of time-invariant observable confounders is available. Some billing information is missing due to technical difficulties with the billing software that MJP encountered over the past 4 years, with a notable year-long gap between the first available data in October-November 2009 and the second available period October-November 2010.

Figure 2 illustrates the availability of billing data for residential connections, and how it relates with the water tariff modifications and the treatment status of the four "treatment" command areas and the remaining "control" areas over the study period.

2.3.3 Component 2: Primary Survey of Nagpur and Amravati Households

Households were interviewed in the CWS and IWS areas of both Amravati and Nagpur in June and July 2013. The surveys were administered by the researcher in English, or through a college-educated Indian interpreter in Hindi or Marathi, depending on the interviewee's preference. Most interviews were completed with the female head of household, although other household members were not excluded if they wanted to participate. The interviews were semi-structured, and allowed for flexible use of follow-up questions, additional questions and feedback. This allowed respondents to elaborate on their behavior choices to gain a nuanced understanding of how respondents interact with their water supply and the respective water supplier. Interviews were audiorecorded as well as noted by hand on interview guides. The interview guide (shown in Appendix B) included general prompts addressing current water sources used, water timings, quantity and

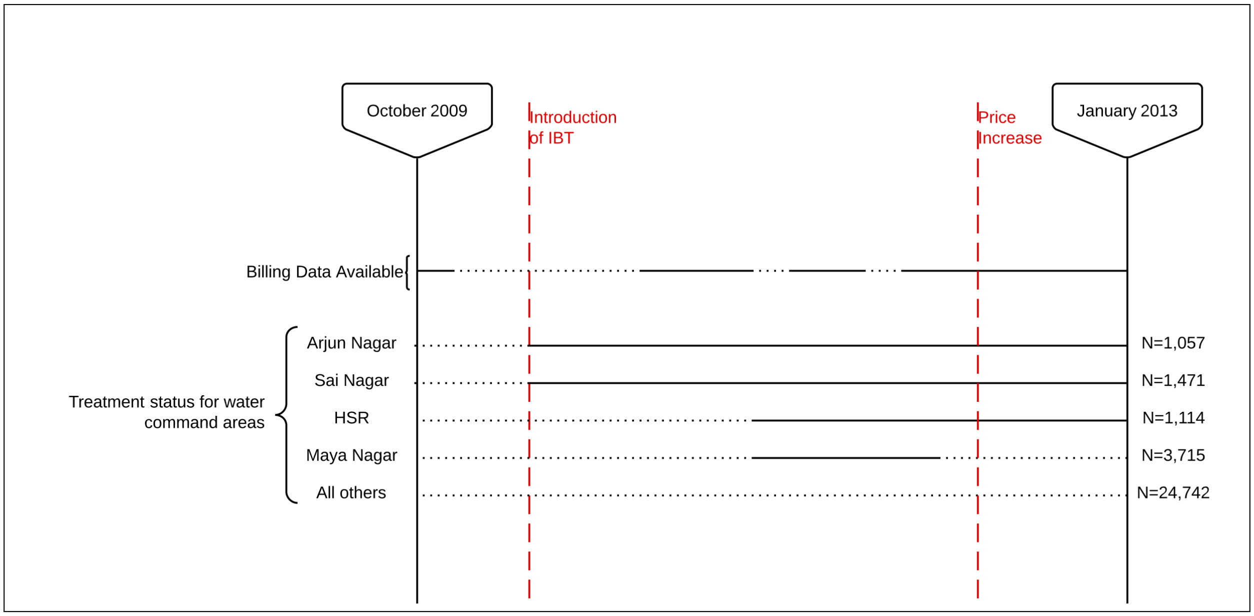


Figure 2: Timeline of domestic billing record availability and CWS treatment group status for Amravati

The first line indicates when billing data is available when the line is solid. The next four lines indicate when the treatment areas Arjun Nagar, Sai Nagar, HSR, and Maya Nagar had CWS. All other zones are combined into a large control group.

quality, billing, storage, treatment, and the process of change to CWS. In addition, all households over the course of the interview were requested to demonstrate how they would prepare water for drinking.

Sampling Households were purposively sampled in slum (as identified in the MJP consumer survey) housing and non-slum (all others) as a proxy for socioeconomic status in order to gauge differential impacts on households with different initial service levels and capacities for more expensive coping mechanisms.

In qualitative research, there are no standard rules to determine the required sample size. The advice of Morse (1994) and Bernard (2000) was followed, both recommending 30-50 interviews for a case in ethnographic-type case studies. The target sample size was 100 connected households, split evenly between each city and between CWS and IWS. Of the 25 households in each combination of water service and city, the target split between slum and formal was for 10 slum and 15 formal households. This split deliberately oversamples slum households, which would not be well-represented in a proportional sampling strategy because relatively few slum households have piped water connections, let alone piped connections with CWS. Clusters of 5 houses each were sampled, and the procedure for choosing clusters was as follows. ArcGIS was used to randomly choose coordinates. In Nagpur, coordinates were chosen as follows:

- Two points in the (only) slum agglomeration of the Nagpur CWS command area.

- Three points in the remainder of the Nagpur CWS command area.
- Five points in the combined IWS area of Nagpur. The two points that were closest to a slum agglomeration as identified in the Nagpur Slum Atlas (CHF International, Nagpur Municipal Corporation, 2008) were reassigned to the centers of those slums.

In Amravati, coordinates were chosen as follows:

- One point in each of the three currently operational CWS command areas in Amravati.
- Two points in an area defined by all three currently operational CWS command areas. These points were reassigned to the nearest slum agglomeration with individual water connections, as determined by MJP's spatial database.
- Five points in the combined IWS area of Amravati. The two points that were closest to slum agglomerations with individual water connections were reassigned to the centers of those slums.

The researcher and translator traveled to each chosen point, and beginning with the nearest dwelling, attempted to interview a household with a piped water connection, and proceeded households down a street until the target sample size was reached. Households would not be interviewed if the household did not answer a door knock, did not consent to be interviewed, or did not have a piped water connection.

2.4 Data Analysis

2.4.1 Component 1: Quantitative Analysis of Amravati Water Demand

The consumer survey and billing records provided by MJP were used to conduct a quantitative estimation of the effect of introducing CWS on domestic water demand using a longitudinal panel fixed-effects, or "difference-in-differences" framework. This analysis was conducted using Stata 12.0 SE (StataCorp, 2011). In order to create a balanced panel dataset, the complete sociodemographic census (consumer survey) was matched with the billing records according to a matching household ID number. Analysis was restricted to only domestic customers. The billing records included metered bimonthly water billed for in cases where meters were functional, or else were recorded as the amount equivalent to the minimum charge in cases where meters were not functional. Since periods of meter nonfunctionality did not have an actual metered water consumption estimate, such data could not be used in the panel. Meter nonfunctionality was assumed to be distributed randomly over cases, and the panel was further restricted to cases for which the meters were functional throughout the available billing record periods. The bimonthly demand was converted to lpcd by dividing by the number of days in the billing period and by the number of people in the household as recorded in the consumer survey.

Average Treatment Effect For the first analysis, the average treatment effect (ATE) on per capita household water consumption from the MJP network of introducing CWS in the place of 2-4 hour IWS was estimated with four related panel fixed-effects models. The dependent variable was the natural log of lpcd. Model A1 represents the most basic specification used, and like all fixed-effects models cannot directly include observed time-invariant covariates.

$$y_{it} = \beta CWS_{it} + BP_t + \alpha_i + \epsilon_{it} \tag{A/B}$$

where

y_{it} is the log of lpcd in HH *i* in billing period *t*

$CWS_{it} = 1$ if HH *i* had continuous water supply in billing period *t* and 0 otherwise

BP_t is the billing period fixed effect

α_i is the household fixed effect

Model B1 is the same as A1, except that time-invariant covariates were incorporated using the kernel propensity score weighting method, which weights observations in the control group (in this case, IWS households) by propensity scores (Dehejia and Wahba, 2002). The propensity score is the likelihood of a household being assigned to the treatment group (receiving CWS), as estimated by a probit model B:

$$probit(T_i) = \Pi X'_{iON9} + BP_t + \epsilon_{it} \tag{B}$$

where

T_i is a treatment group dummy

X'_{iON9} is a series of covariates available in the consumer survey[1]

[1]Covariates used for the propensity score model include the following: household population; ln(garden size in sq. meters); ln(plot size in sq. meters); ln(distance to water main line in meters); ln(total number of taps in house); initial survey estimates for

This method provides the benefit of balancing the treatment and control groups by all observable characteristics, while still retaining all information from households that might be excluded using matching methods that exclude nonmatched controls. Models A2 and B2 correspond to A1 and B1, but include interaction terms for slum dwellers, storage tanks, and alternative sources:

$$y_{it} = \beta_0 CWS_{it} + \beta_1 SC_{it} + \beta_2 TC_{it} + \beta_3 AC_{it} + BP_t + \alpha_i + \epsilon_{it} \qquad \text{(A2/B2)}$$

where

$SC_{it} = 1$ if HH *i* is classified as a slum dwelling and had CWS in billing period *t* and 0 otherwise

$TC_{it} = 1$ if HH *i* had a storage tank and had CWS in billing period *t* and 0 otherwise

$AC_{it} = 1$ if HH *i* had an alternate water source and had CWS in billing period *t* and 0 otherwise

The purpose of these models is to test if there is a difference in the impact of CWS between slum households and non-slum households, households with external storage tanks and households without, and households with private borewells or dug wells and households without. The hypothesis is that slum households, households without storage tanks, and households with private wells would tend to increase their consumption under CWS moreso than other households. This is because households with external storage tanks already functionally have 24x7 supply within their home, that slum households would substitute away from standpipes with the increased convenience of CWS, and that households with borewells and dug wells would substitute away from these sources to reduce electricity and time costs.

Distributional Impacts The above analysis imposes a single response coefficient β on all households conditional on billing period. That is, the effect of the treatment variable is assumed to have the same impact on all households. This may not be the case, however. For instance, households that were already consuming some threshold amount of wanted and needed water may be unaffected by the introduction of CWS, while households that were not consuming much water from the municipal supply to begin with might increase their consumption due to the service improvement. Using quantile regression techniques with panel fixed-effects models has proven to be difficult since differencing independent and dependent variables in different time

initial water use per capita per day for cooking, bathing, washing clothes, washing utensils, and other uses; ln(total overhead and underground storage tank capacity in liters). Dummy variables were also included for: house type-Apartment; house type-Chawl; house type-Slum; three income levels; eight education levels; five occupation categories for male head of household; whether the female head of household works outside the home; household using water from public standpost, private borewell, public handpump, private dug well dummy; and installation of underground tank, overhead tank periods will not be equal to the difference in conditional quantiles (Koenker and Hallock, 2001). There is no consensus in the literature on the appropriate way to conduct such an analysis. However, some pooled quantile regression techniques for 2-period panel data that preserve the unobserved heterogeneity-controlling qualities of fixed-effects models have been developed. I follow the method used by (Abrevaya and Dahl, 2008) in an impact assessment that found that the effect of a mother's smoking on birthweight varies over birthweight distribution. In this method, conditional quantiles for 2-period panel data take the form:

$$Q_\tau(y_{i1}|x_i) = \phi^1_\tau + x'_{i1}(\beta_\tau + \lambda^1_\tau) + x'_{i2}\lambda^2_\tau \tag{Ia}$$

$$Q_\tau(y_{i2}|x_i) = \phi^2_\tau + x'_{i1}\lambda^1_\tau + x'_{i2}(\beta_\tau + \lambda^2_\tau) \tag{IIa}$$

where

y_{i1} is lpcd in period 1 for HH *i*

y_{i2} is lpcd in period 2 for HH *i*

$x'_{i1} = 0$

$x'_{i2} = 1$ if HH *i* has CWS in period 2, 0 otherwise

ϕ^1_τ, ϕ^2_τ are location shifts in conditional quantile for each year

$\lambda^1_\tau, \lambda^2_\tau$ are unobserved effects for each quantile

β_τ is the quantile treatment effect estimator

Equations Ia and IIa simplify to Equations Ib and IIb, for which pooled linear quantile difference-in-differences regression is implemented where the observations corresponding to the same household are stacked as a pair, with bootstrapped standard errors over paired observation samples with replacement.

$$y_{i1} = \phi^1_\tau + x'_{i1}\beta_\tau + x'_{i1}\ \lambda^1_\tau + x'_{i2}\lambda^2_\tau \tag{Ib}$$

$$y_{i2} = \phi^1_\tau + x'_{i2}\beta_\tau + x'_{i1}\ \lambda^1_\tau + x'_{i2}\lambda^2_\tau \tag{IIb}$$

More explicitly, the quantile regression for the τ^{th} quantile would be run as in the matrix equation below. π is what amounts to a time fixed effect. Since only one observation before the implementation of CWS in any area of Amravati is available (October-November 2009), quantile difference-in-difference regressions were performed for the same billing period in each of the following years to ensure comparisons in similar

$$
\begin{bmatrix} y_{11} \\ y_{22} \\ \cdots \\ y_{21} \\ y_{22} \\ \cdots \\ \vdots \\ \cdots \\ y_{n1} \\ y_{n2} \end{bmatrix}
=
\begin{bmatrix}
1 & 0 & x'_{11} & x'_{11} & x'_{12} \\
1 & 1 & x'_{12} & x'_{11} & x'_{12} \\
\cdots & \cdots & \cdots & \cdots & \cdots \\
1 & 0 & x'_{21} & x'_{21} & x'_{22} \\
1 & 1 & x'_{22} & x'_{21} & x'_{22} \\
\cdots & \cdots & \cdots & \cdots & \cdots \\
 & & \vdots & & \\
\cdots & \cdots & \cdots & \cdots & \cdots \\
1 & 0 & x'_{n1} & x'_{n1} & x'_{n2} \\
1 & 1 & x'_{n2} & x'_{n1} & x'_{n2}
\end{bmatrix}
\begin{bmatrix} \phi \\ \pi \\ \beta \\ \lambda_1 \\ \lambda_2 \end{bmatrix}
$$

climactic conditions. Separating the analysis this way can also identify changes in the magnitude or direction of the effect of CWS over time, and thus also by price levels. The analysis was separated by household slum classification in order to explore the possibility of a different response in slum dwellers. This could be due to substitution of water consumption away from public sources, or inability to pay due to concurrent price increases, although the exact causal mechanism cannot be explored with this data. All analyses were performed in two forms: (A) without accounting for observed covariates, (B) with propensity score weighting. Due to differences in zonal availability of CWS over time, the categorization of the households into treatment groups changes according to the specification below. "A" refers to being specified without covariates. The corresponding "B" specifications with propensity score weighting are omitted. "ON10" refers to models where the second period is the October-November 2010 billing period. "ON11" and "ON12" refer to the corresponding models for 2011 and 2012.

(A1-a) t=ON10, CWS=Arjun Nagar + Sai Nagar
(A2-a) t=ON10, CWS=Arjun Nagar + Sai Nagar, restrict dataset to non-slum cases
(A3-a) t=ON10, CWS=Arjun Nagar + Sai Nagar, restrict dataset to slum cases

(A1-b) t=ON11, CWS=Arjun Nagar + Sai Nagar + Maya Nagar + HSR
(A2-b) t=ON11, CWS=Arjun Nagar + Sai Nagar + Maya Nagar + HSR, non-slum
(A3-b) t=ON11, CWS=Arjun Nagar + Sai Nagar + Maya Nagar + HSR, slum

(A1-c) t=ON12, CWS=Arjun Nagar + Sai Nagar + HSR
(A2-c) t=ON12, CWS=Arjun Nagar + Sai Nagar + HSR, non-slum
(A3-c) t=ON12, CWS=Arjun Nagar + Sai Nagar + HSR, slum

2.4.2 Component 2: Qualitative Analysis of Coping Behaviors in Nagpur and Amravati

Interview responses were coded manually and entered into a spreadsheet format. Elaborations and nuances not captured directly by the interview guide prompts were also categorized and coded after the completion of all interviews. Since respondents were not sampled with a probability sample, statistical tests were eschewed. Instead, counts of responses were tabulated in order to elucidate the diversity and general trends of coping behaviors.

3 Results

This section presents a brief summary of the context provided by preliminary interviews with water utility staff, followed by the results of the quantitative analysis of the effect of CWS on water demand in Amravati, and finally the results of interviews with households on CWS effects on coping behaviors in Nagpur and Amravati.

3.1 Comparing the Amravati and Nagpur Water Supplies

In order the contextualize the effects of CWS on water demand and coping behaviors in Amravati, the overall results in both Nagpur and Amravati as indicated by interviews, water utility documents, and publically available data of the shift to CWS in pilot command areas are reported. Table 2 summarizes common service indicators for the two cities during the CWS intervention period. There are a few notable differences in the overall outcomes in the two cities that stand out. First, Nagpur (which is much larger than Amravati) has a better water services coverage rate, both overall, and among slum households than Amravati. Second, Amravati has a far lower cost per connection to upgrade to CWS than Nagpur. While a detailed political economic explanation is outside the scope of this paper, institutionally this outcome is indicative of structural differences in the water supply approach in each city.

OCW's overall priority, as required in the terms of its contract, is to improve service levels and connect all unconnected households in the areas of Nagpur that currently have the worst service levels. Water pricing remains a politically determined process and is under the ultimate jurisdiction of the Municipal Corporation, with no input from OCW. As a result, OCW faces pressure from the municipality to prioritize extending and improving service to those areas with the worst service levels first, while charging subsidized rates to the

Table 2: Comparison of Nagpur and Amravati water supplies, 2009-2013

Water Service Indicator	Unit	2009-10	2010-11	2011-12	2012-13
Total Connected Households	#				
Nagpur		421,072	427,785	438,932	*NA*
Amravati		66,070	69,329	71,890	*NA*
Household water supply coverage	%				
Nagpur		84.9	86.5	85.4	83.8
Amravati		50.7	51.9	52.4	56.6
% of Households in Slums	%				
Nagpur		32.6	32.1	32.5	32.2
Amravati		27.5	28.2	31.0	39.1
Household water supply coverage in slums	%				
Nagpur		82.0	85.0	83.5	84.5
Amravati		20.8	19.8	18.5	15.7
Water consumption per capita	lpcd				
Nagpur		126.1	112.7	101.5	102.9
Amravati		79.7	79.7	77.5	75.7
% connections with functional meters	%				
Nagpur		20.8	24.9	28.1	32.7
Amravati		76.6	75.4	74.6	81.1
Non Revenue Water	%				
Nagpur		30.0	32.2	47.8	58.9
Amravati		32.4	33.2	34.0	42.5
Average continuity of supply	hrs/day				
Nagpur		3.0	3.0	6.0	7.0
Amravati		2.0	2.0	2.0	2.0
Cost Recovery)	%				
Nagpur		117.8	109.3	98.4	105.1
Amravati		NA	204.1	155.0	189.1
Water charge collection efficiency (Revenues/ Assessed bills)	%				
Nagpur		66.5	66.5	58.5	66.1
Amravati		NA	65.8	65.3	59.0

These data were compiled from administrative documents from both utilities and from the Performance Assessment System (PAS) project (PAS Project, 2013)

poorest consumers. In practice, these areas are highly spatially correlated with slum settlements, and so many slum areas were connected without connection charges and are charged subsidized volumetric water tariffs.

Amravati, facing more stringent cost constraints, offers services to a smaller proportion of its population, and in particular to a much smaller proportion of its slum population. MJP-Amravati is not accountable to the Municipal Corporation for its pricing policies or service delivery. The central state-level office in Mumbai sets water tariffs, and redistributes revenue surpluses from its profitable utilities such as Amravati to its utilities operating in deficit and other administrative expenses such as pensions. As such, the management of the Amravati utility faces pressure that results in prioritizing revenue generation over extending coverage. It is also unable to use its profits to invest in improvements, and is dependent on small periodic grants from the state office for any capital investments. This constraint forces MJP to focus its improvements on those areas that are easiest to repair, which tend to be the areas that are in the best condition, and have the lowest slum populations, to begin with.

These differences are most evident in the operational indicators and tariff structures (see Appendix C for the evolution of water tariffs). Amravati, despite a similar bill collection efficiency to Nagpur, has much better cost recovery, lower per capita water consumption, and lower non-revenue water[2] (NRW). This may be due to its higher metering rate combined with its much higher water tariffs and a lack of a special rate for slum dwellers.

3.2 Component 1: Water Consumption

On average, water demand fell by 8%-10% other than in peak demand season after October-November 2009, likely due to tariff increases. However, this decrease in CWS households was less than the decrease in IWS households. As such, CWS was estimated to cause a 6-8% demand increase over IWS. The main result of the quantile analysis is that the largest and longest-lasting demand changes occurred among households that were consuming the least amount of water to begin with, with non-slum households at the lower end of the initial distribution of water demand showing increases of 5-10 lpcd, and slum households at the lower end of the initial distribution of water demand showing increases of 20-30 lpcd. These effects also suggest that those with CWS have lower price elasticities of demand for water than their IWS counterparts, since these effects occurred over a period where water prices were raised for both groups by the same amount.

3.2.1 Summary of Consumer Survey and Billing Data

Figure 3 shows the median of lpcd, for the IWS area and each of the four CWS areas in Amravati, for each billing period. Generally, water demand was reduced in both CWS and Non-CWS areas between October-November 2009 and October-November 2010, and this trend carried forward. Peak water demand in Amravati generally occurred in April-May, corresponding to the region's highest temperatures. Very few slum households (320) were connected to the network in the CWS areas. This is unsurprising, given MJP's strategy of prioritizing improvements in the parts of the network that were in the best condition, which tended to be newer, wealthier and lacking in slum settlements. Also indicative of this difference is that water demand in CWS zones was higher than in IWS zones throughout most of the study period than demand in IWS zones.

[2] Non-revenue water refers to all water produced by the utility that is not paid for. This includes water that is not billed, water that is billed but unpaid for, water that is delivered but underestimated by meters, water consumed through illegal connections, and any water leaks and overflows in the distribution network before the customer connection.

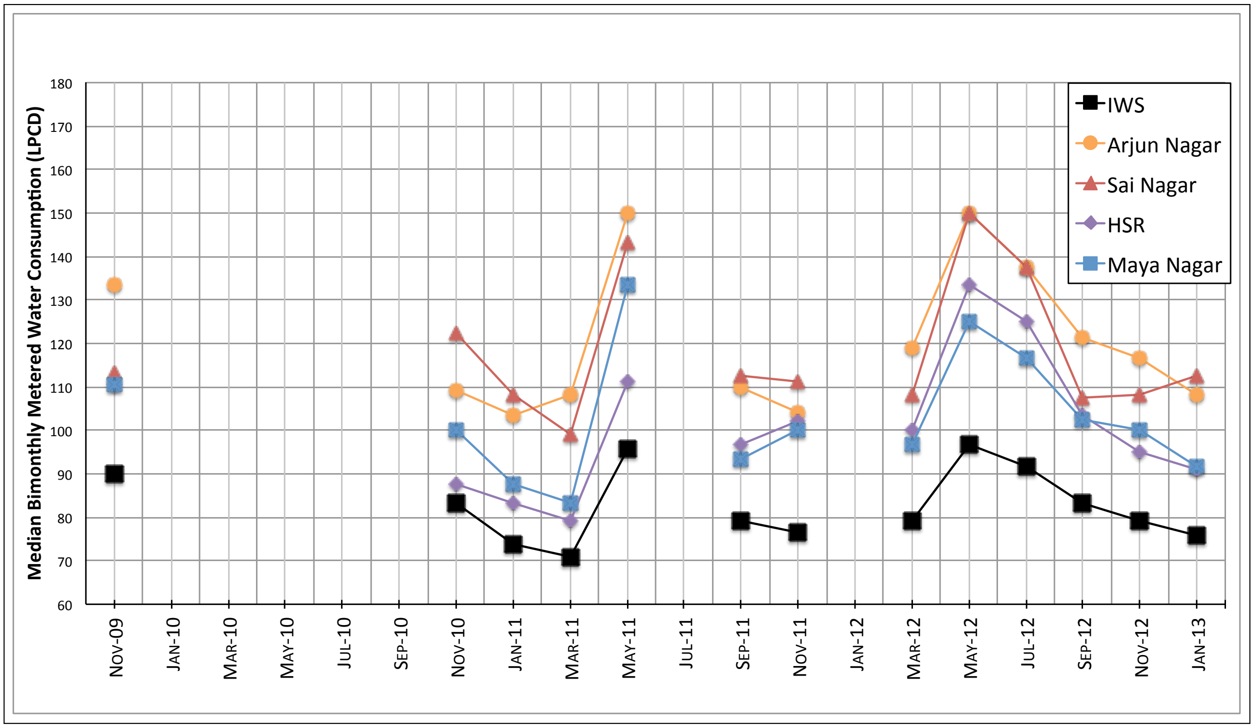


Figure 3: Median lpcd in Amravati domestic water connections, October-November 2009 to December-January 2013 (unweighted)

The propensity score procedure successfully alleviated some of the bias due to systematic differences between the treatment CWS households and control IWS households. Table 3 shows the probit model. Table 4 shows the mean difference between the treatment and control groups, before and after weighting by propensity score. Before weighting, there were statistically significant differences ($p<0.05$) between the groups in 28 out of the 35 observed time-invariant covariates. After weighting, there were only four such differences, and these differences were still reduced by the procedure. Figure 4 shows the median LPCD trend when the data weighted by propensity score. Note the higher relative demand of the IWS customers, and especially the closeness to initial demand in the Sai Nagar, HSR, and Maya Nagar CWS zones.

3.2.2 Average Treatment Effect

The results of the four models are shown in Table 5. Standard errors were bootstrapped to account for clustering and serial autocorrelation by panel, as suggested by Bertrand et al. (2004). The number of observations is larger in models A1 and A2 than in models B1 and B2 because the propensity score weighting method required dropping observations that had missing data in the observed covariates. All coefficients can be interpreted as approximately equal to percent changes in lpcd produced by 1-unit changes in the the

Table 3: Probit regression for propensity scores based on observed household characteristics

CWS Treated	β	SE	p-value
House population	-0.0910	0.00599	0.000
Income level 2	-0.00365	0.0243	0.880
Income level 3	0.0807	0.0497	0.104
educ_class2	-0.202	0.130	0.120
educ_class3	0.0691	0.108	0.522
educ_class4	0.317	0.0934	0.001
educ_class5	0.413	0.0926	0.000
educ_class6	0.437	0.0931	0.000
educ_class7	0.442	0.0967	0.000
educ_class8	0.301	0.113	0.008
Occupation-government	0.347	0.0428	0.000
Occupation-private sector	0.426	0.0439	0.000
Occupation-self employed (formal)	0.00140	0.0409	0.973
Occupation-informal	-0.351	0.0928	0.000
Women work outside of home	0.0323	0.0464	0.486
Apartment	-0.443	0.0853	0.000
Slum	-0.178	0.0544	0.001
Chawl	0.152	0.209	0.466
Overhead tank	0.163	0.0350	0.000
Underground tank	-0.302	0.0305	0.000
Borewell	-0.144	0.0354	0.000
Standpost	-0.537	0.145	0.000
Handpump	0.0417	0.0684	0.542
Openwell	0.0729	0.0314	0.020
ln_tankcap	0.0224	0.00752	0.003
ln_dist_main	-0.109	0.00449	0.000
ln_total_taps	0.0362	0.00887	0.000
ln_garden_area	-0.0228	0.00848	0.007
ln_cook	-0.111	0.0207	0.000
ln_bath	0.442	0.03603	0.000
ln_clothes	0.225	0.0318	0.000
ln_utensils	0.222	0.0195	0.000
ln_other	0.209	0.0307	0.000
ln_total	-1.17	0.104	0.000
intercept	1.25	0.232	0.000
$LR\chi^2$	2356.93		
$Prob > \chi^2$	0.000		
Log likelihood	-10352.561		
N	20,938		
pseudo-R^2	0.102		

Notes: Dependent variable is a dummy variable that equals 1 if the household was located in an area that ever had CWS. β is the coefficient for each predictor. SE is the standard error of the mean difference of the predictor between the households that ever got CWS and the households that had IWS throughout the study period

Table 4: Observed covariates over continuous water supply treatment before and after Propensity Score Matching

		Mean		t-test				Mean		t-test	
Variable		Treated	Control	t	p-value	Variable		Treated	Control	t	p-value
House population	Unmatched	4.47	4.99	-15.030	0.000	Is a Chawl	Unmatched	0.00	0.00	-0.230	0.816
	Matched	4.47	4.53	-1.910	0.056		Matched	0.00	0.00	-0.280	0.778
Income level 2	Unmatched	0.34	0.26	10.330	0.000	Has overhead tank	Unmatched	0.67	0.53	17.410	0.000
	Matched	0.34	0.33	0.620	0.535		Matched	0.67	0.65	1.700	0.089
Income level 3	Unmatched	0.05	0.04	3.860	0.000	Has underground tank	Unmatched	0.41	0.53	-14.730	0.000
	Matched	0.05	0.05	-0.310	0.756		Matched	0.41	0.42	-0.860	0.388
educ_class2	Unmatched	0.01	0.02	-6.750	0.000	Uses private borewell	Unmatched	0.09	0.09	0.610	0.544
	Matched	0.01	0.01	-0.990	0.324		Matched	0.09	0.10	-0.560	0.575
educ_class3	Unmatched	0.02	0.05	-8.790	0.000	Uses public standpost	Unmatched	0.00	0.01	-3.190	0.001
	Matched	0.02	0.02	-0.860	0.388		Matched	0.00	0.00	-0.070	0.941
educ_class4	Unmatched	0.17	0.23	-9.450	0.000	Uses public handpump	Unmatched	0.02	0.02	-0.320	0.747
	Matched	0.17	0.18	-1.150	0.249		Matched	0.02	0.02	-0.110	0.910
educ_class5	Unmatched	0.29	0.29	0.290	0.768	Uses private dug well	Unmatched	0.13	0.11	4.060	0.000
	Matched	0.29	0.29	0.030	0.977		Matched	0.13	0.13	-0.010	0.996
educ_class6	Unmatched	0.35	0.27	10.650	0.000	ln(storage tank capacity (kL)	Unmatched	5.49	5.32	4.310	0.000
	Matched	0.35	0.34	0.410	0.680		Matched	5.49	5.43	1.180	0.237
educ_class7	Unmatched	0.13	0.09	6.970	0.000	ln(tap distance from water main (m))	Unmatched	0.67	1.49	-22.740	0.000
	Matched	0.13	0.12	1.370	0.172		Matched	0.67	0.83	-2.850	0.004
educ_class8	Unmatched	0.03	0.02	1.760	0.079	ln(number of taps in house)	Unmatched	0.59	0.49	4.950	0.000
	Matched	0.03	0.02	0.440	0.660		Matched	0.59	0.54	1.720	0.085
Occupation-government	Unmatched	0.40	0.28	16.580	0.000	ln(garden size sq. m)	Unmatched	-4.43	-4.42	-0.510	0.612
	Matched	0.40	0.38	2.220	0.027		Matched	-4.43	-4.41	-0.770	0.444
Ocucpation-private sector	Unmatched	0.25	0.18	11.430	0.000	ln_cook	Unmatched	1.25	1.32	-6.720	0.000
	Matched	0.25	0.25	0.540	0.589		Matched	1.25	1.27	-1.940	0.052
Occupation-self employed (formal)	Unmatched	0.28	0.42	-18.020	0.000	ln_bath	Unmatched	2.88	2.81	8.610	0.000
	Matched	0.28	0.30	-2.860	0.004		Matched	2.88	2.88	0.610	0.539
Occupation-informal	Unmatched	0.01	0.03	-6.610	0.000	ln_clothes	Unmatched	2.48	2.52	-3.280	0.001
	Matched	0.01	0.01	-0.310	0.755		Matched	2.48	2.52	-2.820	0.005
Occupation-other	Unmatched	0.06	0.10	-8.490	0.000	ln_utensils	Unmatched	2.15	2.13	1.890	0.058
	Matched	0.06	0.06	0.050	0.959		Matched	2.15	2.15	0.400	0.690
Women work outside of home	Unmatched	0.05	0.05	2.740	0.006	ln_other	Unmatched	2.39	2.44	-3.220	0.001
	Matched	0.05	0.05	0.070	0.941		Matched	2.39	2.40	-0.110	0.913
Is an Apartment	Unmatched	0.01	0.02	-3.940	0.000	ln_total	Unmatched	4.10	4.13	-4.080	0.000
	Matched	0.01	0.01	0.000	0.999		Matched	4.10	4.12	-1.630	0.103
Is a Slum dwelling	Unmatched	0.03	0.06	-8.300	0.000						
	Matched	0.03	0.03	-1.150	0.249						

Notes: This table shows the differences between the means of observed time-invariant covariates in treated (CWS) and control (IWS) households, without propensity score weighting and with weighting by propensity score. The mean of each observed variable is shown for households with CWS (Treated) and with IWS (Control). The difference between the means are tested with a students t-test, and the p-values are also shown. Each variable shows these means and t-test statistics for samples that are unweighted (Unmatched) and weighted (Matched) by propensity score.

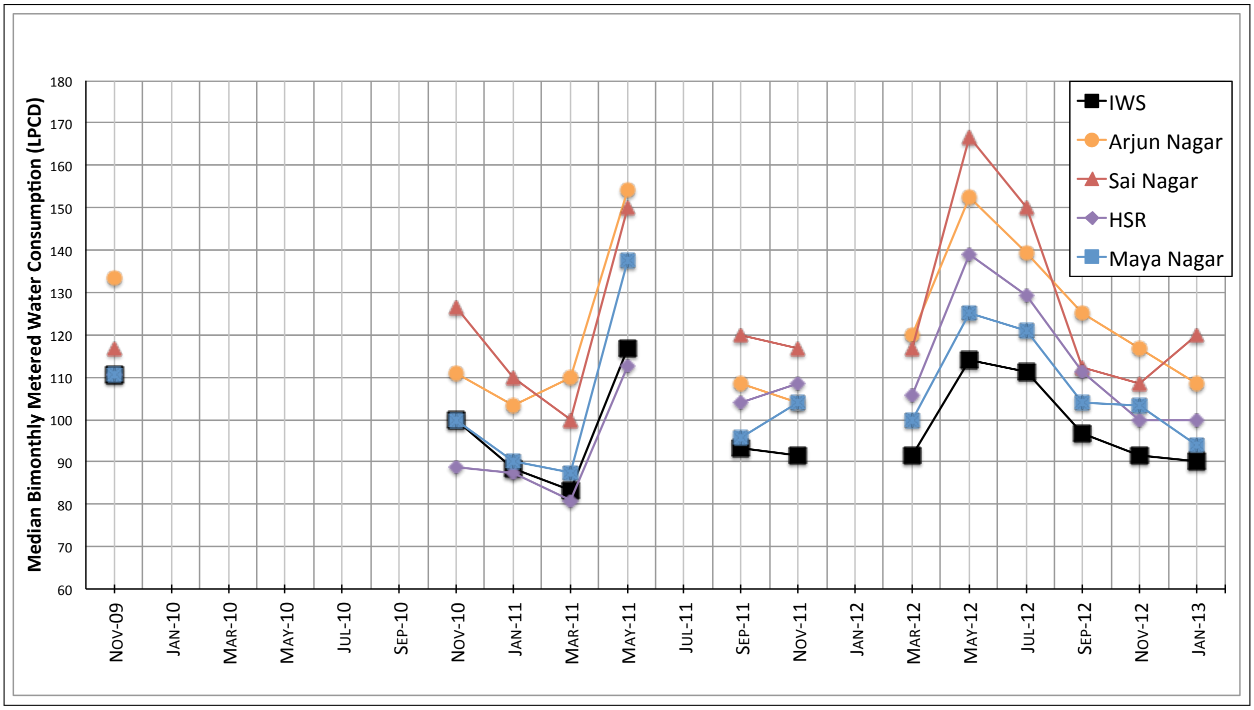


Figure 4: Median lpcd in Amravati domestic water connections, October-November 2009 to December-January 2013 (weighted)

regressors. The basic model (A1) estimates an average treatment effect of CWS of an additional 8.1% of water consumption per person in the household. This effect is still present in the propensity-score matched model (B1), although the estimate is reduced to 7.1%. In the model (A2) including interaction terms for being in a slum (SC), having an external storage tank (TC), and having an alternate water source (AC), there is a significant positive coefficient of 0.045 for TC. However, this coefficient is not significant in the model (B2) with propensity score weighting. Taken together, these results indicate that there was, on average, a statistically significant positive effect on consumption from CWS in Amravati over the first 3 years. Any differences, on average, in the effect between slum dwellers and non slum dwellers, households with and without tanks, and households with and without alternate water supplies, were not found to be significant.

3.2.3 Distributional Impacts

Tables 6 and 7 show the coefficients and bootstrapped standard errors on the treatment (CWS) at the 0.1, 0.25, 0.5, 0.75, and 0.9 quantiles of water consumption (lpcd). Table 6 shows results for the unmatched models, and Table 7 shows results for the models with propensity score weighting.

Table 5: The average effect of continuous water supply on water demand

ln(lpcd)	(A1)	(A2)	(B1)	(B2)
CWS	0.081***	0.074***	0.071***	0.068***
SC	–	-0.042	–	0.012
TC	–	0.045***	–	0.013
AC	–	-0.001	–	-0.001
BP2	-0.300***	-0.301***	-0.289***	-0.290***
BP3	-0.429***	-0.430***	-0.400***	-0.401***
BP4	-0.469***	-0.470***	-0.435***	-0.436***
BP5	-0.133***	-0.134***	-0.079***	-0.080***
BP6	-0.381***	-0.382***	-0.364***	-0.365***
BP7	-0.411***	-0.412***	-0.378***	-0.377***
BP8	-0.397***	-0.398***	-0.375***	-0.376***
BP9	-0.194***	-0.195***	-0.145***	-0.145***
BP10	-0.241***	-0.242***	-0.185***	-0.185***
BP11	-0.342***	-0.343***	-0.314***	-0.314***
BP12	-0.369***	-0.370***	-0.336***	-0.336***
BP13	-0.423***	-0.425***	-0.424***	-0.395***
(Intercept)	4.631	4.631	4.774	4.774
N	30,613	30,613	20,059	20,059
R^2	0.044	0.044	0.05	0.05

Notes: Dependent variable: Natural log of bimonthly household water consumption (lpcd). Model (A1) includes only the CWS treatment with billing period and household fixed effects. Model (A2) includes interactions between CWS and slum (SC) having an external storage tank (TC) and having an alternate water source (AC). Model (B1) is the same as (A1), with panels weighted by propensity score. Model (B2) is the same as (B1), with panels weighted by propensity score.
Significance: *p<.05, **p<.01, ***p<.001

For the model where the second period is October-November 2010, without weighting, the model shows modest increases of about 5-6 lpcd due to CWS among non-slum households that were consuming below the median in the initial period. Slum households show no significant effects except for at the median, where a substantial increase of 24 lpcd is estimated. However, with propensity score weighting, in this period there is no detected effect in slum households, while non-slum households show significant decreases of 11-22 lpcd in the upper quantiles.

For the models where the second period is October-November 2011, the models with and without propensity score weighting show consistent results of significant increases in consumption for both non-slum and slum households, although non-slum households show increases up to the 0.75 quantile of consumption, while slum households show increases up to the 0.5 quantile. The increases for the slum households are also greater than the increases in the non-slum households, indicating a strong effect at this point in time for the

Table 6: Quantile difference-in-differences, effects of continuous water supply on lpcd

Quantiles:	0.1	0.25	0.5	0.75	0.9
Initial Demand					
Full Sample	55	66	97	151	218
Non-Slum	55	67	100	154	221
Slum	47	66	82	111	166
OCT-NOV 2010					
Full Sample	5.616***	8.423***	4.444*	5	-9.275
	(1.324)	(1.529)	(2.482)	(5.217)	(6.606)
Non-Slum	5.616***	6.458***	6.112**	9.167	-7.5
	(1.617)	(1.993)	(2.962)	(5.935)	(7.803)
Slum	7.523	13.889*	23.786**	-16.589	23.919
	(6.921)	(7.582)	(10.891)	(19.217)	(34.599)
OCT-NOV 2011					
Full Sample	3.532**	4.257***	5.000***	13.889***	3.354
	(1.390)	(1.103)	(1.915)	(3.050)	(5.078)
Non-Slum	1.929	3.215**	6.518***	10.893***	2.778
	(1.394)	(1.281)	(1.748)	(2.859)	(5.459)
Slum	9.884	19.434***	17.436**	1.344	9.322
	(6.52)	(5.91)	(8.55)	(11.70)	(19.97)
OCT-NOV 2012					
Full Sample	0.75	3.794**	5.00*	2.5	0.616
	(1.772)	(1.670)	(2.944)	(4.129)	(7.391)
Non-Slum	0.213	4.257***	3.611	2.833	-3.339
	(1.668)	(1.624)	(3.034)	(4.229)	(6.329)
Slum	2.106	23.275***	30.452***	8.368	10.767
	(7.035)	(5.226)	(9.512)	(16.858)	(28.045)

Notes: Top rows show initial demand for each sample at each quantile of initial water demand. Dependent variable: Bimonthly household water consumption (lpcd). Bootstrapped standard errors of the mean effect in parentheses.
Significance: *p<.05, **p<.01, ***p<.001

Table 7: Quantile difference-in-differences with kernel propensity score weighting, effects of continuous water supply on lpcd

Quantiles:	0.1	0.25	0.5	0.75	0.9
Initial Demand					
Full Sample	65	83	111	167	250
Non-Slum	66	83	111	168	251
Slum	53	66	83	133	180
OCT-NOV 2010					
Full Sample	6.719*	1.585	-2.148	-10.744*	-22.263**
	(3.122)	(2.920)	(3.580)	(6.285)	(9.451)
Non-Slum	6.639**	0.685	-2.723	-11.832**	-22.428**
	(3.150)	(3.090)	(3.674)	(5.710)	(10.080)
Slum	10.206	9.88	6.403	-13.905	-4.825
	(9.812)	(8.577)	(7.638)	(12.821)	(18.041)
OCT-NOV 2011					
Full Sample	9.875***	8.856***	4.377**	5.273**	8.301
	(1.205)	(1.356)	(1.786)	(2.461)	(6.141)
Non-Slum	9.472***	9.346***	4.176**	5.279*	7.69
	(1.294)	(1.202)	(1.698)	(2.826)	(4.912)
Slum	21.285***	21.222***	9.594*	-14.904	2.878
	(7.94)	(6.46)	(5.79)	(13.62)	(23.65)
OCT-NOV 2012					
Full Sample	4.824**	7.661***	0.0557	-3.561	-10.369
	(2.359)	(1.840)	(2.699)	(4.144)	(7.577)
Non-Slum	2.813	6.286***	-1.573	-5.221	-8.474
	(2.134)	(2.247)	(2.796)	(4.998)	(8.482)
Slum	17.425*	24.636***	26.931***	0.489	15.575
	(9.854)	(4.381)	(8.966)	(12.794)	(18.015)

Notes: Top rows show initial demand for each sample at each quantile of initial water demand. Dependent variable: Bimonthly household water consumption (lpcd). Bootstrapped standard errors of the mean effect in parentheses.
Significance: *p<.05, **p<.01, ***p<.001

poorest (connected) households who were consuming low amounts of water to begin with, but not much of an effect for slum households consuming more water.

For the models where the second period is October-November 2012, the effects are similar but more modest, and restricted to the 0.5 quantile and below for non-slum households. This may reflect long-run adjustments. However, the second price increase in July 2012 may also be a contributing factor. This price increase raised the price of water in the lowest block as well as the upper blocks, so it is possible that the effects are more modest at the lower quantiles than before due to a reaction to this price. Reductions in consumption in the upper quantiles return in this period, although they are not significant. The effect in slum households is not moderated in this period, however.

3.3 Component 2: Coping Behaviors

3.3.1 Summary of primary survey

Table 12 and Table 13 in Appendix D summarize responses to direct questions about coping behaviors. In this section, tabulated results are supplemented with illustrative examples from households that volunteered elaborations. 48 households were interviewed in Nagpur (22 in CWS and 26 in IWS zones) and 46 households in Amravati (21 in CWS and 25 in IWS zones). The targeted sample sizes were not attained primarily due to time constraints. For example, only 10 total slum households out of a target of 20 were interviewed in Amravati because connected slum households were so rare that not enough examples could be found that would consent to be interviewed. The target sample sizes were exceeded for non-slum households with IWS in Nagpur and with IWS and CWS in Amravati because members of neighboring households became curious and requested to be interviewed.

3.3.2 Storage

Storage behavior responses in Nagpur and Amravati under IWS and CWS conditions are summarized for non-slum and slum households in Figure 5 and Figure 6, respectively.

Storage under intermittent water supply

Non-slum households Of non-slum households, 13 out of 16 in Nagpur and 16 out of 20 in Amravati used some combination of overhead storage and underground sumps to store large quantities of water. The most

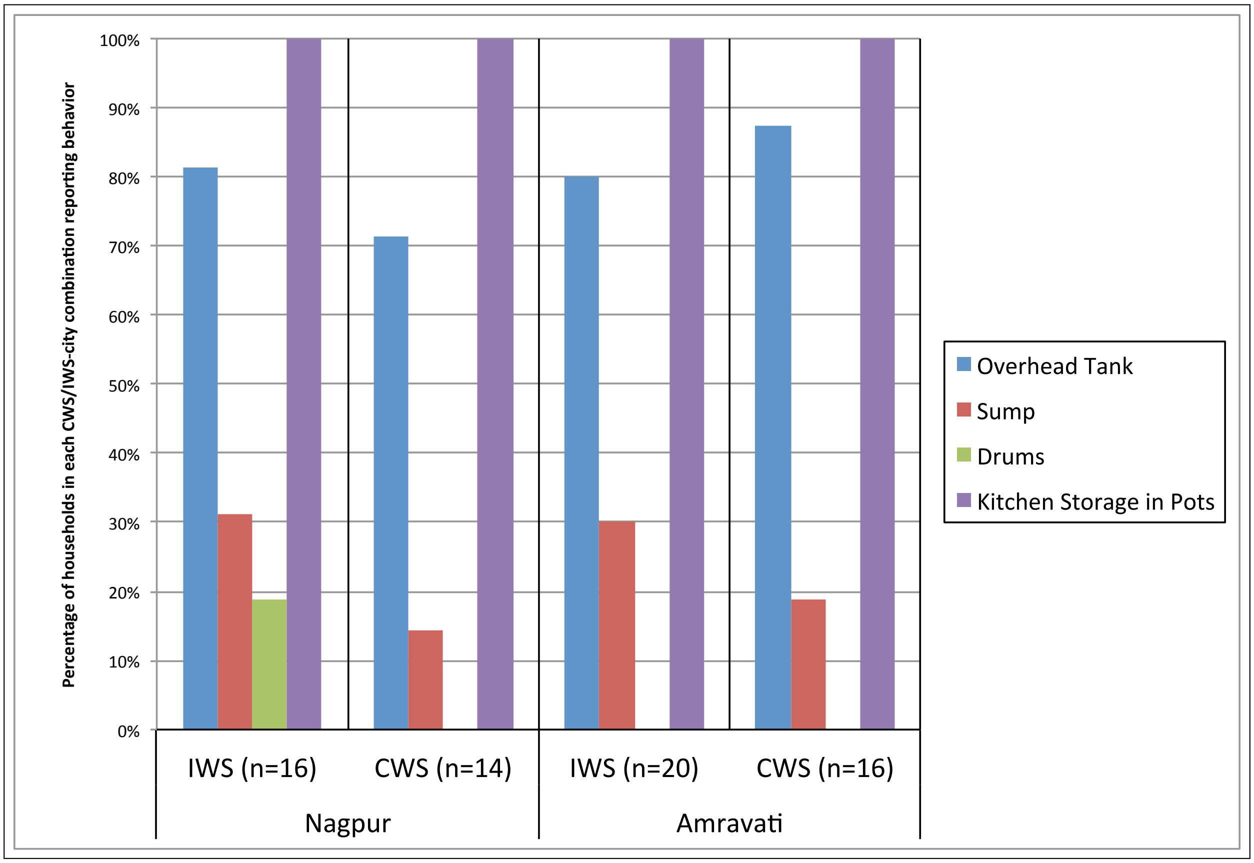


Figure 5: Percentage of non-slum households exhibiting storage behaviors

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

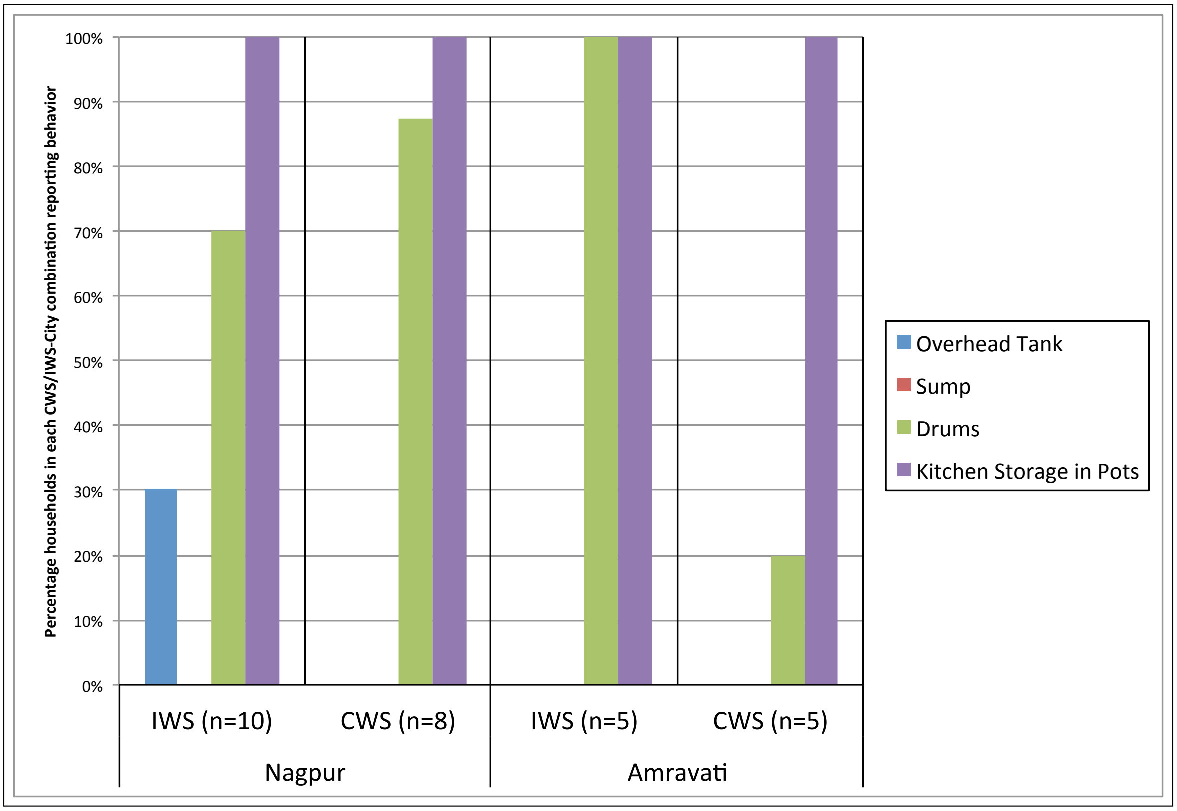


Figure 6: Percentage of slum households exhibiting storage behaviors

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

common storage strategy was one or more 500 or 1000-liter capacity plastic cylindrical water tanks that cost between 2000 and 4000Rs (40-80 USD in 2013) to purchase and install. They are mounted on the roofs of households. Water connections usually enter the property through a 15mm metal pipe with a meter and stop valve. From there, a metal or PVC pipe is usually run to one or two taps in the veranda and/or kitchen to provide water directly during service hours. This pipe usually continues directly into a PVC pipe that runs up the side of the house and deposits water into the tank through the top. Water is then distributed into various additional taps in the house through PVC pipes with stopcocks installed in the bottom of the tank.

Four households in Nagpur and six in Amravati had equipped their overhead tanks with float valves that prevent the water tanks from overfilling, while the others described a variety of strategies to deal with this issue. In Amravati and some neighborhoods of Nagpur, the intermittent water supply comes at predictable hours. In these cases, households open the valve after the water meter when the water is scheduled to come, and close it soon after the flow stops. In some areas of Nagpur with poorer-quality service, the water comes at irregular times, and some respondents described having to actively listen for the sound of their tanks overfilling. One household reported just leaving the tap open all the time and ignoring their tank when it overflowed, because they could not guarantee having someone at home in case the water came.

Five households in Nagpur and Six in Amravati had an augmented version of this system, having built a cement-lined underground storage sump into which the water connect flowed directly. From here, water is pumped to the overhead tank. This system is designed to cope with water service pressures not being high enough to fill overhead tanks and serve taps on upper floors of houses. In Nagpur, the three households without overhead tanks stored water in 2-6 200-liter capacity plastic drums on the ground floor of the house, filled with hoses attached to the veranda tap.

All households reported directly filling ceramic or metal vessels in the kitchen with 20-50 liters of water from the network during service hours. This water is used for drinking and cooking. Most respondents demonstrated abstracting water from these vessels directly with cups, using a separate utensil to pour into a serving cup, or had equipped their storage vessels with spigots. Respondents reported using water from the overhead tanks only for toilet pour-flushing, bathing, and for washing clothes, cooking utensils, household surfaces, and vehicles.

Slum households In the slum areas, storage strategies were generally simpler. Three interviewed slum households in Nagpur had overhead storage tanks, but no others. Slum households universally collected drinking/cooking water directly during service hours for daily storage in small vessels in the kitchen. The majority of households also filled plastic drums with water for washing purposes. The majority of households had connected their taps to a plastic hose that was could be left in a storage vessel. The taps were often left on all of the time, allowing water to flow into storage without monitoring. This practice was observed by sight in many slum households that were not interviewed directly. Not only does this represent wastage of water in many cases, but it also represents a backflow (and thus, health) risk similar to one of the most common such risks in the United States: the leaving of unattended hoses in swimming pools (EPA, 2001).

Storage under continuous water supply

Non-slum households In Nagpur, six of 14 households reported abandoning use of their overhead storage tanks with the coming of CWS. These households all had multiple direct taps in their kitchen and bathrooms, and described their overhead storage as no longer necessary. Respondents who had CWS but still used overhead storage tanks gave several explanations. These are summarized in Figure 7.

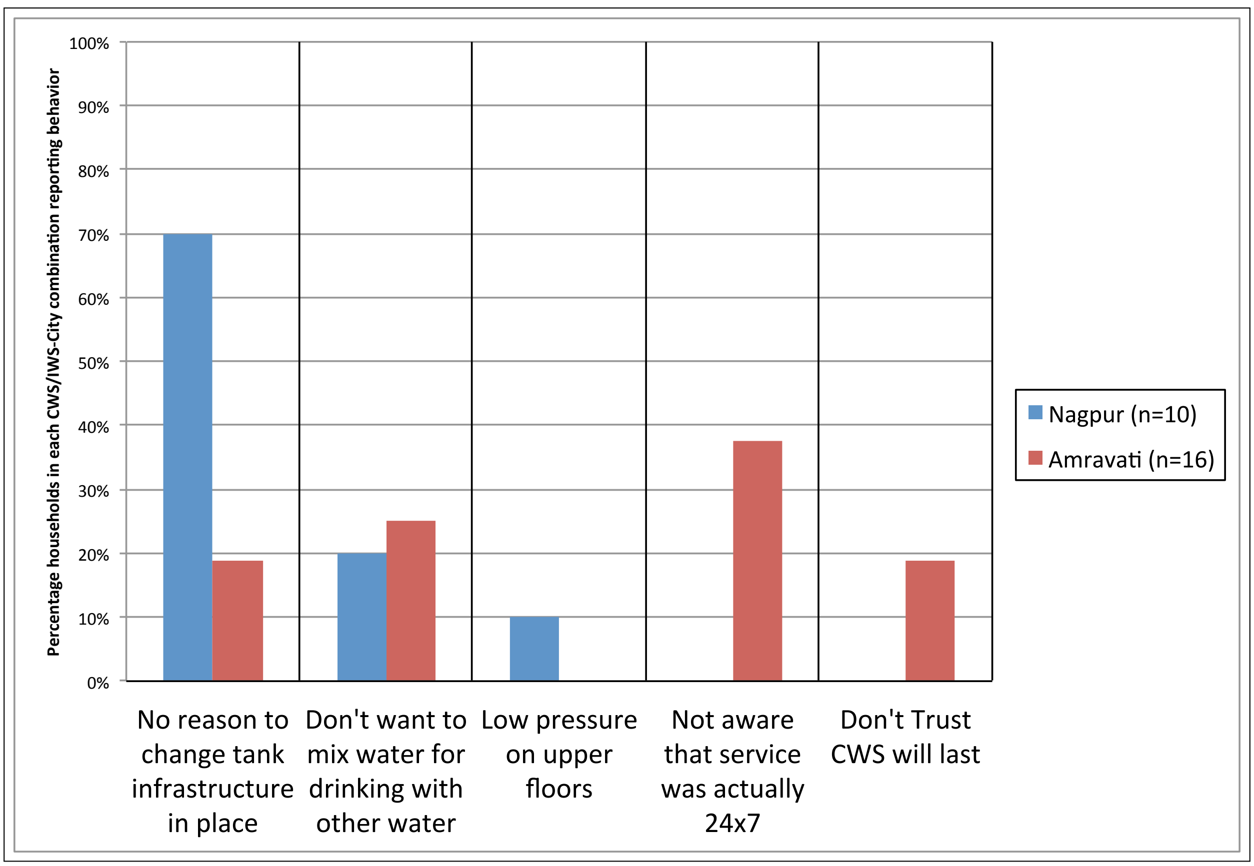


Figure 7: Reasons given by households with continuous water supply using tanks why they still use tanks

In Nagpur, the most common response was that there was no reason to change the storage system that distributed water throughout the house, or that it would be expensive to make the change to direct plumbing. Two households expressed a concern that using water directly from the tap both for drinking or cooking and for toilets or bathing could somehow lead to cross-contamination. Another household claimed that the water pressure from the network was not high enough to deliver water directly to their upper floors, and so had to use a sump-pump-overhead tank system.

In Amravati, almost all respondents with CWS had not abandoned use of their storage facilities. In fact, curiously, many households in the Sai Nagar and Arjun Nagar CWS zones did not even realize or report that their water service was continuous, instead reporting that the water came 2-3 hours in the morning and/or 2 hours in the evening. However, these households were revisited, and their meter stop valves were checked during hours when water should not have been supplied according to respondents. It was clear that water was in fact, being delivered throughout the day in these areas. Evidently, MJP had not adequately publicized the continuous water supply program. Households with overhead storage tanks had never noticed changes in service hours, even after 3 years, and had continued operating their water storage systems as they always had. This pattern was not evident in Nagpur, where the "24x7" project was well-publicized and controversial due to the privatization, the participation of a foreign company, and rising water tariffs.

The households that were aware of CWS in Sai Nagar and Arjun Nagar gave similar explanations as given by Nagpur residents, citing inertia in changing the house plumbing or concerns about cross-contamination. All respondents in the HSR zone were aware of the CWS. This zone is interesting because it is for the most part a newly developing area, and the households interviewed here had recently completed building their homes. Each of these households, despite knowledge of the CWS, had built their homes with overhead storage tank plumbing systems. When asked for an explanation, all gave a variant of the same explanation: they did not trust that the CWS would continue as the city continued to grow, and therefore tanks would be necessary to store water throughout the day eventually.

All respondents in both cities with CWS continued to store water in vessels in the kitchen for drinking and cooking purposes, citing that water from overhead storage tanks was likely to be somewhat stagnant and unsuitable for such uses. A few households used metal or plastic vessels with integrated filters and spigots, but the vast majority used metal or clay pots from which water was abstracted with a utensil or directly with drinking cups.

Slum households No slum households with CWS in either city had overhead tanks or sumps. Only one respondent in Amravati stored water in bulk plastic drums as the IWS slum households commonly did. This demonstrates that slum households saw more immediate benefits from the CWS than formal households, as they modified their behavior more consistently than the households with elaborate storage systems. However, as with the formal households, storage in vessels in the kitchen remained universal. An interesting difference that was evident upon observation of slum communities in Nagpur and Amravati was that in Nagpur, slum households with CWS would often leave their taps open unattended, overfilling small storage containers. In Amravati, the slum households with CWS would open the tap to use the water immediately or to fill empty containers, and then close the tap. A plausible explanation for this difference would be that Nagpur slum households face a subsidized, flat monthly water tariff, while Amravati slum households face the same IBT as all other households, and thus stand to incur higher costs for consuming large amounts of water.

3.3.3 Treatment

Seventy-nine out of 94 households demonstrated treating their water with a small nylon or cloth filter affixed with a plastic part to water taps from which drinking or cooking water was drawn. However, some households used other treatment methods in addition. An important aspect of treatment behavior cited by all respondents is perceived water quality. In Nagpur, CWS households reported marked improvements in water quality in terms of turbidity and smell with the advent of the service. Given the general state of disrepair of Nagpur's network, and the CWS project areas essentially corresponding to network repair and replacement, this is unsurprising. By contrast, Amravati's improvement program involved making subtle improvements in pressure throughout the network with targeted pipe replacements. This meant that both CWS and IWS customers would have seen improvements in water quality during the study period.

Non-slum households Treatment behavior responses in Nagpur and Amravati under IWS and CWS conditions are summarized for non-slum households in Figure 8.

In Nagpur, four out of 14 CWS and two out of 16 IWS households had small treatment devices that used reverse-osmosis (RO) or UV technology to treat and store 5-10L batches of water. Some households in IWS used chlorine solution or alum. Most of those with CWS noted that water quality had improved significantly. In Amravati, a similar pattern in treatment was found, although almost all respondents reported

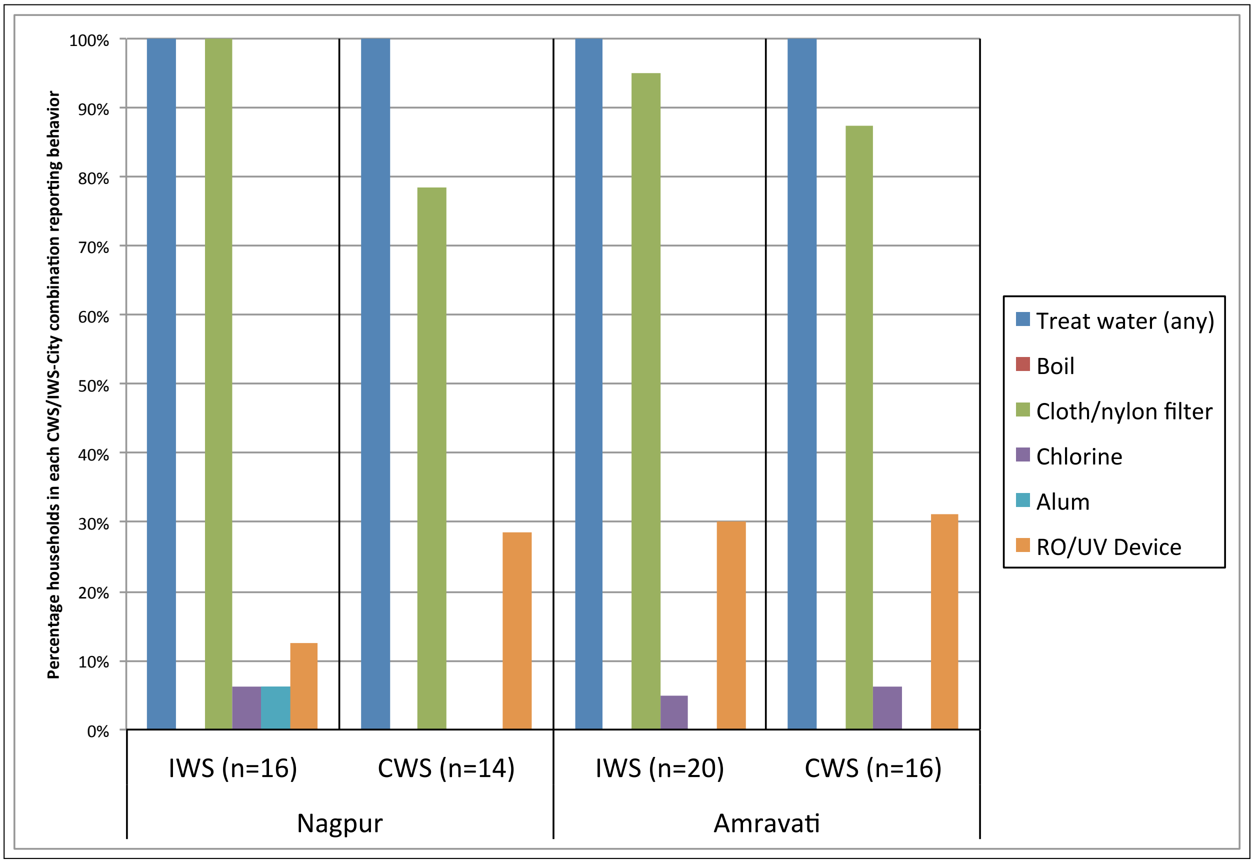


Figure 8: Percentage of non-slum households exhibiting treatment behaviors

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

that the water was clean regardless of CWS. Despite this generally high opinion of the water quality, several CWS and IWS respondents also used RO or UV treatment devices.

Slum households Treatment behavior responses in Nagpur and Amravati under IWS and CWS conditions are summarized for slum households in Figure 9.

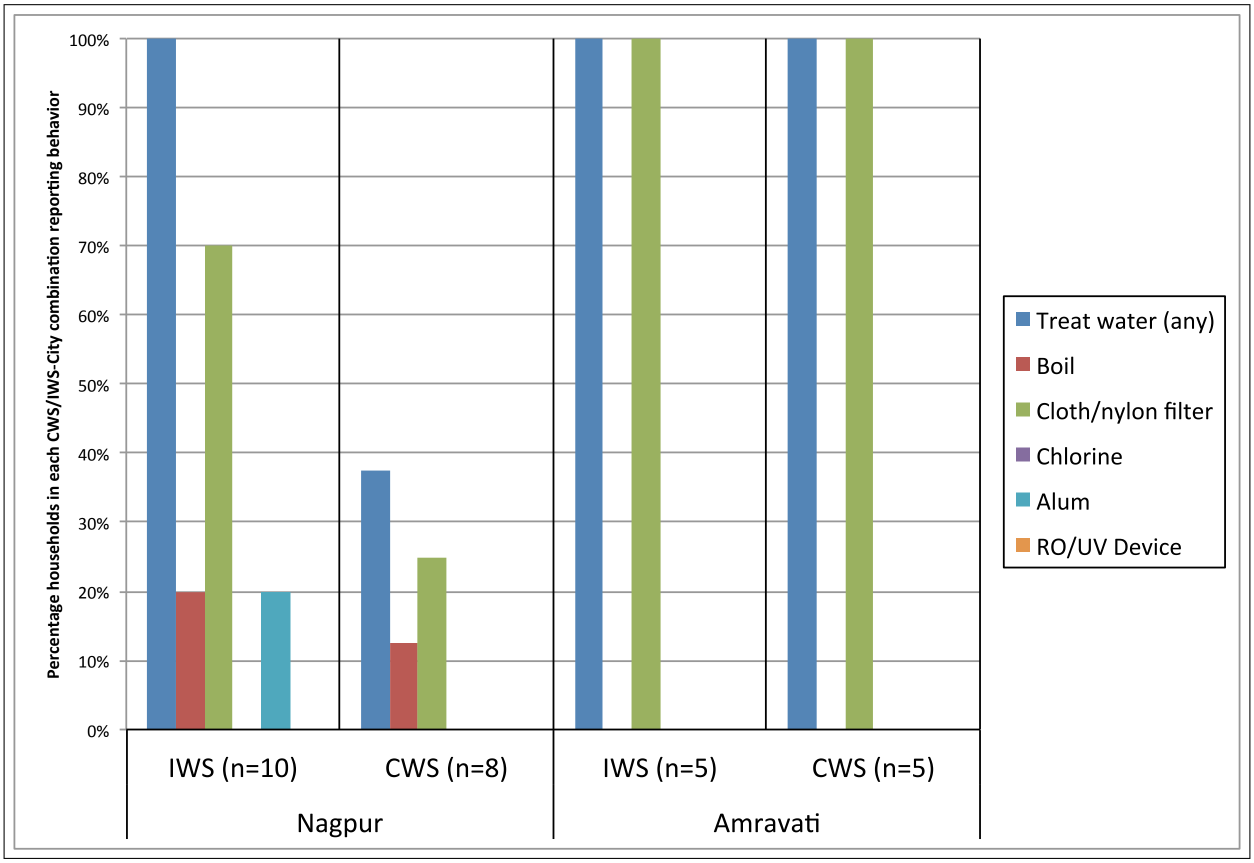


Figure 9: Percentage of slum households exhibiting treatment behaviors

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

In Nagpur, all slum households with CWS reported good water quality and only used the nylon or cloth filters. Seven out of 10 slum households with IWS reported very poor water quality, including turbidity and poor taste, and all used the cloth filters. Two out of 10 reported boiling water regularly and another two reported using alum. In Amravati, slum households reported clean water regardless of CWS, and no other treatment than the cloth filters was reported.

3.3.4 Alternative sources

Non-slum households Alternative water sources reported to be used in Nagpur and Amravati under IWS and CWS conditions are summarized for non-slum households in Figure 10.

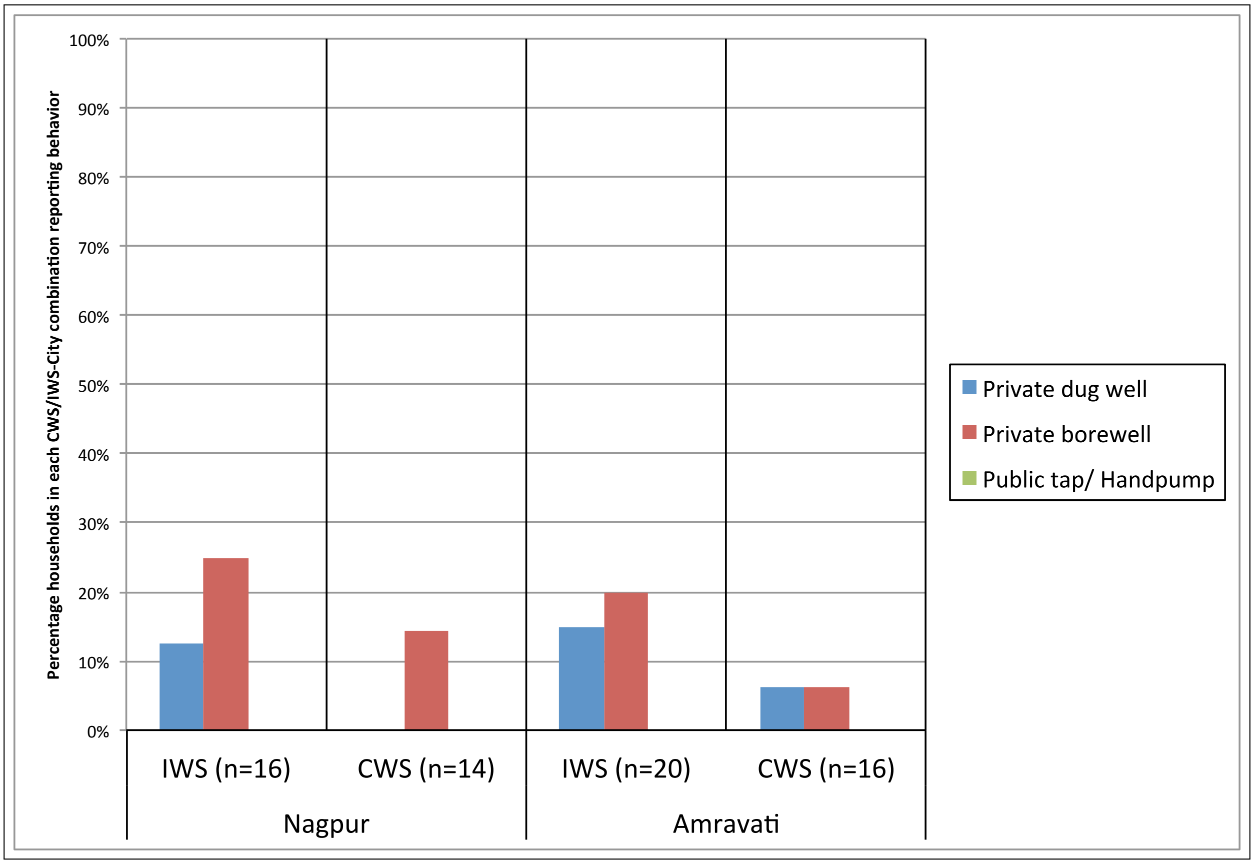


Figure 10: Percentage of non-slum households using alternate water sources

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

Twenty-five of 30 households in Nagpur, and 29 of 36 households in Amravati, had borewells or dug wells on their plots that were constructed to serve as the water source during house construction. Of these, eight in Nagpur and nine in Amravati with network reported using these wells as water sources anymore. However, in both cities, more respondents with IWS reported using private wells than CWS respondents. The IWS households who used their wells all reported using them to give themselves water on-demand, thus approximating CWS service. The CWS households in both cities reported using their private wells in order to spend less money on the network water. In this case, for some, CWS resulted in more coping rather than less.

Slum households Alternative water sources reported to be used in Nagpur and Amravati under IWS and CWS conditions are summarized for slum households in Figure 11

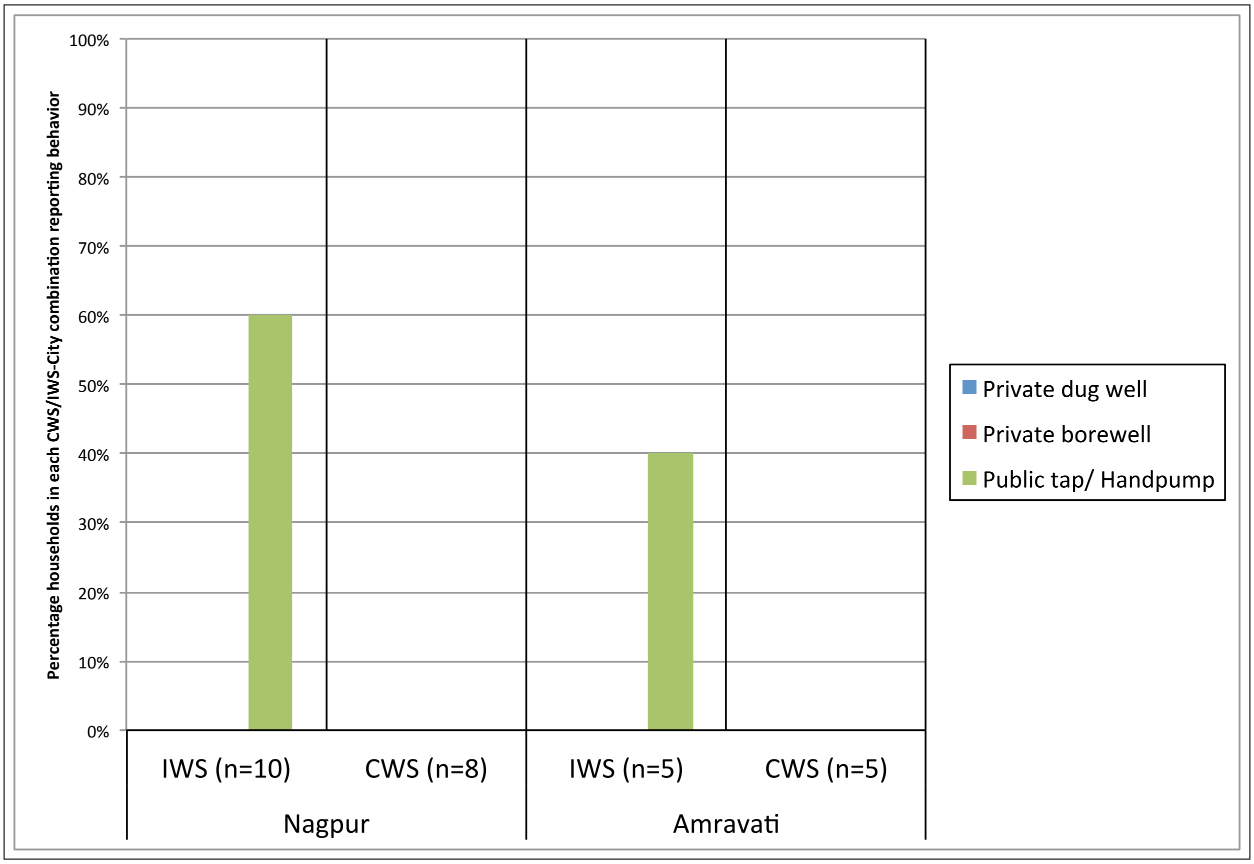


Figure 11: Percentage of slum households using alternate water sources

The two clusters of columns on the left represent percentages of respondents from Nagpur, and the two clusters of columns on the right represent Amravati. IWS columns refer to households with intermittent water supply. CWS columns refer to households with continuous water supply. N, the total number of respondents in each IWS/CWS-City combination, is indicated

In Nagpur, six of ten slum respondents with IWS in reported collecting water from standpipes or public handpumps in order to supplement the network supply. In Amravati, two of five did so. No CWS slum households in either city reported using alternative sources, indicating that among this group, CWS may have eliminated the costs of collecting from public sources.

3.3.5 Pumping

There were generally three uses for pumping in the Nagpur and Amravati contexts: booster pumps to extract water from the network when pressures are too low to deliver a water to an overhead tank, to pump water from a sump to an overhead tank, or to operate a borewell. No slum households used pumps.

In Nagpur, 16 of 26 households with IWS used pumps for at least one of the above purposes. In Amravati, eight of 20 IWS households with borewells and sumps used pumps, although no one reported needing booster pumps over the past few years, corresponding in time to Amravati's improvements in pressure across the entire network. In both cities, fewer CWS households used pumping of any kind. No CWS respondents reported using booster pumps. Respondents in both cities with CWS reported improved pressures, and all CWS households in Amravati with less than two floors reported no longer needing pumps to get water into the overhead tank. Respondents still using borewells still used pumps necessarily.

3.3.6 Preference of households with intermittent water supply for continuous water supply

All respondents in Nagpur were aware of CWS or some kind of water supply project in the city, most having heard about through newspapers, observing construction workers making significant work on pipes, or being informed directly by their local municipal corporation representatives. Only two respondents in Amravati were aware of the project, one having read about it in the newspapers, and one who lived in a neighborhood where bureaucrats were concentrated having been informed by MJP officials.

Among non-slum households with CWS, 12 of 16 Nagpuri respondents reported a preference against CWS, while 10 of 20 of Amravati respondents did. Six of 10 Nagpuri slum households, and four of five with IWS were interested in CWS, however. When asked to elaborate on why IWS was preferable, a variety of explanations were given, and these are summarized for Nagpur and Amravati in Figure 12 and Figure 13, respectively.

The responses were similar in the two cities. Households with wells said they already have water whenever they need. The next most common concern was that the improved water service would be too expensive. The other responses focused on already having an adequate supply of water, and that somehow CWS would involve consumption of more water, and that this might be wasteful. Most respondents expressed a keen awareness of water stress in the region, and were worried about the implications of having water all of the time.

3.3.7 Preference of households with continuous water supply for intermittent water supply

In Nagpur, 10 of 14 non-slum households, and all slum respondents, were satisfied with the CWS service, although most non-slum respondents did make comments expressing dissatisfaction with the higher tariffs. However, in Amravati, some slum households expressed that they would rather pay less for IWS,

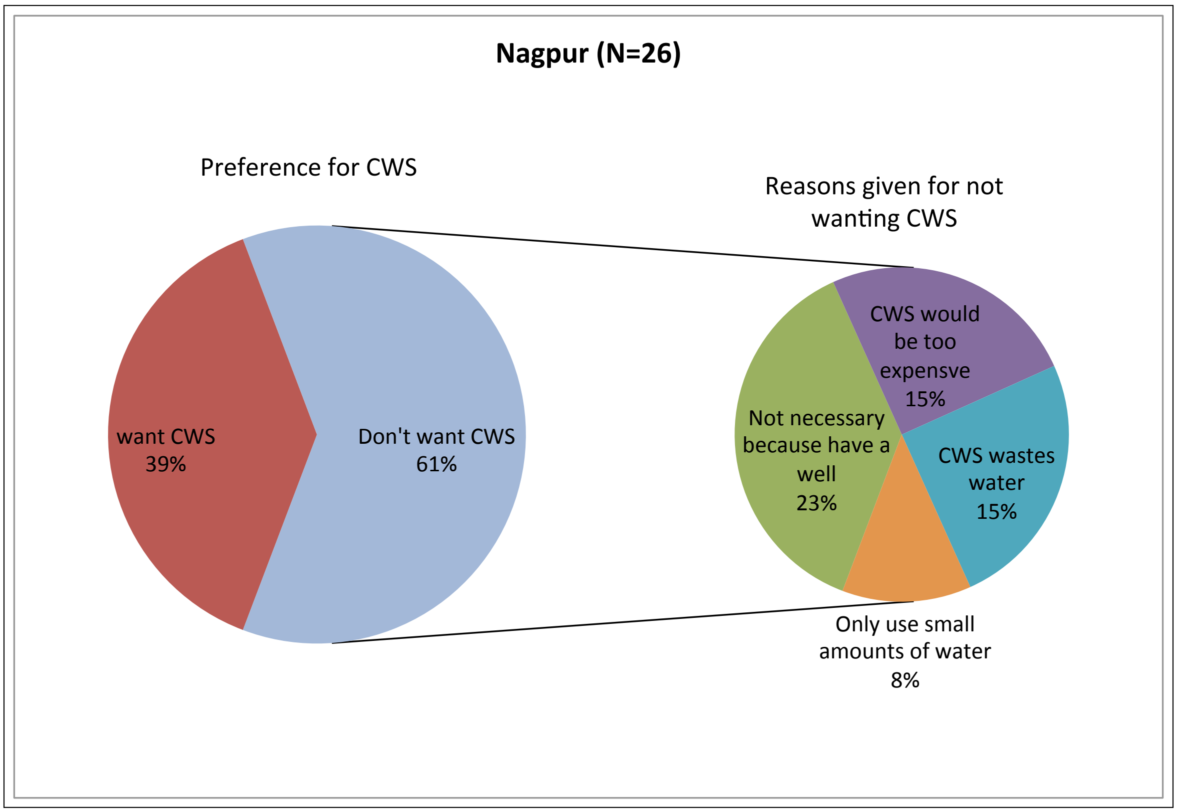


Figure 12: Preference of intermittent water supply households for continuous water supply (Nagpur)

The pie chart on the left indicates the percentages of households with IWS in Nagpur wanting or not wanting CWS. The right pie chart indicates the proportions of households not wanting CWS citing each given reason for this preference.

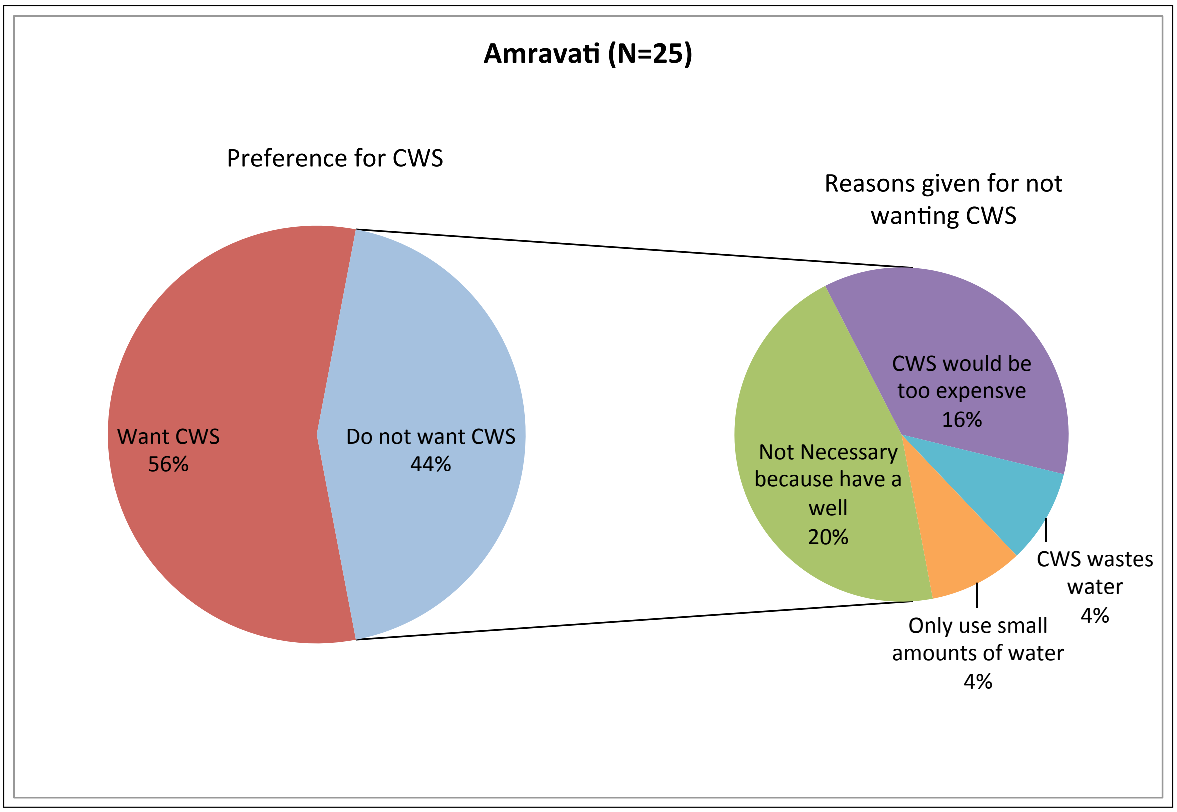


Figure 13: Preference of intermittent water supply households for continuous water supply (Amravati)

The pie chart on the left indicates the percentages of households with IWS in Amravati wanting or not wanting CWS. The right pie chart indicates the proportions of households not wanting CWS citing each given reason for this preference.

as well as half of non-slum respondents, primarily because of higher water tariffs. However, six of the eight non-slum respondents who preferred IWS were not aware that they were receiving water continuously. Reasons given by households with CWS that preferred reverting to IWS are summarized in Table 8.

Table 8: Reasons given by households with continuous water supply why they do not prefer continuous water supply

Response	Nagpur (N=6)	Amravati (N=12)
CWS is too expensive/ prefer lower tariff for IWS	3	8
CWS wastes water	2	3
Only use small amounts of water	1	0
Prefer using well	0	1

In Nagpur, some non-slum households indicated dissatisfaction with the price levels, and indicated that they would rather have IWS at a lower price. In Amravati, this was the most common explanation for both slum and non-slum households. Four such households volunteered to show their water bills, expressing incredulity that the water bills could possibly be so high. One household explained how after one particularly high bill, they elected to use only about 30L of water per day from the tap for drinking, and use their borewell for all other water.

4 Conclusion

4.1 Summary of Main Findings

This study investigated the effects of upgrading from intermittent to continuous water supply on households with on-plot or in-house piped water connections. These effects were examined in two parts, with one research component exploring the impact of CWS on water demand and variations in this impact over different household types, initial water use patterns and time and water tariffs, and the other exploring the effects of CWS on household storage, pumping, and treatment of piped water and the use of alternative sources to the piped network.

Water Demand On average CWS was found to have increased water demand relative to IWS by 7% to 8% in Amravati. The demand increase was found to be persistent in the lower quantiles of initial water demand, and to be largest among slum households consuming relatively low amounts of water to begin with. There was also evidence for an initial tariff shock among households in the upper quantiles of initial water demand, although this effect disappeared in CWS households over time.

Coping Behaviors This study found evidence for modest reduction in the use of alternative sources and pumping. Surprisingly, this study also found that storage and water treatment behaviors were not clearly affected by CWS in either city's implementation, which were most obviously differentiated by levels of publicity and awareness.

4.2 Limitations

Both components of this study are inextricably tied to context, so the main results cannot be easily extrapolated to other implementations of CWS around the world. However, the results of this study, interpreted in concert with context, still provide valuable information.

In addition, both components of this study framed CWS as a treatment onto a uniform IWS condition. In reality, IWS can take a variety of forms, including: unpredictable service hours of varying length, predictable service hours that are perceived as inadequate or undesirable, and predictable service hours that are perceived as adequate and desirable. In Amravati, all interviewed IWS households characterized service hours as predictable and adequate, and so the impacts of CWS in this case should be characterized as the impact of introducing CWS to households accustomed to predictable and reliable IWS. In Nagpur five of the 25 interviewed IWS households experienced unpredictable water supply, while the remainder experienced predictable and adequate service hours. While this study cannot formally assess the impact of CWS relative to different service levels within IWS, it is plausible that greater impacts would be noticed by households moving from unpredictable IWS to CWS than households by households moving from predictable IWS to CWS.

4.2.1 Component 1: Water Demand

The quantitative component of this study was limited by the historical development of CWS in Amravati and the nature of the administrative data. While the analysis included methods to mitigate selection bias, it can never be completely ruled out as a threat to internal validity in nonrandomised experiments. Any conclusions about interactive effects between CWS and water tariff changes are limited by the fact that the increasing block tariff imposes endogeneity between water consumption and price. By splitting the quantile analysis between periods with different prices, price-CWS interactions could be explored, but cannot be completely separated from possible maturation effects in water demand in CWS households and throughout Amravati. This design also relied on water meter data, and thus the analysis assumed that the water meters in Amravati are accurate, and that their accuracy is unchanged between IWS and CWS conditions. Theoretically, water meters under IWS can overestimate consumption as air rushes through the meters when pipes are charged (Totsuka et al., 2004). Since the estimated effect of CWS was a demand increase, the theoretical consequence of this type of meter inaccuracy would be to underestimate this effect, since water demand would be overestimated in IWS relative to CWS.

4.2.2 Component 2: Coping Behaviors

The qualitative component of this study is vulnerable to sampling bias as well as various forms of reporting bias and error. This component was not intended to determine effect sizes or to assess their statistical significance, but rather was meant to convey the range of responses to CWS in the two cities. The geographical cluster sampling strategy allowed a large number of interviews in varied settings to be conducted by the small research team in a short amount of time. However, this approach introduces sampling bias since the clusters are not likely to be heterogeneous relative to the population of residential water customers in each city. In terms of reporting bias and error, the semi-structured interviews allowed for multiple clarifications and on-the-spot corrections.

4.3 Discussion

This study investigated a similar suite of potential impacts of CWS on households as elaborated by World Bank (2010) and Rana (2013) in their discussion of feasibility and impacts of "24x7" water supply pilots in Karnataka. This study either conflicts directly with or adds important qualifiers to most of the proposed benefits that relate to households.

4.3.1 Water Demand

The quantitative component of this study confirms the claim that poor consumers will be able to consume more water more consistently and with less time cost under "24x7" supply than under IWS, as the slum population was the group estimated to persistently increase their water demand by up to 25 lpcd from the piped network relative to IWS slums. There is also evidence to support the claim that "water conservation is also encouraged through metering and price signals via a volumetric tariff to consumers" (Rana, 2013), as overall, water demand in comparable seasons fell overall in Amravati with implementation of an IBT. However, these two claims are somewhat contradictory in and of themselves, at least for poor households with low water consumption. In the case of Amravati, the combination of CWS service and the tariff increase still resulted in an overall decrease in water demand; those with CWS reduced their consumption less than those with IWS. For example, median water demand in the slum households with CWS fell from an initial 83 lpcd to 76 lpcd, while in slum households with IWS demand fell from 83 lpcd to 68 lpcd lpcd. Thus, in the case of Amravati, CWS may have increased accessibility or reduced the time costs of procuring water from alternative sources enough to continue to consume water from the network in the wake of tariff increases, while IWS households chose to reduce demand from piped water even further below the Indian SLB of 135 lpcd (CPHEEO, 1999).

The results of the quantile regressions over the different time periods could indicate threshold effects as well as different price responses between different types of consumers.

For the quantile regression for the period ending in 2010, CWS had a small positive impact on demand from slum households in the lowest quantile of initial demand, and a negative impact on demand from non-slum households in the upper quantiles of initial demand. This could represent reductions due to reduced hoarding and wasting of water in association with filling storage tanks and emptying unused water. Alternatively, the higher marginal price at the upper levels of consumption that were introduced in mid-2010 by the IBT could have reduced demand in the upper quantiles, since the IBT did not affect the existing real price of water at the time in the lower blocks.

For the period ending in 2011, the effects in the upper quantiles for non-slum households were reduced or non-significant, while slum households in lower quantiles had large and significant demand increases. Only those slum households who were consuming low amounts of water from the municipal supply before CWS may have increased their water consumption outright, or substituted away from alternate sources due to improved convenience and/or willingness to pay for the improved service. Non-slum households up to the 0.75 quantile also increased their demand, but less than the slum households. This could indicate a threshold of needs effect as in (Andey and Kelkar, 2009), whereby those who already were consuming needed amounts of water under IWS would not respond very much to CWS.

For the period ending in 2012, after an increase in the block prices of the IBT, the non-slum households no longer exhibited consistent positive demand responses to CWS, while the slum-households with CWS still exhibited the response pattern from 2011. It is possible that slum households are more willing to pay than non-slum households for CWS at the lower end of the initial consumption distribution, suggesting that not only do CWS households have lower price elasticities of demand than IWS households, but that slum households with CWS have lower price elasticities of demand than non-slum households with CWS.

Overall the short-term effects (within 1 year) of CWS with an increasing block tariff appear to be reductions in consumption for those consuming relatively large amounts of network water. Given the observed lack of change in storage behavior from the primary interviews (see the next section), the most plausible explanation for this is the tariff modification combined with the CWS households' higher initial water demand. Longer term, there is evidence for increases in water demand for those that were consuming relatively low and modest amounts of network water, especially among slum-dwellers. Non-slum households consuming relatively less water still had increases attributable to CWS, but may have been more sensitive to price increases than slum households. This counterintuitive result could be due to slum households valuing CWS more than do non-slum households, perhaps because non-slum household primarily use coping behaviors that dampen the impact of CWS on perceived service quality.

This study did not evaluate direct impacts of CWS on "health and hygiene" (World Bank, 2010). The extent to which CWS has ramifications for hygiene in particular depends on how the water demand attributable to an upgrade to CWS is allocated. In the contexts of Amravati and Nagpur, it is possible that some water is simply leaked in internal plumbing systems that leak 24x7 rather than intermittently, or that some water is used for non-hygiene related purposes. This data could not determine water demand to this level of detail.

Both components of this study offer evidence in line with the claim that CWS reduces the burden on water resources or discourages water wastage from overflowing storage tanks and unattended taps only when paired with water tariffs that encourage efficient water use (Rana, 2013). The quantitative analysis suggests that in Amravati, water demand would have increased in the absence of the water tariff increases. In Nagpur, many households would leave their taps on continuously, filling to overflow small containers with unattended hoses, both wasting water and introducing backflow risk to the network. In Amravati, respondents only filled containers as needed and did not leave taps on unattended. However, very few slum households in Amravati can afford network connections relative to those in Nagpur. The most obvious difference in the situations that this might be attributed to is that slum households in Nagpur are charged a flat monthly rate, while those in Amravati see the same tariff structure as all other domestic users.

4.3.2 Coping Behaviors

As for coping behaviors, this study suggests that the relationship between water service quality and coping costs is more complex than is typically presented in the literature, and is dependent on the interaction between different household characteristics and qualities of implementation. For instance, willingness to pay for improved service might depend on more than the nature and monetary costs of service improvement. Pattanayak et al. (2005) estimated that households were willing to pay more for improved services than the sum of the value of their coping costs for the inadequate and intermittent supply. This study showed that storage, treatment, and pumping persisted after years of CWS service. There was also representation in both cities in this study of households who experienced CWS and explicitly preferred IWS with a lower price. In addition, this study raised the possibility of households that might increase their coping costs in response to increased water tariffs by shifting to alternative supplies, even if the service was improved. This lends credence to the possibility of counterintuitive combinations of coping behaviors, consumption, and price levels, that may be suitable for modeling as in (Rosenberg et al., 2007).

Storage strategies involving overhead tanks and sumps seem to have much inertia, as they are still common among households with CWS up to three years after the intervention. This makes sense given that these are sunk investments with relatively long useful lives, and the monetary, time, and convenience costs of converting such a household to direct plumbing. The persistence of this type of storage has also been observed in the Karnataka 24x7 pilot cities (Burt and Ray, 2014). However, while some households in Nagpur, had, in fact made this conversion, new houses in Amravati continued to be built with this type of storage despite knowledge of CWS. Thus the purported benefit of CWS eliminating storage costs can depend crucially on the communication and trust between consumers and service providers. Moreover, overhead storage can serve the useful purpose of ensuring water supply during unpredicted service outages, and of protecting the distribution network from backflow contamination from households.

Also notable is that in-home storage remained universal in both cities. Two of the main purported benefits of CWS are removing the need to store water in the home, and improving water safety. However, this study found that this practice is not necessarily linked with service reliability in the Indian context. Kumpel and Nelson (2013) found that that continued in-home storage in CWS households was associated with contamination of water at the point and time of use that was delivered clean by the CWS distribution system to the tap.

This study offers some confirmatory evidence for the claim that CWS can increase perceived water quality delivered at the tap (World Bank, 2010; Rana, 2013), although biological or chemical water quality was not tested , with many households in Nagpur noticing improvements in water quality. This is consistent with recent water quality evaluations of CWS improvements (Kumpel and Nelson, 2013). However, households with IWS in Amravati, where pressure improvements during service hours were made even in IWS areas, reported similar water quality to the CWS households. This suggests that there could be intermediate improvements to water supply mode, the relationship between water quality and which is currently unexplored. In addition, CWS did not seem to affect routine treatment behavior for the most part, despite respondents noting better water quality from the tap. In these contexts, the most common treatment method of cloth filtering is relatively cheap and maintenance-free. The decision to use more expensive RO/UV filtering was generally reported to be independent of water supply continuity. While this finding is at odds with the purported CWS benefit of reducing treatment costs, this result is not surprising, as evidenced by the markets for bottled water and domestic water filtration devices in higher-income countries with continuous and high-quality tap water(Doria, 2006; Hedden, 1996).

The findings of this research indicate that many of the proposed benefits of CWS do not accrue automatically to the consumer, although substantial convenience benefits to slum populations are convincing. Many assumptions about consumer responses to water service improvements that are used to guide investment may not always bear out in practice.

4.4 Implications

Health and Hygiene

This study cannot offer conclusive evidence regarding, but does not contradict the proposed health and hygiene benefits of CWS. In Nagpur, CWS consumers perceived improved water quality at the tap relative to IWS, although in Amravati, similar water quality was noted between consumers with CWS and reliable, predictable IWS. The universality and persistence of storage of water in kitchen vessels indicates that this important risk to water quality is not automatically eliminated by CWS. The absolute *reduction* in water demand observed over the study period in Amravati indicates that CWS implemented with an IBT may result in decreased water use volumes from the piped supply, whether for hygiene in particular or other domestic uses. However, this study does not signal that the introduction of CWS is of direct concern to public health authorities, as CWS was not shown to reduce water quality or to directly impact hygiene behaviors negatively.

Equitable Water Demand Management

The example of Nagpur shows that higher volumetric tariffs may be necessary to discourage severe wasting of water under CWS, while the example of Amravati shows that the poor may reduce consumption from already less-than-recommended levels for health and hygiene after conversion from IWS to CWS under unsubsidized volumetric tariffs. In order for the water conservation benefits of CWS to be realized, water utilities and their regulators should design water tariffs and non-price water demand management approaches that effectively incentivize water conservation while still allowing the poorest to afford sufficient quantities of water for health and hygiene.

Evaluation of Water Supply Investments

Presentations of CWS water supply improvements have assumed coping cost reductions (World Bank, 2010). This study provided evidence that in at least two implementations, coping behaviors are not substantially changed, especially regarding storage. This study also provided evidence that it is even possible for some households to *increase* coping behaviors in order to avoid increasing water tariffs. Uncertainty in the magnitude and direction of coping cost changes as a result of water supply improvements should be incorporated into formal evaluations such as cost-benefit analyses of water supply investments. Storage and treatment-related cost reductions need to be more rigorously evaluated by those implementing water supply improvements before being considered an economic benefit to households that justify water supply investments.

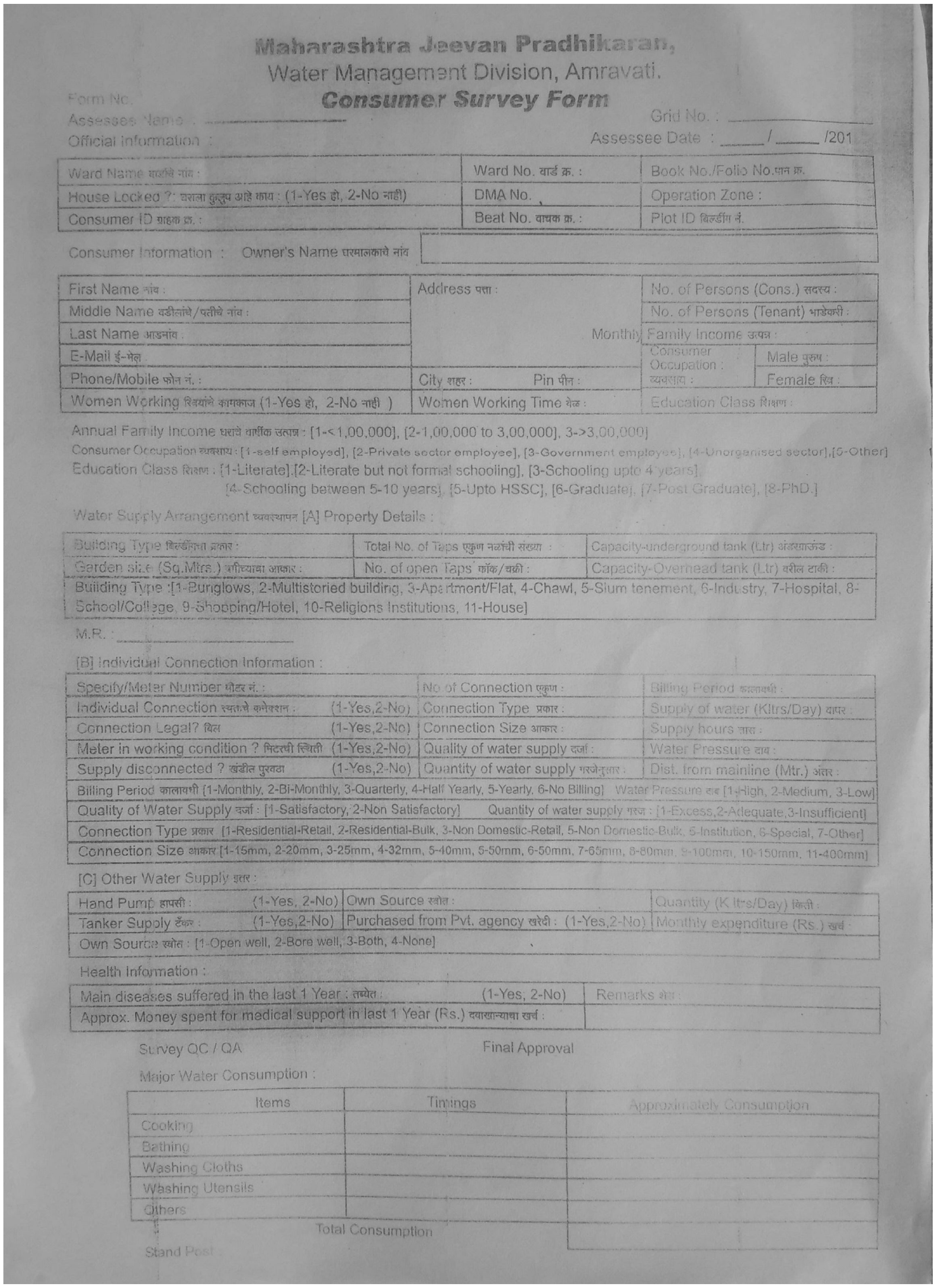
Consumer education in implementation of continuous water supply and other service delivery reforms

The lack of awareness of CWS by some households and the persistence of the practices of unattended taps and in-home storage reveal that continuing education about efficient water use and the risks of water storage should be integrated with water supply improvements. Reforming consumer interaction with water supply could be as necessary as service delivery reforms in order to ensure that the benefits of CWS, both at the household level and at the service area level can be realized.

4.5 Avenues for Future Research

This study demonstrated that CWS increases water demanded relative to IWS under similar price conditions. However, it is unknown how such water is used. Field evaluations of the impact of CWS on detailed water budgets and use patterns would be valuable for determining if and under what conditions CWS has consequences for hygiene practices. Another question that this research raises is the extent to which water quality can be improved by intermediate improvements. A rigorous evaluation of water quality under unreliably intermittent, varying degrees of reliable intermittency, and continuous water supply would would be suitable. This research also demonstrated that it is possible for CWS to increase water demand. As CWS interventions proliferate across urban India, the water resource implications of CWS under varying assumptions of water demand effects should be explored.

APPENDIX A: MAHARASHTRA JEEVAN PRADHIKARAN CONSUMER SURVEY



Maharashtra Jeevan Pradhikaran,
Water Management Division, Amravati.
Consumer Survey Form

Form No.
Assesses Name : ______________
Official information :
Grid No. : ______________
Assessee Date : _____/_____ /201

Ward Name वार्डचे नांव :	Ward No. वार्ड क्र. :	Book No./Folio No.पान क्र.
House Locked ?: घराला कुलूप आहे काय : (1-Yes हो, 2-No नाही)	DMA No.	Operation Zone :
Consumer ID ग्राहक क्र. :	Beat No. वाचक क्र. :	Plot ID बिल्डींग नं.

Consumer Information : Owner's Name घरमालकाचे नांव

First Name नांव :	Address पत्ता :	No. of Persons (Cons.) सदस्य :	
Middle Name वडीलांचे/पतीचे नांव :		No. of Persons (Tenant) भाडेकरी :	
Last Name आडनांव :		Monthly Family Income उत्पन्न :	
E-Mail ई-मेल		Consumer Occupation : व्यवसाय :	Male पुरुष :
Phone/Mobile फोन नं. :	City शहर : Pin पीन :		Female स्त्रि :
Women Working स्त्रियांचे कामकाज (1-Yes हो, 2-No नाही)	Women Working Time वेळ :	Education Class शिक्षण :	

Annual Family Income घराचे वार्षिक उत्पन्न : [1-<1,00,000], [2-1,00,000 to 3,00,000], 3->3,00,000]
Consumer Occupation व्यवसाय : [1-self employed], [2-Private sector employee], [3-Government employee], [4-Unorganised sector],[5-Other]
Education Class शिक्षण : [1-Literate].[2-Literate but not formal schooling], [3-Schooling upto 4 years], [4-Schooling between 5-10 years], [5-Upto HSSC], [6-Graduate], [7-Post Graduate], [8-PhD.]

Water Supply Arrangement व्यवस्थापन [A] Property Details :

Building Type बिल्डींगचा प्रकार :	Total No. of Taps एकुण नळांची संख्या :	Capacity-underground tank (Ltr) अंडरग्राऊंड :
Garden size (Sq.Mtrs.) बगीच्याचा आकार :	No. of open Taps कॉक/चक्री :	Capacity-Overhead tank (Ltr) वरील टाकी :
Building Type :[1-Bunglows, 2-Multistoried building, 3-Apartment/Flat, 4-Chawl, 5-Slum tenement, 6-Industry, 7-Hospital, 8-School/College, 9-Shopping/Hotel, 10-Religions Institutions, 11-House]		

M.R. : ______________

[B] Individual Connection Information :

Specify/Meter Number मीटर नं. :	No of Connection एकुण :	Billing Period कालावधी :
Individual Connection स्वतःचे कनेक्शन : (1-Yes,2-No)	Connection Type प्रकार :	Supply of water (Kltrs/Day) वापर :
Connection Legal? बिल (1-Yes,2-No)	Connection Size आकार :	Supply hours तास :
Meter in working condition ? मिटरची स्थिती (1-Yes,2-No)	Quality of water supply दर्जा :	Water Pressure दाब :
Supply disconnected ? खंडीत पुरवठा (1-Yes,2-No)	Quantity of water supply गरजेनुसार :	Dist. from mainline (Mtr.) अंतर :
Billing Period कालावधी [1-Monthly, 2-Bi-Monthly, 3-Quarterly, 4-Half Yearly, 5-Yearly, 6-No Billing] Water Pressure दाब [1-High, 2-Medium, 3-Low]		
Quality of Water Supply दर्जा : [1-Satisfactory, 2-Non Satisfactory] Quantity of water supply गरज : [1-Excess,2-Adequate,3-Insufficient]		
Connection Type प्रकार [1-Residential-Retail, 2-Residential-Bulk, 3-Non Domestic-Retail, 5-Non Domestic-Bulk, 5-Institution, 6-Special, 7-Other]		
Connection Size आकार [1-15mm, 2-20mm, 3-25mm, 4-32mm, 5-40mm, 5-50mm, 6-50mm, 7-65mm, 8-80mm, 9-100mm, 10-150mm, 11-400mm]		

[C] Other Water Supply इतर :

Hand Pump हापसी : (1-Yes, 2-No)	Own Source स्त्रोत :	Quantity (K ltrs/Day) किती :
Tanker Supply टँकर : (1-Yes,2-No)	Purchased from Pvt. agency खरेदी : (1-Yes,2-No)	Monthly expenditure (Rs.) खर्च :
Own Source स्त्रोत : [1-Open well, 2-Bore well, 3-Both, 4-None]		

Health Information :

Main diseases suffered in the last 1 Year : तब्येत : (1-Yes, 2-No)	Remarks शेरा :
Approx. Money spent for medical support in last 1 Year (Rs.) दवाखान्याचा खर्च :	

Survey QC / QA   Final Approval

Major Water Consumption :

Items	Timings	Approximately Consumption
Cooking		
Bathing		
Washing Cloths		
Washing Utensils		
Others		
Total Consumption		

Stand Post

APPENDIX B: INTERVIEW GUIDE

Interview Guide

Zone: CWS/ IWS **Type:** Slum/ House/ **Neighborhood (Cluster):**

Interview Number:

Q1 Verbal Consent

"Hello, my name is Kyle Onda. I am a student at the University of North Carolina, Chapel Hill, USA. We are conducting a research study about the "24x7" reforms taking place in the water utilities and infrastructure improvements to the water systems in [Nagpur /Amravati], and about how these changes affect water utilities and water customers. With your permission, I would like to ask you a few questions about water use in your home, and what you think about the 24x7 service. The interview should take about 20 minutes of your time and your responses will be anonymous. With your permission, I will audiorecord the interview. If you don't wish to be recorded, I will take notes. If there are any questions that you would prefer not to answer, please let me know. Your responses will be kept confidential. Would you like to participate in the interview?

Underlined questions only asked of households in 24x7 areas

Basic Questions

Q2 May we speak in English? (If not, ask preference for Hindi or Marathi)

Q3 What do you do?

Q4 How many people are in the household?

Q5 How long have you been here?

Service Level Questions

Q6.1 Where do you get your water?

*If they have a municipal corporation connection:

Q6.2 When did you get this connection?

Q6.3 Where did you get water before this connection?

Q7.1 Does the water come every day?

Q7.2 How many hours per day?

Q7.3 At what times?

Q8.1 Do you have an overhead tank?

Q8.2 Do you need a motor or pump to get the water to the overhead tank from the connection?

Q8.3 Do you have an underground tank or sump?

Q8.4 Do you use a motor or pump to get the water to the overhead tank from the sump?

Q8.5 How is the pressure now? Before the changes?

Q8.5.1 On the ground floor?

Q8.5.2 On upper floors?

Water Quality Questions

Q9.1 What is the quality of the water you received?

Q9.2 Before 24x7?

Q9.3 After?

Q9.4 Has the water quality improved recently? When did the quality improve?

Q10.1 Did you purify the water before 24x7?

Q10.2 Do you purify the water now? Why?

Q10.3 How? (Aquaguard, RO, filter, etc.)

Q11 (If they have a sump or overhead tank AND said they get 24x7 water) Do you still use the sump/tank?

Q11.1 Why?

Q12.1 What do you do when water quality is poor?

Q12.1.1 Before 24x7?

Q12.1.2 After 24x7?

Q12.2.1 Did you complain to the someone when water quality is bad? To who?

Q12.2.1 After 24x7?

Q12.2.2 How responsive were they?

Q12.2.3 How responsive are they now?

Billing Questions

Q13.1 How much is your water bill on average?

Q13.1.1 How about during the summer?

Q13.2 Was there any difference in your bill when 24x7 happened?

-Prompt about electric bill if they have pump

Q13.3 Who brings the bill?

Q13.4 How often?

Q13.5 Where do you pay the bill?

Q13.6 Do you pay by cash? Check?

Leakage Questions

Q14.1 Do you ever have leakages you need to repair?

Q14.2 How do you prevent leakages?

Q14.3 (If they have tank) How do you make sure tank does not overflow?

Q14.4 Do you repair yourself, or does corporation come?

Q14.5 (If above is corporation/MJP) How do you get the corporation/MJP to repair?

Q14.6 How responsive are they?

Change Process Questions

Q15.1 Were you informed about the change to 24x7?

Q15.2 Who informed you?

Q15.3 What did they explain?

(May have to prompt for:)

-Tariff increase

-Metering

-Pressure improvement

-Water quality improvement

Q15.4 Did you have to change the pipes in your home?

Q15.5 Who made the changes?

- *You?*
- *Corporation?*
- *Plumber?*

Q16.1 Where do you have water taps in your home?

Q16.2 Do you have separate taps from the corporation and your tank?

Q16.3 How do you use the water from direct tap?

Q16.4 Do you store drinking and cooking water in the kitchen?

**Ask if they can show how they would abstract water for drinking, and cooking.*

Q16.5 What do you use tank water for?

Q16.6 Why do you feel the need to fill the tank?

Q16.7 How much water per day did you use before 24x7? After?

Q18 How satisfied are you with the 24x7 water?

Q18.1 Why? Q18.2 Why Not?

Thank you for your time, if you have any questions, please contact me using the contact information on this card!

*Offer contact card

APPENDIX C: TARIFF STRUCTURES

Table 9: Amravati domestic water tariff structure

Period	Nominal Access Charge (Rs)	Block (1000L/ 2 months)	Price (Nominal Rs)
October 2009-June 2010	204	(Uniform Rate)	10.2
June 2010-June 2012	220	20-30	11.2
		30-40	12.3
		40-50	16.8
		>50	22.4
July 2012-Present	220	20-30	13
		30-40	20
		40-50	26
		>50	52

Table 10: Nagpur domestic water tariff structure (non-slum)

Period	Nominal Access Charge (Rs)	Block (1000L/ 1 month)	Price (Nominal Rs)
Old	0	0-10	3
		10-40	3.5
		>40	4
Pilot April 2009	56	7-8	8
		8-15	9
		15-80	12
		>80	16
Proposed full city August 2009	56	0-30	5
		30-80	9
		>80	15
Approved full city February 2010	56	0-20	5
		20-30	8
		30-80	11
		>80	15

Table 11: Nagpur domestic water tariff structure (slum)

Period	Nominal Access Charge (Rs)	Block	Price (Nominal Rs)
Old	25	(Monthly Rate)	–
Pilot April 2009	50	(Monthly Rate)	–
Approved full city February 2010	50	0-20	0
		20-30	8
		30-80	11
		>80	15

APPENDIX D: Coping Behavior Responses

Table 12: Reported coping behaviors for non-slum households

	Nagpur		Amravati	
	CWS (N=14)	IWS (N=16)	CWS (N=16)	IWS (N=20)
Storage				
Overhead Tank	8	13	14	16
Sump	2	5	3	6
Bulk storage in Drums	0	3	0	0
Kitchen storage in pots	14	16	16	20
Treatment				
Treat water (any)	14	16	16	20
Cloth/nylon filter	11	16	14	19
Chlorine	0	1	1	1
Alum	0	1	0	0
RO/UV Device	4	2	5	6
Alternate Sources				
Use private dug well	0	2	1	3
Use private borewell	2	4	1	4
Other	0	0	0	0
Pumping				
Pump (all types)	4	13	3	8
Booster Pump	0	4	0	0
Sump to Overhead Tank	2	5	2	4
Borewell Pump	2	4	1	4
Preference for CWS				
Satisfied with CWS	10	–	8	–
Would Like CWS	–	4	–	10

Table 13: Reported coping behaviors for slum households

	Nagpur		Amravati	
	CWS (N=8)	IWS (N=10)	CWS (N=5)	IWS (N=5)
Storage				
Overhead Tank	0	3	0	0
Sump	0	0	0	0
Bulk storage in Drums	0	7	1	5
Kitchen storage in pots	8	10	5	5
Treatment				
Treat water (any)	3	10	5	5
Boil	1	2	0	0
Cloth/nylon filter	2	7	5	5
Chlorine	0	0	0	0
Alum	0	2	0	0
RO/UV Device	0	0	0	0
Alternate Sources				
Use private dug well	0	0	0	0
Use private borewell	0	0	0	0
Public tap/ Handpump	0	6	0	2
Pumping				
Pump (all types)	0	0	0	0
Booster Pump	0	0	0	0
Sump to Overhead Tank	0	0	0	0
Borewell Pump	0	0	0	0
Preference for CWS				
Satisfied with CWS	8	–	1	–
Would Like CWS	–	6	–	4

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