From Intermittent to Continuous Water Supply

A Household-level Evaluation of Water System Reforms in Hubli–Dharwad

Isha Ray, Narayan Billava, Zachary Burt, John M Colford Jr, Ayşe Ercümen, K P Jayaramu, Emily Kumpel, Nayanatara Nayak, Kara Nelson, Cleo Woelfle-Erskine

Employing a matched cohort research design, eight wards with intermittent water supply are compared to eight wards upgraded to continuous (24 x 7) supply in a demonstration project in Hubli–Dharwad, Karnataka, with respect to tap water quality, child health, water storage practices, and coping costs across socio-economic strata. Water consumption and waste in the intermittent zones, and the potential for scale-up of continuous supply to the entire city, are estimated. It was found that the 24 x 7 project improved water quality, did not improve overall child health, but did reduce serious waterborne illnesses in the lowest-income strata, reduced the costs of waiting, increased monthly water bills, and potentially reduced water security for some of the poorest households.

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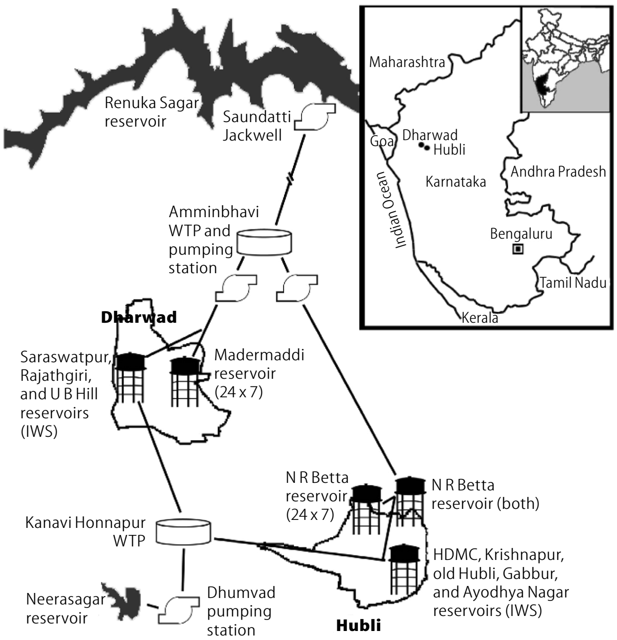
In March 2003, the World Bank came to the twin cities of Hubli–Dharwad, Karnataka, to discuss the much-needed reforms to its piped water network. The Hubli–Dharwad Municipal Corporation (HDMC) had been struggling to provide adequate water to its customers; 25% of the city's households accessed water through public standpipes, while many accessed water through unauthorised connections. Non-payment of bills was common, and water was being supplied intermittently at intervals of between one and eight days, with a median frequency of five days. Shortly after this visit, the Karnataka Urban Water Sector Improvement Project (KUWASIP) was set up as a private–public partnership (PPP) to supply and manage water to three cities in Karnataka: Hubli–Dharwad, Belgaum, and Gulbarga. The new water supply was to be continuous and fully pressurised ("24×7 water"), and would be piloted in demonstration zones within these chosen cities with a view to scale it up over time. Continuous water supply (CWS or 24×7) is the international supply standard for urban water utilities; it is favoured by the World Bank for all but the most water-short urban areas (World Bank 2004), and it is also the urban service norm approved by the Government of India (Ahluwalia 2011).

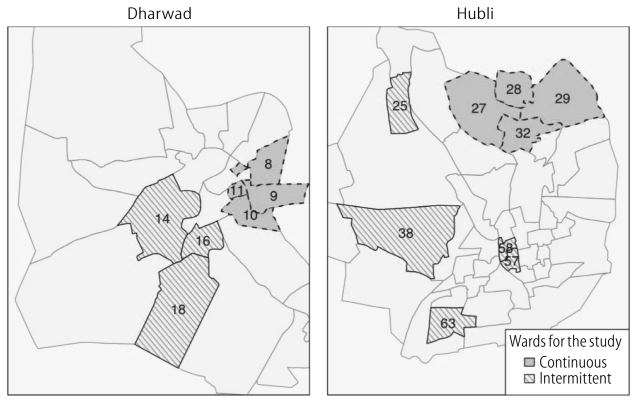
Almost immediately, 24×7 water became controversial in India. Critics argued that capital cost recovery coupled with public standpipe closure would hurt the poor; that the current water availability in Hubli–Dharwad might not be sufficient to provide continuous supply to the rest of the city; and that the necessary infrastructure upgrades were too expensive to be justified by the stated benefits. In addition, 24×7 water projects were, and continue to be, launched as PPPs, and water privatisation faces strong opposition from citizens and activists. Proponents expected that water quality would improve under 24×7 (mainly because pipes under continuous pressure leak clean water out whereas pipes that periodically are empty leak contaminated water in). They also argued that under intermittent water supply (IWS), households discarded any remaining stored water when new deliveries came, because "fresh" water was preferable to stored water, and that 24×7 regimes would prevent such waste. Furthermore, 24×7 would reduce household costs associated with IWS deliveries, such as waiting for, and then collecting, storing and treating water (collectively referred to as "coping costs"); utilities would also

Figure 1: Layout of the Hubli–Dharwad Water Distribution System, Location of Hubli and Dharwad in Karnataka State in the Inset



Source: Reproduced with permission from Kumpel and Nelson (2013: 5178).

Figure 2: Eight Continuous Water Supply Wards in Hubli–Dharwad and Eight Matched Intermittent Water Supply Wards under Study



benefit from better managed water deliveries with less leakage and thus higher rates of cost recovery. On grounds of better water quality, (resulting in) better health, less water waste, reduced coping costs, and better cost recovery, the proponents argued that the capital and other associated investments were justified. Our research team attempted to evaluate these claims, primarily from the vantage point of households.

Between 2010 and 2012, over a 15-month data collection period, our team investigated the household-level impacts of the IWS-to-CWS upgrade in Hubli–Dharwad. We employed a matched cohort research design to compare communities receiving 24×7 to those that did not, with respect to water quality at the tap, child health outcomes, water handling and storage practices, and coping costs across socio-economic strata. In addition, we estimated water consumption and waste in the intermittent zones, and the potential for sustainable scale-up of 24×7 to the entire city. In addition to collecting water quality samples, observing water use at the tap, and measuring stored volumes of water in a systematic subsample of households, our primary data collection method was a survey. We conducted the survey in four waves with a panel of households.[1] The number of households was 1,969 in 24×7 zones and 1,953 in IWS zones. Our goal was a rigorous evaluation of the household-level impacts attributable to a shift from intermittency to continuous supply. Our primary focus was on the demand or consumer side of 24×7 rather than on the utility-level capital costs or broader governance costs associated with these reforms.[2] In other words, was the upgrade to 24×7 water supply living up to its *ex ante* expectations for most households? In particular, was it beneficial for low-income households?

We present here the key results of our research efforts. Methodological details of this work and related findings have appeared in other discipline-specific journals; a list of these is provided at the end of this paper.[3] This paper synthesises the main methods and results of the entire effort, in one consolidated piece, for an interdisciplinary audience of academics, non-governmental organisations, and policymakers. The Hubli–Dharwad pilot project has been lauded in the national press as a success and as a model for other cities, for example:

> World Bank-funded pilot projects in three cities of Karnataka—Belgaum, twin cities of Hubli–Dharwad and Gulbarga have shown that a well-operated water system can indeed deliver water 24×7 in our cities, bringing an affordable, reliable service to urban households, including to the poor. The project has delivered improved water in terms of both quality and quantity to all urban consumers in the zones with a reduction in costs and health burden. (Guha 2014)

Given the visibility of this pilot project, and the ongoing efforts towards scaling it up, our comprehensive quasi-experimental study highlights both the promise and the pitfalls of 24×7 water supply in mid-sized cities of India.

The 24×7 Upgrade in Hubli–Dharwad

Hubli and Dharwad have a combined population of over 9,00,000 (Registrar General of India 2011), with a growth rate of just over 2% per year. Surface water is drawn from two sources: the Renuka Sagar reservoir, fed by the Malaprabha River and located 65 kilometres (km) north-east of Dharwad, and the rain-fed Neerasagar lake, located 20 km south-west of Hubli (Figure 1). The Amminbhavi and Kanavi Honnapur treatment plants treat the water in multiple steps. The treated and chlorinated water is delivered via transmission mains to service reservoirs and then to consumers through the distribution network. Consumers receiving intermittent piped water supplies commonly supplement their municipal water with groundwater from private or municipal borewells and tanker trucks, or, in a few neighbourhoods, through a community-based piped groundwater system.

Hubli–Dharwad has 67 administrative units (or "wards"). Four wards each in Hubli (starting in 2007) and Dharwad (starting in 2008) were provided with 24×7 water supply (Figure 2), through an upgrade managed by the KUWASIP and financed by the World Bank. The remaining 59 wards (about 90% of the city)[4] continued to receive piped water intermittently.

The KUWASIP selected the 24×7 wards based on the criteria of a socio-economically diverse population and the ability to hydraulically isolate the ward's network from the rest of the system (Sangameswaran et al 2008). Our research team walked around extensively in the 24×7 wards to create detailed maps of the areas to be sampled for this study, and visually verified that low-, middle- and high-income neighbourhoods were represented in the 24×7 zones (also see Table 1).

Table 1: Comparison of Study Households in Intermittently Supplied and Continuously Supplied Wards, Hubli–Dharwad

Characteristics	CWS (N=1,969)	IWS (N=1,953)
Persons per household, mean	6.5	6.5
Number of children <5 years per household, mean	1.4	1.4
Age of primary caregiver of children <5 years, mean	26.9	27.0
Number of rooms in household, mean	2.4	2.3
Households with concrete roof, %	44.0	45.2
Households with illiterate mother, %	8.5	10.1
Households with indoor handwashing facility, %	73.6	73.5
Households with private latrine, %	91.2	91.6
Households with piped sewers within block, %	78.3	74.4
Households with open sewers within block, %	71.6	75.1

CWS Stands for continuous water supply; IWS for intermittent water supply; N for sample size
Source: Ercümen et al (2015).

The KUWASIP sought to change the terms of agreement between the municipal corporation and residents by promising "international standards," and by encouraging water users to think of themselves as water consumers. The project's goals were to make all connections within the 24×7 zones metered (and therefore legal), improve reliability, and foster the development of "customer responsive and commercially-oriented utilities" (World Bank 2004). All the iron and PVC (polyvinyl chloride) pipes within the 24×7 zones were replaced with high-density polyethylene to reduce leakage, and better meters were installed than those that existed in the intermittent zones (Franceys and Jalakam 2010). Three years into the reforms, our surveys in the 24×7 demonstration wards showed that services remained almost (but not completely) uninterrupted. Nearly all households with formerly unauthorised connections were given meters and were receiving monthly bills. At the same time, access to free public water sources was greatly reduced: all 84 hand-pumps, an unspecified number out of the 110 motorised borewells, and all 115 public standpipes in the 24×7 zones were closed. Unkal Lake—the largest surface water body within Hubli's city limits, once freely available for non-potable uses and for domestic buffaloes—was fenced off. Access to this "recreational area" now requires a nominal fee.

Research Design and Methods

Study design and data analysis: We used a matched cohort quasi-experimental research design for our study in Hubli–Dharwad. To allow an unbiased comparison of our outcomes of interest between the two supply regimes, we had to find wards that closely matched the eight 24×7 zones on key socio-economic and demographic characteristics and water and sanitation services. We used a genetic matching algorithm (Sekhon 2009; Diamond and Sekhon 2013) and an older data set from Hubli–Dharwad (CMDR 2006) to select eight IWS wards as "controls" for the eight 24×7 "intervention" wards. We carried out all statistical analyses on the water quality, health outcomes, and cost-benefit analysis at the household- and system-levels using R (R Core Team 2012) and Stata; maps were created in R and ARCGIS (ESRI 2013).

Household sample and surveys: The household surveys formed the basis of health as well as household economics studies. We recruited 3,922 households in 16 wards (that is, eight with 24×7 and eight with IWS), each of which we surveyed with four visits over the 15-month study period. As we were interested in health outcomes from the upgrade to 24×7 water, we recruited only households with at least one child under the age of five years; this is a particularly vulnerable group for gastrointestinal illnesses. Wherever possible, the household member we enrolled was the primary caregiver for the child(ren). We divided each ward into (approximately) socio-economically homogeneous sampling sections, and recruited participants in proportion to the population density of each section. We trained our field team to start sampling from the street closest to a prominent landmark in each segment, such as a temple or major bus stop, and then systematically approach every household until the target number of households for that segment had been reached. We took GPS (global positioning system) coordinates for all houses to make sure that the participating households were spatially spread throughout the study wards; and to make it easier for the field team to return to the same houses for each survey wave.

Our team hypothesised that low-income neighbourhoods would have higher coping costs from intermittent water, because studies have reported lower-quality water services in low-income areas compared to middle- and upper-income ones (for example, Björkman 2014), and because low-income households often do not have overhead storage tanks that mimic continuous supply even when the underlying supply is intermittent. For these reasons, we also expected greater health impacts on low-income households from the switch to 24×7. Our sample was, therefore, sized to allow pre-specified subgroup analyses by socio-economic status, which we carried out by stratifying our sample into wealth quartiles. Reported incomes have a downward bias in most household surveys, so we created a wealth indicator index based on observed assets and housing materials using principal component analysis (following Vyas and Kumaranayake 2006; also see Ercümen et al 2015), and we used this index to demarcate the quartiles.

Water quality monitoring and tap samples*:* A total of 624 samples in 24×7 wards and 602 samples from IWS wards were

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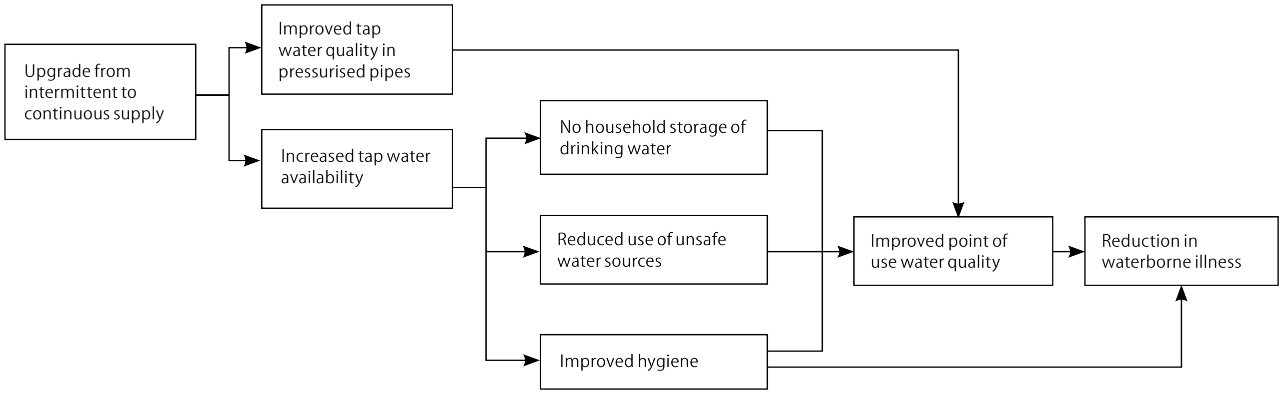
Figure 3: Causal Chain between Upgrading from Intermittent to Continuous Water Supply and Reduction in Waterborne Illness



Upgrading from intermittent to continuous water supply is expected to be associated with reduced waterborne illness through improved tap water quality and increased water availability, which, in turn, is expected to eliminate household storage of drinking water, reduce water use from unsafe non-municipal sources, and improve hygiene practices.
Source: Reproduced with permission from Ercümen et al (2015: 6).

collected from taps used by households. In general, our research team sampled 8–12 taps during a visit to a ward. In IWS wards, taps were selected from the area within the ward where water was on at the time of sampling, while similarly sized areas were selected for sampling on each visit to 24×7 wards. The team conducted three to four visits in each ward per survey wave to collect at least 25 samples per ward. We let the taps run for 1 minute before sampling and sprayed them with a chlorine solution prior to sample collection; thus any contamination in tested water quality would not be conflated with contamination at the tap itself. In addition to the tap sampling, we collected 14 samples from the finished water well at the two water treatment plants, and 69 samples from the reservoirs supplying the IWS and 24×7 zones. All water samples were collected in sterile bottles, transported on ice to a local laboratory, and tested within eight hours for total coliforms, *E. coli*, and turbidity.[5] Free and total chlorine residuals were measured in the field. In addition, at 11 sites over five wards, we periodically measured pressure and physico-chemical parameters at the main pipes and consumer taps, using sensors that collected continuous data. We simultaneously collected grab samples to test for total coliforms and E. coli.

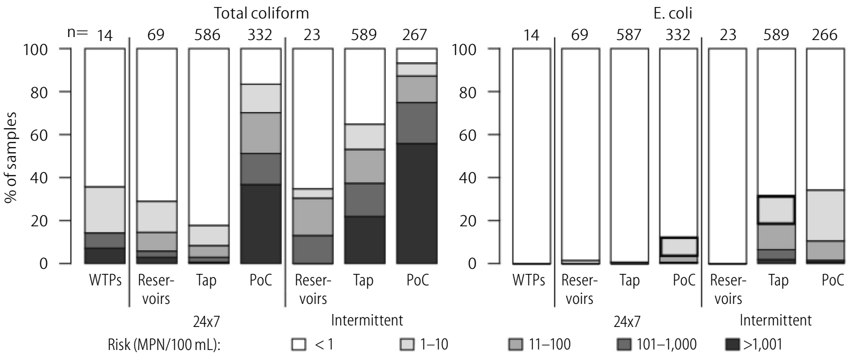
Household water storage practices: Under IWS, all households store water between deliveries. In-home storage is a significant contributor to overall coping costs, increases the chances of water contamination (Amrose et al 2015) and limits the household's water supply to the available storage volume. Under 24×7, significant volumes of water should no longer need to be stored in-home. A subset of our study houses (with sample size of 707), sampled systematically, participated in a separate container survey that included measurement of the heights, diameters and shapes of all of their water storage containers. In the full survey, we collected reported data on the volume of underground and/or overhead tanks from households that had these. The combined data of container survey and reported tank volume allowed us to estimate storage volumes and storage practices in households with and without 24×7 water.

Child health: Our primary health outcome was the caregiver-reported prevalence of diarrhoea[6] in children below five years, in the seven days preceding each interview. We also collected data on other potential outcomes of unsafe water, such as prevalence of blood/mucus in the child's stool (an indicator of severe diarrhoea), and highly credible gastrointestinal illness (HCGI).[7] In addition, we measured weight for age in children aged below five years, collected caregiver-reported data on death of a child aged below two years, and reported incidences of typhoid fever, hepatitis, or cholera in any household member since the 24×7 upgrade in 2007–08. Typhoid fever, hepatitis, and cholera are typically diagnosed locally, based on symptoms only, in our study setting; we did not seek laboratory confirmation for the reported cases. Finally, as negative control outcomes, following Lipsitch et al (2010), we asked caregivers about coughs/colds, and scrapes/bruises; these symptoms should be unaffected by any change in water supply, and any reported correlation of such symptoms with the water supply regime would indicate reporting bias in the survey. Figure 3 shows our hypothesised causal pathway between an upgrade to 24×7 and a measurable reduction in waterborne illnesses.

Cost of household water: We surveyed IWS and CWS households regarding all costs related to household water management. Coping costs included time spent in waiting for, collecting, storing and possibly treating water from any of the sources used, municipal or otherwise (Pattanayak et al 2005). Ongoing expenditures included utility bills, bottled or tanker-supplied water, and consumables used during treatment. Investments included household-level infrastructure (such as overhead tanks or private borewells) or durable equipment (such as buckets and barrels). We collected price information for all investments in a comprehensive, local market survey. These data allowed us to compare all three categories of cost in households with, and without, the 24×7 upgrade.[8]

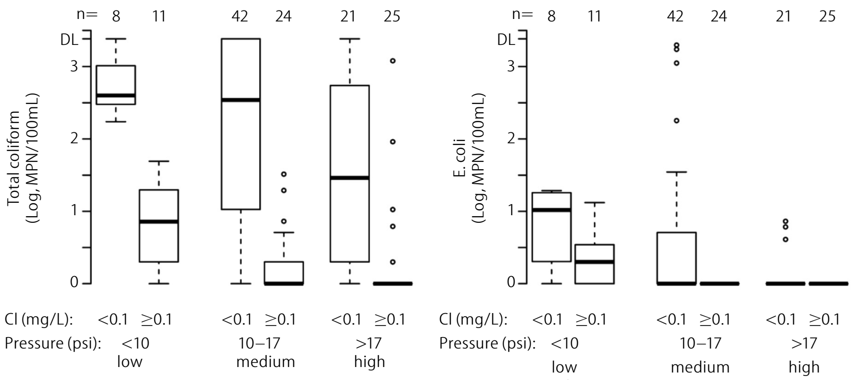
Water consumption and waste: We measured household water consumption and losses only in our intermittent supply

Figure 4: Percentage of Samples in Risk Levels Based on WHO Guidelines Comparing 24×7 and IWS Throughout the Distribution System



Water treatment plants (WTP), service reservoirs, consumer taps, and point-of-consumption (POC). The 24×7 zones not only supplied continuous water but also had entirely new pipes installed.
Source: Reproduced with permission from Kumpel and Nelson (2013: 5185).

Figure 5: Median, Lower and Upper Quartiles of Indicator Bacteria Concentrations from all Supply Cycles during Supply Period



Grouped by Average Pressure and Chlorine Residual during the 30-minute period before each grab sample was collected and tested for total coliform and E. Coli. Under low pressures, even in the presence of a chlorine residual, high levels of indicator bacteria were detected. CL indicates chlorine; MPN is most probable number; N is sample size; DL is detection limit.
Source: Reproduced with permission from Kumpel and Nelson (2014: 2770).

zones, to see whether IWS customers "waste" water or throw stored water away when new deliveries commence. Based on a household's presence or absence of an overhead tank, ownership of a private or shared tap, and the number of households sharing the tap (if not a private tap), we classified every study household in the IWS zones into four access categories: restricted, limited, partial, and plentiful.

We used three methods to measure household water use: (i) metered data when available, (ii) inventories of storage containers, described above, and (iii) estimates of water use directly from the tap when the household or shared tap was on. The direct use estimates relied on survey data on the time it took to fill household containers, the time for which the running tap was used for washing or bathing, the number of days between water deliveries, the number of people in the household, and the number of households sharing a tap. Using the data from our surveys and over 1,000 tap observations, we constructed a simple model to calculate median water use per person per day in all four access categories.

Water supply capacity: Finally, going beyond the household-level, we estimated whether or not 24×7 could realistically be scaled-up to all of Hubli–Dharwad. Using bulk water demand data from the 24×7 zones of Hubli after the upgrade, and publicly available weather and national income forecasts, we developed three different forecasting models to assess whether (i) average water demand per connection was commensurate with the design capacity of the 24×7 zone; and (ii) projected water demand in 24×7 zones would exceed projected (that is, planned) system capacity in the near-term.

Results

Household matching for health and economics survey: As explained above, we used a genetic matching algorithm to find eight IWS wards with similar characteristics to the eight, pre-selected, 24×7 wards. A comparison on key characteristics, such as socio-economic indicators, educational attainment, and water and sanitation conditions, measured in our household survey, showed that the 24×7 wards and the selected IWS wards resembled each other closely (Table 1). This result gives a high degree of confidence that any differences in our outcomes of interest between the two supply regimes were unlikely to have been driven by socio-economic or demographic differences.

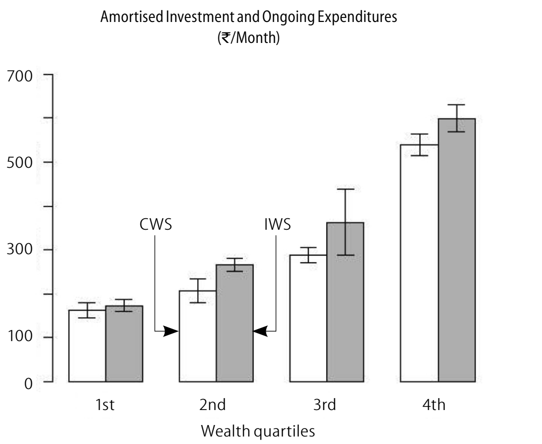
Water quality: Water quality was similar at the sources (that is, the water treatment plants and storage reservoirs) supplying the continuous and intermittent sections of the piped network. However, we detected indicator bacteria more frequently and at higher concentrations in samples from the IWS taps compared to 24×7 taps (the difference was statistically significant). Under continuous supply, less than 1% of tap samples were positive for E. coli compared to almost 32% of intermittent supply tap samples. Source water quality declined slightly during the rainy season, but only tap water from intermittent supply had measurably higher indicator bacteria during the rainy season compared to the dry season. Total coliform and E. coli decreased from service reservoirs to 24×7 taps, indicating the presence of residual chlorine; both total coliform and E. coli increased between reservoirs and the IWS taps, indicating contamination during transmission (Figure 4).

What are the mechanisms through which water quality got affected in these two supply regimes? In intermittent zones, when the supply was first turned on, water with high turbidity and high concentrations of indicator bacteria were flushed out of pipes through the tap. This "first flush" of water (that is, the water that comes out of the tap when service commences after a dry period), which lasted up to one hour, represents the highest risk for exposure to contaminated water. However, even after this first flush was expelled from the pipes, when the pressure was low (less than 10 psi, or pounds/square inch), high levels of indicator bacteria were frequently detected even when there was a chlorine residual; this suggests that contamination had occurred through intrusion (that is, contamination leaking into pipes under low pressure). Almost no total coliform and no E. coli were detected after the first flush period when water was delivered with a chlorine residual and at pressures of more than 17 psi (Figure 5, p 43). In 24×7 zones, intrusion would have been greatly reduced because the pipes were always pressurised, and because the pipes were new and would have had few cracks or fissures.

Household water storage practices: All IWS households and more than 90% of 24×7 households that we tested for water quality, stored drinking water; households were sampled almost three years after the upgrade to 24×7 supply. The 24×7 households collected and stored their drinking and cooking water (from their own private taps) once every 1.5 days on an average, with an in-home median stored volume of 50 litres per household.[9] Our interviews with the households produced a range of reasons for continued storage, including "it is a backup, in case," or "this is how we use water" (Burt and Ray 2014). We observed that, for most households, the tap was not in the kitchen but just outside the home, or a few feet from the home. Even this small inconvenience prompted families to retain their storage vessels, as they were already used to this. Furthermore, though the 24×7 zones were generally smoothly managed, about half of our study households with continuous supply had experienced at least one interruption in water service during the 15-month study period.

Child health: We found no significant differences between the IWS and 24×7 households either on child diarrhoea (our pre-specified primary health outcome of interest; Table 2) or weight-for-age measures. It is possible that continued in-home storage of drinking water, which is susceptible to recontamination, could have attenuated health benefits from the significantly better tap water quality under 24×7. However, we did find a significant 37% reduction in severe (bloody) diarrhoea in children from lower-income 24×7 households compared to lower-income IWS households. There were no comparable reductions in higher-income households. The 24×7 sample also had 42% fewer households having at least one reported case of typhoid fever (Table 3). Our results indicated lower reported mortality of children under the age of two years in 24×7 households, but this was not statistically significant and is only a suggestive association. There was no difference in the negative control outcomes (such as coughs or bruises) between 24×7 and IWS, suggesting that there was no bias in our data collection.

Figure 6: Average Monthly Cash Costs Per Household, IWS and 24x7 Zones



Cost of household water: Amortised investment costs for household water were lower in 24×7 compared to IWS households; this is an expected result as the need for storage, while it clearly was not eliminated, would have declined sharply when households converted from IWS to CWS. We found that for all wealth quartiles, 24×7 areas had lower water-related investments compared to IWS areas. The lower investment cost

Table 2: Caregiver-reported Seven-day Prevalence of Diarrhoeal Illness in Children Aged below Five Years over Four Waves of Data Collection[a]

	IWS		CWS		CWS vs IWS	
	N	P %	N	P %	Unadj. PR (95% CI)[b]	Adj. PR (95% CI)[c]
Main analysis						
HCGI[e]	10,000	11.3	10,035	11.5	1.02 (0.93–1.11)	1.01 (0.92–1.11)
Diarrhoea	10,019	8.4	10,054	7.9	0.94 (0.84–1.05)	0.93 (0.83–1.04)
Blood/mucus in stool	10,016	1.9	10,052	1.5	0.81 (0.65–1.02)	0.78 (0.60–1.01)
Above-median wealth[d]						
HCGI	5,034	10.1	5,026	10.4	1.03 (0.90–1.18)	1.04 (0.91–1.19)
Diarrhoea	5,043	7.0	5,037	6.9	0.98 (0.83–1.17)	0.98 (0.84–1.16)
Blood/mucus in stool	5,041	1.2	5,036	1.4	1.11 (0.77–1.58)	1.08 (0.73-1.63)
Below-median wealth[d]						
HCGI	4,960	12.6	4,983	12.6	1.00 (0.88–1.13)	0.99 (0.86–1.13)
Diarrhoea	4,970	9.8	4,991	8.8	0.90 (0.78–1.04)	0.89 (0.76–1.04)
Blood/mucus in stool	4,969	2.5	4,990	1.6	0.64 (0.47–0.86)	0.63 (0.46–0.87)

P: Prevalence; N: Sample size; PR: Prevalence ratio; CI: Confidence interval.
a: The diarrhoea outcomes were recorded at each survey wave to capture seasonal trends.
b: Unadjusted comparison of CWS versus IWS.
c: Adjusted comparison of CWS versus IWS, controlling for potential confounding from season, socio-economic indicators, and hygiene and sanitation conditions. The unadjusted and adjusted estimates are similar, indicating that our matched design removed confounding from measured covariates.
d: We defined above-median wealth as the top two wealth quartiles and below-median wealth as the bottom two wealth quartiles based on the wealth index we generated using principal component analysis.
e: HCGI—highly credible gastrointestinal illness.
Source: Ercümen et al (2015: 12).

Table 3: Caregiver-reported Incidence of Waterborne Disease and Below Two Child Mortality, Ascertained at the Third Wave of Data Collection[a]

	IWS			24×7			24×7 vs IWS	
	N	n[b]	I[c]	N	n[b]	I[c]	Unadj. CIR (95% CI)[d]	Adj. CIR (95% CI)[e]
Typhoid	1,690	103	60.9	1,711	58	33.9	0.56 (0.40-0.76)	0.58 (0.41-0.78)
Cholera	1,691	4	2.4	1,711	6	3.5	1.48 (0.37-6.92)	—[f]
Hepatitis	1,690	46	27.2	1,711	59	34.5	1.27 (0.87-1.87)	1.13 (0.76-1.73)
<2 Child death	1,695	20	11.8	1,713	12	7.0	0.59 (0.26-1.19)	0.51 (0.22-1.07)

N: Sample size; I: Incidence; CIR: Cumulative incidence ratio; CI: Confidence interval.
a: The incidence of these outcomes was recorded during a single wave of data collection.
b: Number of households reporting at least one case since 2007–08.
c: Incidence per 1,000 households of at least one reported case since 2007–08.
d: Unadjusted comparison of CWS versus IWS.
e: Adjusted comparison of CWS versus IWS, controlling for potential confounding.
f: Not calculated due to sparse data.
Source: Ercümen et al (2015: 14).

Figure 7: Average Monthly Time Cost of Waiting and Collecting Water Per Household

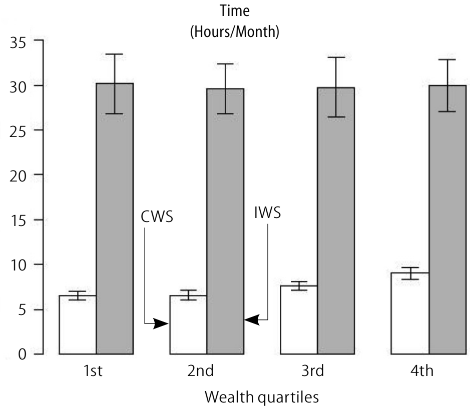
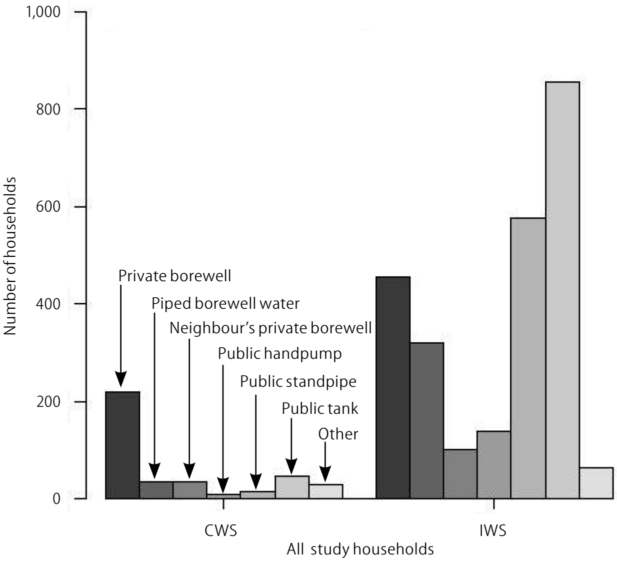


Figure 8: Borewell and Standpipe Usage in 24×7 versus IWS Zones



During the previous month (reported by survey respondents).
Source: Reproduced with permission from Burt et al (2018: 128).

was roughly offset by the increase in ongoing monetary expenditures (Figure 6, p 44); higher utility bills accounted for most of the estimated increases in monetary expenditures (Table 4). Overall, therefore, water costs did not increase under 24×7, though the monthly bills did (Burt et al 2018). It could be argued, however, that in-home investments are entirely private, whereas water tariffs contribute to the utility's overall revenues and can be used towards cost recovery or system-wide

Table 4: Average (Estimated) Monthly Water Bills (₹/month)

	BMW		AMW	
	Mean Usage	Median Usage	Mean Usage	Median Usage
Monthly bill (IWS tariff-metered household)	107	90	154	131
Monthly bill (24x7 tariff)	213	148	408	313
Bill increase (Conversion from IWS to 24x7)	106	58	254	182

$1 = ₹51, January–March 2012; BMW: Below Median Wealth; AMW: Above Median Wealth. Data from 24×7 households that showed us their bills (sample size was 1,131). Expected bills for the volumes consumed were calculated with both IWS and 24×7 tariffs; last row shows difference between bills under the two tariff structures.

improvements. In this sense, the cost regime under 24×7 represents a shift of investment from the private to the public realm.[10]

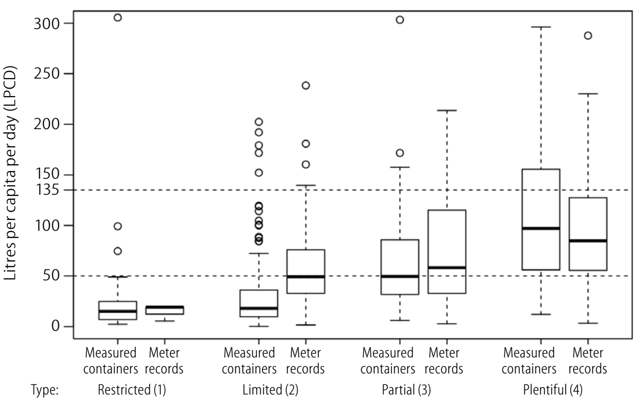
The time savings in the 24×7 zones were significant; this is also an expected result. The cost of waiting and collecting remained about the same across quartiles (Figure 7). This was initially surprising to us, as our hypothesis was that low-income households without automatically filling overhead tanks would save more time in a 24×7 regime. We found, however, that lower quartile households often shared taps with others. They had to fill their containers quickly and in turns (Kumpel et al 2017), and, in effect, collected less water over a shorter period of time than they otherwise might have done. Also, high-income households often collected their drinking water by hand, while their overhead tanks passively collected non-drinking water.

Finally, there was a dramatic drop-off in the use of (free) standpipes and borewells in 24×7 zones (Figure 8). This was due in part to the reduced need for such sources, but also due to the utility closing off public water systems in an effort to eliminate previously free alternatives to paid-for municipal water. This policy represents a decrease in water security: public borewells and standpipes are backup sources if pipes fail, whether through utility disconnection or insufficient supplies, or if the higher water tariffs under 24×7 become unaffordable for some vulnerable households. Our data shows that many 24×7 households with private borewells continued to use them for domestic (non-drinking) uses, but those who relied on public borewells for themselves or for domesticated animals lost this source. Continued access to public sources would, therefore, have been a pro-poor measure in the 24×7 zones (see also Connors 2005).

Water consumption and waste: We found little support for the hypothesis that households with intermittent water supply waste stored water by throwing it away when new supplies start. We observed very little household water waste in Hubli–Dharwad, despite mostly unmetered connections. Households without overhead storage tanks consumed water during the delivery period for water-intensive chores such as laundry or bathing children. Lower-income households, in particular, were supply- and storage-constrained such that there was not much stored water left by the time the new deliveries commenced. According to our estimates, hardly any households, even those with plentiful supplies (that is, households with overhead storage tanks and private taps), consumed the Government of India's urban service standard of 135 litres per person per day (Figure 9, p 46). Households with limited or restricted access typically consumed much less than the commonly cited "human right to water" standard of 50 litres per person per day (Gleick 1998).

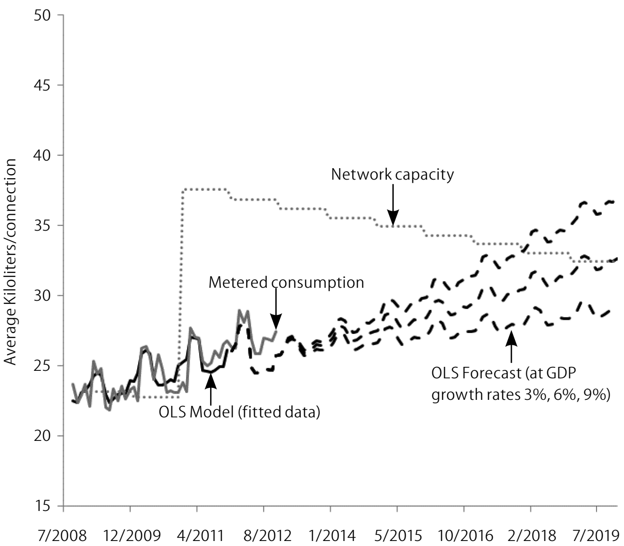
Based on our estimates of household water consumption and the metered quantities of bulk supply, we estimated that unaccounted for water in five IWS wards was about 50% (range 41% to 59%). Much of this is likely due to physical losses via leakage. These levels are especially high given that the pipes only contained pressurised water during a fraction (approximately 5%)

Figure 9: Water Consumption Grouped by Household Type



Box and whisker plots with median (thick line), lower and upper quartiles (bottom and top of the boxes), the minimum and maximum values (the tails), and outliers (dots) litres per capita per day, grouped by household type, using storage container measurements and meter records. The horizontal line at 50 LPCD denotes a common "human right to water" standard. The line at 135 LPCD is the Government of India's piped water service standard for urban areas.
Source: Kumpel et al (2017: 9).

Figure 10: Monthly Forecasts Using an Ordinary Least Squares (OLS) Analysis of Bulk Demand per Connection



Even under moderate economic growth, demand is projected to exceed the supply capacity per connection within seven years of scale-up. The projections are based on the lower levels of leakage expected under 24X7 water supply.
Source: Reproduced with permission from Jayaramu et al (2015: 210).

of the time. In contrast, "lost" water in the pilot 24×7 zones was reported to be 7%, though these pipes were full of pressurised water 24×7 (World Bank 2011: 12). This lower level of water loss is expected given that all of the pipes were replaced in the 24×7 pilot zones.[11] Controlling leaks via repairs or replacement is a necessary, but expensive part of conversion from IWS to CWS.

Water supply capacity: We compared our forecasted models of bulk water[12] demand under 24×7 with planned future system capacity up to 2021. We did this in order to test the sustainability of supply capacity, but also as part of our overall assessment of equity impacts. We created three models: (i) a simple correlation model (ordinary least squares or OLS), including temperature and economic growth as explanatory variables; (ii) a univariate forecasting model; and (iii) a classified household method that assumed a constant usage per connection. We assumed a constant ratio of people per connection based on current data, then projected the future number of connections based on past population growth rates. The projections for connections allowed us to forecast demand and supply capacity on a per-connection basis. If 24×7 is expanded to the rest of Hubli–Dharwad, all three models indicate that planned system capacity may be insufficient to meet demand for the city soon after scale-up (Figure 10; this shows the OLS model, which is often used for short-term forecasts). It was unclear from the project documentation whether planned capacity was being determined by demand analysis going forward, by access to capital, or by water source constraints, but the HDMC engineers believed that water source constraints were the limiting factor for system capacity. If system capacity and/or high capital costs prevent the scale-up of 24×7 to the entire city, then partial 24×7 does not serve intra-city equity. The point of the pilot, after all, was—if benefits outweighed costs—to scale it up.

In Conclusion

Optimistic projections in the press quoting the KUWASIP and the World Bank engineers about doing more with less under 24×7, and their pessimistic counterparts predicting dire consequences of "privatised" water for the urban poor, became opposing stances soon after the 24×7 pilot projects in Karnataka. Different segments of India's political waterscape pointed to different observations in Hubli–Dharwad of customer satisfaction, customer protests, water insecurity for the poor, and willingness to pay by the poor. In particular, concerns were raised about the accountability of KUWASIP—a parastatal rather than a municipal agency—and about the affordability of water when it is managed by a PPP. However, 24×7 as a policy is gaining ground, with the World Bank and the Government of Karnataka having already signed a $100 million loan agreement to scale-up 24×7 in Hubli–Dharwad, beyond the demonstration zones (World Bank 2016). Other cities are considering or are already implementing partial, or full, upgrades to 24×7.[13] We conducted this multi-year, multi-disciplinary study to rigorously evaluate the key goals of the upgrade to continuous water supply, and to inform both public opinion and public policy about the promise and challenges of such upgrades.

Between 2010 and 2012, our research team investigated the impacts of the switch to 24×7 piped water, primarily from the household-level perspective. We did not investigate the ramifications of handing over water management to a PPP, or whether the total capital investment of the 24×7 reform was justified by its total benefits; these are essential questions but are beyond the scope of our research design. We found that 24×7 water

(i) significantly improved water quality at the tap, which is a result of both continuously pressurised pipes and the replacement of old pipes with new and non-leaking ones;
(ii) reduced storage times, but did not reduce the practice of in-home water storage, and much-continued storage could lead to re-contamination and attenuated health benefits from 24×7;

(iii) did not measurably improve overall child health outcomes, but did improve child health with respect to serious waterborne illness in the lowest-income strata, and did reduce typhoid fever incidence;
(iv) significantly reduced coping costs across socio-economic strata, mainly by reducing wait times;
(v) increased monthly water bills across the board, but reduced costs on storage equipment;
(vi) potentially increased water insecurity for the very poor by shutting down public standpipes and borewells that provided a free, backup water supply in times of stress; and
(vii) resulted in an increased average consumption per connection, in part because IWS users tended to be quantity-constrained.

Very few IWS households were "wasting" water, in contrast to the arguments of 24×7 supporters. Many IWS households were, in fact, using less water than is recommended to meet basic daily needs.[14] Our model forecasts showed that planned system capacity going forward could be inadequate to scale 24×7 to the entire city; partial conversion to 24×7 would then serve to deepen intra-city inequality.

Our work suggests that should a city not be able to implement or scale up 24×7, for reasons of cost or resource capacity constraints or governance challenges, several interim steps to improve urban water supplies could be considered. These include better characterising the physical system (such as more accurate maps and valve area boundaries); reducing leaks and repairing or replacing old pipes; emphasising to all households that first flush water should never be used for cooking or drinking; disseminating accurate information on water supply schedules so that waiting times are reduced; and using statistical models to forecast demand to verify whether planned supply capacity is sufficient. These investments and planning practices would be beneficial for households as well as for the utility, even if a transition to 24×7 water never occurs.

We conclude that, for the majority of households, it is not surprising to find that continuously flowing and pressurised piped water is a desirable service; there is good reason that such systems are the benchmark by which urban utilities are judged. In a small subset of our surveyed households, an additional survey module found that 97% of users were satisfied with the quantity supplied under 24×7 compared to 59% under IWS, and 67% were satisfied with water quality under 24×7 compared to 51% under IWS (Nayak and Billava 2016). But how, at what cost, and at whose cost 24×7 is implemented, determines whether it is sustainable and equitable. If low-income households lose their fallback option of free public sources because cost-recovery demands the removal of all non-revenue water, or if high capital costs and/or network capacity prevent the equitable scale-up to an entire city once the demonstration zones have proven to be successful, then continuous water supply will be at risk of remaining an unequally distributed and unsustainable reform.

Epilogue

This paper focused on the household-level results of an impact evaluation of the pilot project on 24×7 water supply in Hubli–Dharwad, the data for which was collected between 2010 and 2012. The CMDR members of our research team, based on an additional survey of 30 households in the original (pilot) 24×7 wards and 60 households in two new 24×7 wards, found that, as of writing this: (i) the original 24×7 zones continue to function smoothly with high levels of customer satisfaction with respect to water availability and quality; (ii) newer layouts and zones that have been converted to 24×7 are not being supplied continuously, and some households actually have both IWS and 24×7 connections; (iii) summer season supply in many IWS zones, whose water delivery conditions had improved to a three to four day schedule because of investments in supply augmentation for the city as a whole, had reverted to a five to eight day delivery frequency; and (iv) installations of pipelines and new connections for scale-up have been carried out fully in 19 wards but only partially in 20 wards (according to the records of the Karnataka Water Supply Board). As of August 2018, the promise of 24×7 water in the demonstration zones was yet to be replicated in the rest of Hubli–Dharwad.

NOTES

1 By "panel of households" we mean that the same households were repeatedly surveyed four times; this was necessary to account for differences due to seasonality in water use practices and in waterborne illnesses.

2 Official World Bank (and related) documents do not give consistent figures for the total capital cost of the project. For a calculation of the potential system-wide cost-benefit analysis of Hubli–Dharwad's 24×7 project, including multiple estimates of capital costs, see Burt et al (2018).

3 The papers from this entire research effort had different combinations of authors; when we use the terms "our research team" or "we," we mean some combination of the co-authors of this paper. In addition, B Manoj Kumar contributed to the water supply capacity work, and Benjamin Arnold contributed to the health outcomes work. The papers from this research that we draw on for this final article are: Burt and Ray (2014); Ercümen et al (2015); Jayaramu et al (2015); Kumpel and Nelson (2013, 2014); Kumpel et al (2017); Nayak and Billava (2016); Burt et al (2018). Full citations are in the references section of this paper.

4 There were two additional wards that were part 24×7 and part IWS. We did not include these wards in our sampling frame for selecting IWS wards for this study.

5 Total coliforms and E. coli are common indicator bacteria for testing drinking water quality used as proxies for potential contamination by pathogens. Total coliform bacteria are commonly found in the environment, while E. coli are a more specific indicator of likely fecal pollution (Gruber et al 2014).

6 Diarrhoea is defined as three or more loose stools in any 24-hour period.

7 HCGI is defined as the occurrence of at least one episode of liquid diarrhoea, soft diarrhoea with abdominal cramps, vomiting, or nausea with abdominal cramps.

8 We also surveyed households on medical/healthcare expenses on account of water-related illnesses; the reported sums were so small across the board that we did not include them in our comparison.

9 We are not including rooftop tank or underground tank storage for this estimate.

10 We are grateful to an anonymous reviewer for pointing out the significance of the changed cost regime.

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11 Technical losses of 7% are low compared to other well-run water systems. We surmise that this estimate is especially low because the entire piped system in 24×7 zones was replaced, and new pipes have little leakage.

12 Bulk water includes water consumption at the tap plus actual leakage in the network.

13 Examples of cities debating or already implementing 24×7 include Pune, Nagpur, Latur, Mumbai, and Mysuru.

14 News articles in India have reported that water demand decreased in the 24×7 wards. Our research suggests that, if true, this is a result of lower leakage from upgraded pipes rather than lower use in households. Our own estimates suggest that leakages were about 50% in IWS wards (Kumpel et al 2017).

REFERENCES

Ahluwalia, I J (2011): "Report on Indian Urban Infrastructure and Services," Ministry of Urban Development, viewed on 26 May 2017, http://indiaenvironmentportal.org.in/files/Estimating%20Investment%20Requirements_Urban%20Infrastructure%20Services%20in%20India_HPEC%20Report_MoUD_2011.pdf.

Amrose, S Z Burt and I Ray (2015): "Safe Drinking Water for Low-income Regions," *Annual Review of Environment and Resources*, Vol 40, No 1, pp 203–31.

Björkman, L (2014): "Becoming a Slum: From Municipal Colony to Illegal Settlement in Liberalisation-era Mumbai," *International Journal of Urban and Regional Research*, Vol 38, No 1, pp 36–59.

Burt, Z and I Ray (2014): "Storage and Non-payment: Persistent Informalities within the Formal Water Supply of Hubli-Dharwad, India," *Water Alternatives*, Vol 7, No 1, pp 106–20.

Burt, Zachary, Ayşe Ercümen, Narayana Billava and Isha Ray (2018): "From Intermittent to Continuous Service: Costs, Benefits, Equity and Sustainability of Water System Reforms in Hubli–Dharwad, India," *World Development*, Vol 109, pp 121–33.

CMDR (2006): *Socio Economic Survey of Hubli–Dharwad City*, Dharwad: Center for Multidisciplinary Development Research.

Connors, Genevieve (2005): "When Utilities Muddle Through: Pro-poor Governance in Bangalore's Public Water Sector," *Environment & Urbanisation*, Vol 17, No 1, pp 201–17.

Diamond, A and J S Sekhon (2013): "Genetic Matching for Estimating Causal Effects: A General Multivariate Matching Method for Achieving Balance in Observational Studies," *Review of Economics and Statistics*, Vol 95, No 3, pp 932–45.

Ercümen, A, B F Arnold, E Kumpel, Z Burt, I Ray, K Nelson and J M Colford Jr (2015): "Upgrading a Piped Water Supply from Intermittent to Continuous Delivery and Association with Waterborne Illness: A Matched Cohort Study in Urban India," *PLoS Med*, Vol 12, No 10, p e1001892.

ESRI (2013): *ArcGIS Desktop: Release 10*, Redlands, CA: Environmental Systems Research Institute.

Franceys, Richard W A and Anand Kumar Jalakam (2010): *India—The Karnataka Urban Water Sector Improvement Project: 24x7 Water Supply Is Achievable*, No 72256, Washington DC: World Bank, pp 1–24.

Gleick, P H (1998): "The Human Right to Water," *Water Policy*, Vol 1, No 5, pp 487–503.

Gruber, J S, A Ercumen and J M Colford (2014): "Coliform Bacteria as Indicators of Diarrheal Risk in Household Drinking Water: Systematic Review and Meta-analysis," *PLoS ONE*, Vol 9, No 9, e107429.

Guha, Subhabrata (2014): "24-hour Water Supply Need Not be a Pipe Dream in Urban India," *Times of India*, 18 January.

Jayaramu, K P, Z Burt and B Manoj Kumar (2015): "A Study of the Consumption Pattern in a Continuous Water Service Demonstration Zone and Bulk Water Demand Forecasting for Hubli–Dharwad, India," *Journal of Water, Sanitation and Hygiene for Development*, Vol 5, No 2, p 201.

Kumpel, E and K L Nelson (2013): "Comparing Microbial Water Quality in an Intermittent and Continuous Piped Water Supply," *Water Research*, Vol 47, No 14, pp 5176–88.

— (2014): "Mechanisms Affecting Water Quality in an Intermittent Piped Water Supply," *Environmental Science & Technology*, Vol 48, No 5, pp 2766–75.

Kumpel, E, C Woelfle-Erskine, I Ray and K L Nelson (2017): "Measuring Household Consumption and Waste in Unmetered, Intermittent Piped Water Systems," *Water Resources Research*, Vol 53, No 1, pp 302–15.

Lipsitch, M, E Tchetgen and T Cohen (2010): "Negative Controls: A Tool for Detecting Confounding and Bias in Observational Studies," *Epidemiology*, Vol 21, No 3, pp 383–88.

Nayak, N and N Billava (2016): "Conversion from Intermittent to Continuous Water Supply (24 x7) in Hubli–Dharwad Twin Cities: Discourse on Governance and Sustenance Issues," unpublished.

Pattanayak, S K, J C Yang, D Whittington and K C Bal Kumar (2005): "Coping with Unreliable Public Water Supplies: Averting Expenditures by Households in Kathmandu, Nepal," *Water Resources Research*, Vol 41, No 2, pp 1–11.

R Core Team (2012): *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/.

Registrar General of India (2011): *Census of India 2011: Karnataka: Dharwad District Census Handbook*, New Delhi: Registrar General of India, viewed on 3 July 2017, http://www.censusindia.gov.in/2011census/dchb/1214_PART_B_DCHB_LOWER%20DIBANG%20VALLEY.pdf.

Sangameswaran, P, R Madhav and C D'Rozario (2008): "24/7,'Privatisation'and Water Reform: Insights from Hubli–Dharwad," *Economic & Political Weekly*, Vol 43, No 14, pp 60–67.

Sekhon, J S (2009): "Opiates for the Matches: Matching Methods for Causal Inference," *Annual Review of Political Science*, Vol 12, No 1, pp 487–508.

Vyas, S. and L Kumaranayake (2006): "Constructing Socio-economic Status Indices: How to Use Principal Components Analysis," *Health Policy and Planning*, Vol 21, No 6, pp 459–68.

World Bank (2004): *Project Appraisal Document on a Proposed Loan in the Amount of $39.5 Million to the Republic of India for the Karnataka Urban Water Sector Improvement Project*, No 27180–IN, Energy and Infrastructure Sector Unit, South Asia Regional Office, World Bank.

— (2011): *Implementation Completion and Results Report (IBRD-47300) on a Loan in the Amount of $39.5 Million to the Government of India for the Karnataka Urban Water Sector Improvement*, No. ICR00001950, Sustainable Development Department, Urban, Water and Disaster Risk Management Unit, India Country Management Unit, South Asia Region, World Bank.

— (2016): "Government of India and World Bank Sign US$ 100 Million Agreement for Urban Water Supply Modernization in Karnataka," 24 May, http://www.worldbank.org/en/news/press-release/2016/05/24/government-india-world-bank-sign-usd100million-agreement-urban-water-supply-modernization-karnataka.

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