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Comparing microbial water quality in an intermittent and continuous piped water supply

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ABSTRACT

Supplying piped water intermittently is a common practice throughout the world that increases the risk of microbial contamination through multiple mechanisms. Converting an intermittent supply to a continuous supply has the potential to improve the quality of water delivered to consumers. To understand the effects of this upgrade on water quality, we tested samples from reservoirs, consumer taps, and drinking water provided by households (e.g. from storage containers) from an intermittent and continuous supply in Hubli–Dharwad, India, over one year. Water samples were tested for total coliform, *Escherichia coli*, turbidity, free chlorine, and combined chlorine. While water quality was similar at service reservoirs supplying the continuous and intermittent sections of the network, indicator bacteria were detected more frequently and at higher concentrations in samples from taps supplied intermittently compared to those supplied continuously ($p < 0.01$). Detection of *E. coli* was rare in continuous supply, with 0.7% of tap samples positive compared to 31.7% of intermittent water supply tap samples positive for *E. coli*. In samples from both continuously and intermittently supplied taps, higher concentrations of total coliform were measured after rainfall events. While source water quality declined slightly during the rainy season, only tap water from intermittent supply had significantly more indicator bacteria throughout the rainy season compared to the dry season. Drinking water samples provided by households in both continuous and intermittent supplies had higher concentrations of indicator bacteria than samples collected directly from taps. Most households with continuous supply continued to store water for drinking, resulting in re-contamination, which may reduce the benefits to water quality of converting to continuous supply.

1. Introduction

In 2010, 73% of urban and 24% of rural populations in developing countries had access to piped water on their household premises (UNICEF and WHO, 2012). While piped water is an improved water source, recent studies suggest that many systems classified as improved may not provide water that is safe and reliable (Onda et al., 2012). Deficiencies in piped water distribution systems, common in many developing countries, have been linked to contamination of water at consumer taps and outbreaks of water-borne illnesses (Geldreich, 1996; Semenza et al., 1998; Lee and Schwab, 2005). One widespread deficiency is the practice of intermittent water supply (IWS). An estimated one-third of piped water supplies in Africa and Latin America and more than half in Asia supply water intermittently (WHO and UNICEF, 2000; van den Berg and Danilenko, 2011).

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Previous studies have found evidence of impaired water quality at consumer taps in intermittently supplied systems (Raman et al., 1978; Tokajian and Hashwa, 2003; Ayoub and Malaeb, 2006; Yassin et al., 2006; Andey and Kelkar, 2007; Elala et al., 2011). When pipes are at low pressure or are empty when supply is off, contaminants from outside of pipes can enter pipes by backflow or intrusion. Additionally, intermittent delivery of water necessitates household collection and storage, a practice associated with recontamination (Wright et al., 2004; Levy et al., 2008; Elala et al., 2011; Eshcol et al., 2009).

No major city in India has continuous water supply (McKenzie and Ray, 2009), though several cities in India have implemented pilot projects or developed proposals to switch from intermittent to continuous supply (World Bank, 2010, 2003; McIntosh and Yiguez, 1997). Improved water quality is often mentioned as a benefit of upgrading an IWS to a continuous supply, but only one study has compared water quality between intermittent and continuous modes of operation, and its conclusions were limited by a small sample size (Andey and Kelkar, 2007). Because the costs of upgrading to continuous supply may be significant, it is important to provide quantitative evidence of whether the expected water quality benefits are actually achieved to aid decision-makers in identifying cost-effective strategies to upgrade intermittent supplies.

This research compares water quality at reservoirs, taps, and in drinking water in homes in intermittent and continuously operated distribution systems in the same cities in India. The results are useful for understanding the benefits of upgrading an intermittent to a continuous supply and can help inform investments to increase access to safe water through piped distribution systems.

2. Background

2.1. Study site

Hubli and Dharwad are twin cities with a combined population of over 900,000 in northern Karnataka, India (Registrar General of India, 2011). The bulk water supplies and distribution networks are managed by the Karnataka Urban Water Supply and Drainage Board (KUWS & DB) (Fig. 1). Surface water is drawn from two sources: the Renukasagar Reservoir, fed by the Malaprabha River and located 65 km northeast of Dharwad, and the rain-fed Neersagar lake located 20 km southwest of Hubli. The Amminbhavi and Kanvihonnapur water treatment plants (WTP) treat the water using aeration, coagulation and flocculation with alum, clarification, rapid sand filtration, and chlorination with Cl_2 gas. Treated water intended for drinking and domestic purposes is delivered via transmission/feeder mains (pumping or gravity) to service reservoirs and then to consumers through the distribution network pipes. Pipes are primarily cast iron mains and PVC service lines, with newer service lines made from HDPE. Additional chlorine is added sporadically at service reservoirs. During the time of the study, water was provided intermittently every one to eight days with a median frequency of five days. Consumers also commonly supplemented their water supply with groundwater from handpumps, electric borewells, tanker trucks, and neighborhood-scale piped groundwater systems. Wastewater infrastructure consisted of a combination of underground sewer networks (which cover 40% of Hubli's area and 30% of Dharwad's area), open drains, septic tanks, and pit latrines (Wilbur Smith Associates Private Limited, 2009).

2.2. Demonstration 24 × 7 supply

The Karnataka Urban Water Sector Improvement Project (KUWASIP) has provided approximately 81,000 consumers with continuous water supply ("24 × 7" supply) through a demonstration project in Hubli and Dharwad since 2007 and 2008, respectively (World Bank, 2010, 2004). Four wards in each of Hubli and Dharwad have 24 × 7 supply while the remaining 59 wards continue to receive water intermittently. Wards were selected by KUWASIP for 24 × 7 supply based on 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).

The KUWS&DB provided bulk water from the Amminbhavi WTP to two reservoirs dedicated to supplying the 24 × 7 demonstration wards, one each in Hubli and Dharwad (Fig. 1). In the 24 × 7 areas, a private contractor operated and maintained the distribution networks that pipe water from the outlets of the service reservoirs to customers' property lines; all of the pipes in these networks were replaced before launching 24 × 7 supply, with higher quality service line materials (high density polyethylene (HDPE)) and meters than those that existed in the intermittently supply network (World Bank, 2010). The results from a sanitary survey conducted along with our water sampling confirmed that infrastructure improvements in house service connections had accompanied the transition to 24 × 7 supply. Among households with IWS, 80% had taps located above ground and 34% had taps located indoors, while among households with 24 × 7 households, 99% of taps were above ground level and 43% were indoors. Only infrastructure relating to the water supply pipe network was improved as part of the 24 × 7 demonstration project; no changes were made to existing wastewater or drainage systems. In the household survey conducted as part of this study, 91% of households in 24 × 7 areas ($n = 1794$) and 92% in IWS areas ($n = 1666$) reported using private latrines and 6% of households in 24 × 7 and 4% in IWS areas reported using public latrines.

2.3. Comparison of intermittent and 24 × 7 supply

Leaks in distribution network pipes and poor quality materials and fittings in consumer service connections can allow contamination to enter a distribution system as intrusion when pipes are at low pressure. In the 24 × 7 network in 2011, an estimated 7–20% of the input water supply is lost through leaks, a rate similar to industrialized countries where these losses average 12% (Kingdom et al., 2006). Water loss estimates in the IWS network were not available, but non-revenue water in Indian cities averages 44% (World Bank, 2010) and 60% of water losses in developing countries are estimated to be physical losses (Kingdom et al., 2006). Based on the best available data, it appears that low pressure was more prevalent in the IWS network than the 24 × 7 network, with pressures reported to be between 0 and 5 m (0–7 psi) in the IWS network and 22–40 m (31–57 psi) in the 24 × 7 network (World Bank, 2010). Pressures in IWS service lines