A study of the consumption pattern in a continuous water service demonstration zone and bulk water demand forecasting for Hubli-Dharwad, India

K. P. Jayaramu, Zachary Burt and B. Manoj Kumar

ABSTRACT

In the year 2008, the Karnataka Urban Water Sector (KUWS) Improvement Project brought continuous water service (CWS) to a demonstration zone in the twin cities of Hubli-Dharwad, India. Scale-up of CWS for the rest of the city has been authorized and the initial stages of construction are currently in progress. We compared the historical consumption pattern in the CWS demonstration zone of Hubli with system capacity. We found that demand in the demonstration zone has stayed within system capacity and below the national standards for adequate supply. We developed two forecast models of bulk water demand under CWS and compared forecasts with planned future system capacity. In the case of full scale-up of CWS to the rest of Hubli-Dharwad, our forecasts indicate that planned system capacity may be insufficient to meet bulk demand. These forecast models can be adopted by similar mid-sized cities in India.

Key words | continuous water service, intermittent water service, water demand forecast

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INTRODUCTION

According to Froukh (2001), the term 'domestic water demand' is the amount of water required for domestic uses. In this paper, we refer to 'bulk demand' as the volume which includes both water demand plus network losses, meaning the total water supplied to the network. Non-revenue water (NRW) is the difference between the bulk demand and the billed water volume (Hirner & Lambart 2000). In this paper, 'system capacity' refers to the maximum water volume that can be pumped, treated, and distributed by the infrastructure present in Hubli-Dharwad.

Water demand forecasting is essential to water utilities, both for day-to-day operations and for long-term planning. Water demand can be forecast by a number of methods; Donker *et al.* (2014) in their review paper have made a comparison of various methods. These methods include the classified households method (CHM) (also known as unit water demand analysis), multivariate regression (MVR), univariate time series analysis (using an autoregressive integrated moving average or ARIMA model), and others. MVR allows forecasts to be based on the correlation demand has with demographics, weather, and tariffs (Bougadis *et al.* 2005; Polebitski & Palmer 2010). ARIMA models use patterns of past demand to forecast future demand (Shang *et al.* 2006; Caiado 2010).

Recently, the Government of India (GOI) and the Karnataka State Government have supported efforts to switch from intermittent water service (IWS) to continuous water service (CWS). The Karnataka Urban Water Sector Improvement Project is a package of reforms and pilot projects in the water sector. With the assistance of the World Bank, the Karnataka Urban Infrastructure Development and Finance Corporation (KUIDFC) has undertaken CWS pilot projects in three cities in Karnataka: Hubli-Dharwad, Belgaum, and Gulbarga, covering about 10% of the total population in each city (World Bank 2011). The

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CWS pilot project in Hubli was launched in a demonstration zone in January 2008. A private operator was selected for construction and operation of the project through a tendering process and was put under contract with KUIDFC (Government of Karnataka (GOK) 2005). Scale-up of CWS to the remaining areas of Hubli-Dharwad is currently under way.

In this paper, we present a study of the water consumption pattern in the demonstration zone of Hubli. Critics have raised questions regarding the feasibility of the CWS project in Hubli-Dharwad. For example, Sangameswaran *et al*. (2008) voiced skepticism about whether there was sufficient water supply to provide CWS to all of Hubli-Dharwad. Few peer-reviewed papers attempt to quantify the difference in water demand resulting directly from a conversion from IWS to CWS. Charalambous (2011) presented a case study of a town in Cyprus which had faced 8 months of severe drought, resulting in a temporary conversion from CWS to IWS. They observed a drop in consumption of 9% during the period of IWS. Andey & Kelkar (2009) observed that when service switched from IWS to CWS in parts of four other Indian cities, domestic water demand did not increase much where demand was already satisfied under IWS.

IWS delivery frequency in Hubli-Dharwad varies; Sangameswaran *et al*. (2008) reported once in 4–5 days for about 3 hours, while Kumpel & Nelson (2014) reported 5 hours every 6 days. Pressure also varies in IWS areas: the World Bank (2010) reported pressure stayed between 0 and 5 meters (0–7 psi), while Kumpel & Nelson (2014) found average pressure during deliveries to range between 0 and 23 psi. The World Bank (2010) has claimed that converting to CWS reduces the 'burden on water resources', by reducing the number of 'overflowing storage systems and open taps' as well as the amount of water 'discarded when new supply comes in'. Our paper does not measure the change in demand due to conversion from IWS to CWS, but it does address the concern raised about the feasibility of CWS. We present the average water demand per person and compare this with the design capacity for the demonstration zone. We also present three different demand forecasting models and compare them with planned future system capacity up to the year 2021. We then discuss implications for full scale-up of CWS to the rest of the city.

METHODOLOGY

Study location

This study was located in the city of Hubli, part of the Hubli-Dharwad Municipal Corporation (HDMC). Hubli-Dharwad has a combined population of 943,185 (Government of India 2011), making it the second largest urban conglomeration in Karnataka. Hubli-Dharwad is divided into 69 administrative areas designated as 'wards' and covers an area of 202.28 km^2. The study area, covering 3.29 km^2, is shown in Figure 1 and comprises two full wards (27 and 28) and portions of two other wards (29 and 32). It includes a mix of low-, middle-, and high-income households.

Data collection

Two and a half years before the commencement of CWS in the demonstration zone, an assessment of bulk demand was made, before any pipe replacement associated with the pilot project had begun. Bulk flow was measured on all five feeder mains using a portable bulk flow meter in October 2005 for one supply cycle (lasting 3 days) (see Table 1).

A ground level service tank near Nrupathunga-Betta, an area elevated above the demonstration zone, is used to supply continuous bulk water to the CWS areas. The capacity of this tank is 2.72 million liters (Ml). An electromagnetic flow meter measured bulk demand at the outlet of the demonstration zone tank and logged flow every 10 minutes. We took billed water volumes and the number of connections from the private operator's monthly reports for the period July 2008 to June 2012.

For air temperature, we used the monthly mean of the daily highest temperature. Weather data were obtained from the Indian Meteorological Department and Dharwad District Statistical Department. Quarterly national GDP estimates were obtained from the National Informatics Centre, (National Informatics Centre (NIC) 2013) and are in constant FY2004–2005 prices.

Bulk demand forecasting

Forecasting methods used in this paper include: (1) CHM; (2) MVR; and (3) ARIMA time series analysis. We estimated

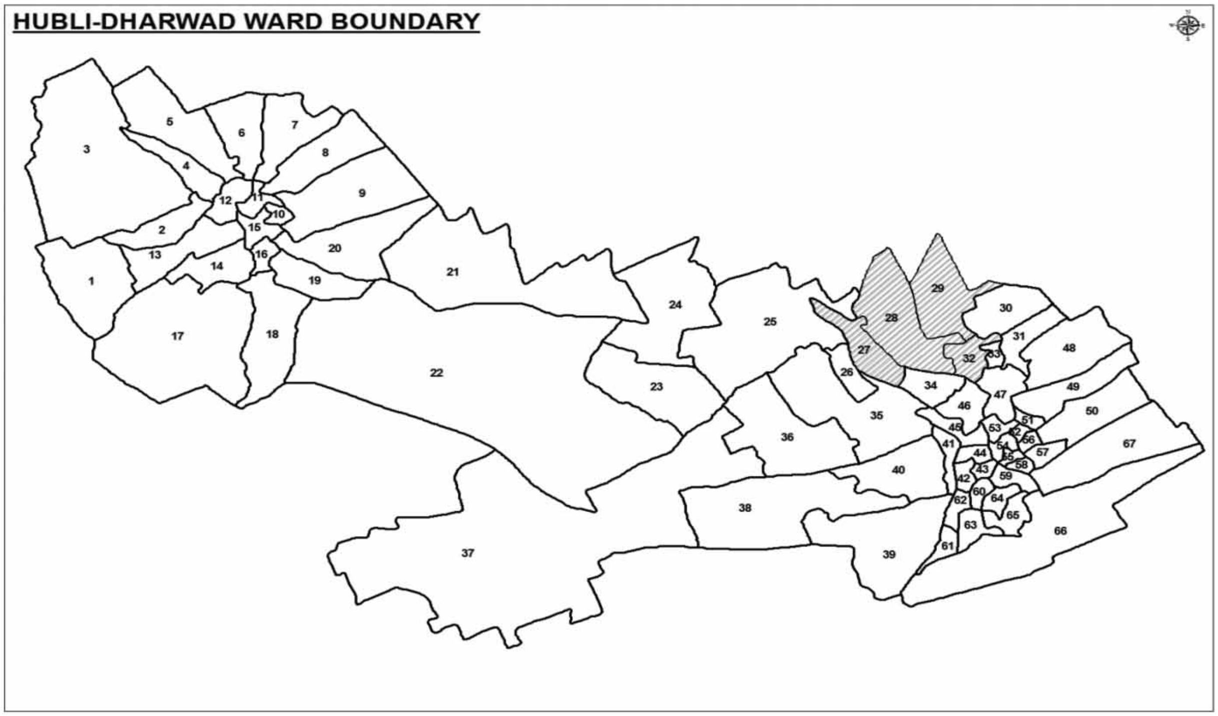

Figure 1 | Location of the CWS demonstration zone in Hubli-Dharwad.

Table 1 | Bulk demand in the Hubli demonstration zone under IWS

Areas in demo zone	Average discharge (l/s)	Supply duration (hrs)[a]	Estimated bulk demand (Ml/d)
Gopanakoppa	32.5	48	5.62
Shanti Colony	16.6	10	0.60
Visweswara Nagar	190	12	8.21
Shiradinagar	16.6	12	0.72
Shakti Colony	16.6	9	0.54
Total for 3-day supply cycle (Ml/d)			15.68
Average daily bulk demand (Ml/d)			5.23
Population in 2005			33,000
Forecast water demand (CHM) (Ml/d)			5.02
Bulk demand per capita (LPCD)			158
Annual bulk demand per connection[b] (Kl/Connection)			354

[a]The supply duration is the number of hours that water was flowing during the 3-day supply cycle in which measurements were taken.
[b]Estimated using bulk demand measured over one 3-day supply cycle, assuming a ratio of 6.13 people per connection.

the models using data from August 2008 to December 2011. Analyses were done using the open source statistical program R (R Core Team 2012).

For the CHM model, we used the current national standard for per capita water supply. The national standard was issued by the Ministry of Urban Development and can be found in the 1999 Central Public Health Environmental Engineering Organization (CPHEEO 1999) Manual: 135 liters per capita per day (LPCD) for domestic usage plus an additional 15% for unaccounted-for water. This total was then reduced proportionately for the number of non-domestic connections in the demonstration zone (3% of connections, for which the standard demand is 40 LPCD), bringing the total for average bulk demand to 152 LPCD.

We converted this to demand per connection by calculating the average number of people per connection in the demonstration zone (6.13 persons per connection) and assuming this ratio held for the rest of Hubli-Dharwad after scale-up of CWS. Although a rough estimate, a better forecast was not available. We multiplied the CHM estimate for LPCD by 6.13 and by the number of days in a given year then divided by 1,000 liters per kiloliter to give the forecasted annual bulk demand in kiloliters per connection (kl/connection).

The independent variables used for the MVR estimation in this paper were monthly air temperature and national quarterly gross domestic product (GDP), while the dependent variable was monthly bulk water demand per connection. The standard MVR formula was used to estimate the model:

$$y(t) = \beta_o + \beta_1 x_1(t) + \ldots + \beta_j x_j(t) + \varepsilon(t) \tag{1}$$

where y is the dependent variable, $x_1(t) \ldots x_j(t)$ are the independent variables, $\beta_1 \ldots \beta_j$ are the correlation coefficients, and $\varepsilon(t)$ is the estimated error. MVR forecasts were estimated on a bulk demand per connection basis.

ARIMA models project past consumption patterns into the future and are often used for short-term forecasts (Box & Jenkins 1976; Kirchgässner *et al.* 2012). They sometimes produce more accurate forecasts than MVR models (Bougadis *et al.* 2005). The first step in estimating the parameters of an ARIMA model is to determine if the function is stationary. This can be done visually and corroborated by plotting the autocorrelation function (ACF). The ACF formula is (Box & Jenkins 1976):

$$\rho_k = \frac{\sum (x(t))(x(t+k)) - (1/(n-k)) \sum x(t) \sum x(t+k)}{\left[\sum x^2(t) - (1/(n-k))(\sum x(t))^2\right]^{1/2} \left[\sum x^2(t+k) - (1/n-k)(\sum (t+k))^2\right]^{1/2}} \tag{2}$$

where x is the variable, t is time, n is the total number of observations (the maximum value of t), k is the series of all positive integers less than n, and all summations are carried out from $t = 1$ to $t = n - k$.

If the peaks of the ACF do not quickly decay to zero, then the function is non-stationary. Non-stationarity can often be corrected by differencing. A standard ARIMA (p,*1*,q) model is of the form:

$$D_t^1 = \sum_{j=1}^{p} \alpha_j \left(D_{t-j}^1\right) - \sum_{j=1}^{q} \theta_j (\varepsilon_{t-j}) + \varepsilon_t \tag{3}$$

where t indexes time, p is the number of autoregressive parameters (α_1, $\alpha_2 \ldots \alpha_p$), and q is the number of moving-average parameters (θ_1, $\theta_2, \ldots \theta_q$). Both p and q are positive integers that are empirically determined through model estimation, and vary based on the patterns existing in the underlying data. The ε_t is the uncorrelated normal random variable (also referred to as white noise) with a mean of zero and constant variance, at time t. D_t^1 is demand, which has been differenced once, at time t. In this analysis, a seasonal multiplier has also been tested (Box & Jenkins 1976). After stationarity is achieved, then the ACF and the partial ACF (PACF) are plotted again in order to determine the likely order of the autoregressive and moving average components, and each model tested is judged by its Akaike information criteria (AIC):

$$\text{AIC} = n^* \ln (\hat{\sigma}^2) + 2(p+q) \tag{4}$$

where n has the same definition as in Equation (2), p and q have the same definitions as in Equation (3), and $\hat{\sigma}^2$ is the maximum likelihood estimation of residual variance. The model with the lowest AIC is determined to have the best statistical fit, and is used in the subsequent demand forecasting (Akaike 1974). ARIMA forecasts were estimated on a bulk demand per connection basis, assuming full scale-up of CWS water to the rest of Hubli-Dharwad.

Estimating system capacity per connection

To compare average system capacity with the forecasts of the MVR and ARIMA models, we converted the total planned system capacity into average capacity per connection. We did this by estimating the average annual population growth rate for Hubli-Dharwad between 2001 and 2011, and then projecting the population into the future, assuming constant growth. We divided total system capacity by the annual population forecast, and multiplied it by our estimated ratio of people per connection (6.13).

Model evaluation

The CHM, MVR, and ARIMA models were evaluated using 2012 data, according to two methods outlined by Donker *et al.* (2014); the average absolute relative error (AARE) and the maximum absolute relative error (MARE). The AARE and the MARE are defined by the following formulas:

$$\text{AARE} = \frac{1}{N}\sum_{t=1}^{N}\left|\frac{x_{\text{obs}}(t) - x_{\text{pred}}(t)}{x_{\text{obs}}(t)}\right| \quad (5)$$

$$\text{MARE} = \max\left\{\sum_{t=1}^{N}\left|\frac{x_{\text{obs}}(t) - x_{\text{pred}}(t)}{x_{\text{obs}}(t)}\right|\right\} \quad (6)$$

where x_{obs} are the observed data and x_{pred} are the model predictions, t is time and in this case $N = 12$.

RESULTS AND DISCUSSION

Past bulk demand and the CPHEEO standard in the Hubli demonstration zone

For comparison purposes only, we present the bulk demand measured in the study area during a single, 3-day IWS delivery cycle, before CWS was implemented (Table 1). A larger data set over a longer time horizon is necessary in order to draw any definitive conclusions about the change in demand that can be attributed to the switch from IWS to CWS. Unfortunately, such a data set is not available.

In Table 2, we present the estimated population, forecast bulk demand (using the CHM method), actual water demand, and NRW from July 2008 to June 2012. The CHM forecast varies from a minimum of 6.93 Ml/d in the third quarter of 2008 to a maximum of 7.84 Ml/d in the second quarter of 2012. The actual bulk demand ranged between 5.33 and 7.63 Ml/d. Compared to the forecast bulk demand, the actual bulk demand was 23.1% lower in the first quarter of CWS. However, that margin was reduced to 2.7% over the next 4 years (see Table 2). The NRW in the demonstration zone varied from a minimum of 9.6% to a maximum of 19.7% with

Table 2 | Bulk demand and NRW

Period	Population	Forecast bulk demand (Ml/d)	Actual bulk demand (Ml/d)	Billed water (Ml/d)	Bulk water saving (%)	NRW (%)
July 8–October 8	44,700	6.93	5.33	4.28	23.1	19.7
November 8–February 9	45,200	7.01	5.52	4.64	21.2	15.9
March 9–June 9	45,700	7.08	5.85	5.13	17.4	12.3
July 9–October 9	46,100	7.15	5.57	4.87	22.0	12.6
November 9–February 10	46,400	7.19	5.83	4.99	18.9	14.4
March 10–June 10	46,600	7.22	6.44	5.58	10.8	13.4
July 10–October 10	47,000	7.29	6.12	5.28	16.0	13.7
November 10–February 11	47,500	7.36	6.15	5.56	16.5	9.6
March 11–June 11	48,700	7.55	6.98	5.97	7.5	14.5
July 11–October 11	49,500	7.67	6.68	5.65	12.9	15.4
November 11–February 12	49,900	7.73	7.12	5.78	7.9	18.8
March 12–June 12	50,600	7.84	7.63	6.39	2.7	16.3
Mean	47,317	7.3	6.3	5.3	14.7	14.7
St. dev.	2,117	0.3	0.7	0.6	6.2	2.8

an average value of 14.7% and a standard deviation of 2.8% (Table 2).

We also calculated per capita demand, by dividing the billed water volume by the estimated population in the demonstration zone. The average per capita demand over the study period was 111 ($\pm\sigma = 8$) LPCD, well below the standard per capita supply rate of 135 LPCD recommended by the CPHEEO manual. In the beginning of the pilot project, per capita demand was well below the CPHEEO standard; however, as the project progressed, there was an increase in per capita demand, approaching the CPHEEO standard (see Figure 2).

Current bulk water supply and planned system capacity for Hubli-Dharwad

Hubli-Dharwad has two main sources of water: the Neersagar dam on the Bedthi river and the Renukasagar dam on the Malaprabha river. In 2003, Hubli-Dharwad faced a severe drought. To address supply scarcity, a new, deeper well was installed at the Renukasagar intake in 2004, increasing system capacity. At the same time, the regional commissioner for Belgaum gained the power to allocate water from Renukasagar to cities and towns in his region, including Hubli-Dharwad. In 2009, the central government of India created the Mahadayi Water Disputes Tribunal to resolve water disputes between Goa and Karnataka (GOI 2009); Hubli-Dharwad would be the largest potential beneficiary of water on the Karnataka side of the border. Decisions from this tribunal are not expected for another 5 to 10 years from now, and the final outcome is, as yet, uncertain.

Owing to the complex system governing local water source investment, and the allocation of developed water resources, a full analysis of future water supply availability, including hydrological, political, and economic considerations, is beyond the scope of this paper. Instead, we compare planned future system capacity with bulk water demand forecasts. Table 3 shows the planned system capacity for 2001–2021.

Modeling bulk water demand

MVR forecast

We used MVR to estimate the correlation between aggregate income levels, weather data, and bulk demand per connection (Table 4). The economic variable was national and therefore a more accurate model might be estimated using data about the local economy instead; unfortunately, such data are unavailable on a quarterly or monthly basis, as far as we know.

We tested the following independent variables: quarterly estimates of national GDP in 10 trillion rupees (GDP), GDP lagged by 1 month (GDP-1), and GDP lagged by 2 months (GDP-2); total rainfall for the month in

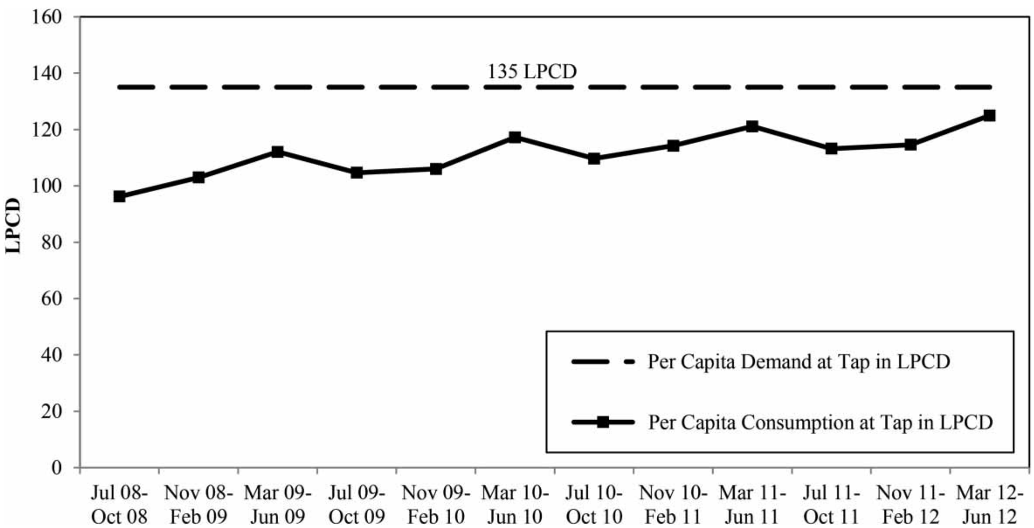

Figure 2 | Variation in per capita consumption.

 Journal of Water, Sanitation and Hygiene for Development | 05.2 | 2015

Table 3 | System capacity in Hubli-Dharwad

	Water sourced from Neersagar (Ml/d)		Water sourced from Malaprabha (Ml/d)			
Years	Current/Planned system capacity	Actual bulk water supply	Current/Planned system capacity	Actual bulk water supply	Current/Planned system capacity (Ml/d)	Total bulk water supply (Ml/d)
2001	40	35	68	45	108	80
2003	40	2[a]	68	53	108	55
2004	40	2[a]	73	73	113	75
2011	40	35	150	150	190	185
2021	40	–	210	–	250	–

[a]Very meager bulk supply was available due to a lack of rain in the Neersagar catchment area.
Source: Karnataka Urban Water Supply & Drainage Board (KUWS&DB).

Table 4 | Descriptive statistics

Variables	Average	SD	Maximum	Minimum
GDP (10 trillion rupees)	1.25	0.12	1.45	1.06
Rain (mm)	64.21	52.93	166.7	0.00
Temperature (°C)	30.36	3.18	37.6	26.0
Demand per connection (kiloliters)	24.25	1.63	27.68	21.82

millimeters (Rain), Rain maximized at 100 mm (Rain100) and Rain maximized at 50 mm (Rain50) (as well as the 1 month lag for Rain, Rain100, and Rain50); and temperature in Celsius (Temp). Quarterly GDP was repeated for each month within a quarter. We regressed each of the independent variables on monthly bulk quantity per connection (Q/C), measured in kiloliters per connection. The estimated coefficients and associated adjusted R^2 are listed in Table 5.

Table 5 | Coefficient of correlation and adjusted R^2 for linear regression

Q/C vs.	β	Adjusted R^2
GDP	6.6021	0.18
GDP-1	8.3785	0.31
GDP-2	10.7353	0.53
Rain	−0.0057	0.01
Rain100	−0.0065	0.00
Rain50	−0.0030	−0.03
Rain-1	−0.0080	0.04
Rain100-1	−0.0111	0.05
Rain50-1	−0.0179	0.03
Temp	0.2213	0.17

In marked contrast to many other water demand forecasting studies, there does not appear to be a significant correlation between precipitation and water consumption. One possible explanation for this is that the keeping of significant lawns and gardens are not common practice within the city limits. Temperature and precipitation were also highly correlated. Therefore, only GDP, GDP-1, GDP-2, and Temp were used to estimate models. Of the five best models (based on the adjusted R^2 statistic), coefficients for GDP and GDP-1 had the wrong sign; this left only one model with a high adjusted R^2 and reasonable estimates for coefficients. That model is displayed in Table 6.

ARIMA forecast

Looking at the plot of Q/C over time, it is clear that an upward trend was present, indicating a non-stationary process (see Figure 3). After differencing once, the data appeared to be stationary (see Figure 4). The ACF for Q/C after one differencing has a larger peak at ρ_1 and a smaller

Table 6 | MVR model: Q/C regressed on GDP-2 and Temp

Parameters	Coefficients	*P*-value
Intercept	8.00	(0.00)[a]
GDP-2	9.75	(2.78×10^{-7})[a]
Temp	0.14	(1.33×10^{-2})[b]
Adjusted R^2	0.60	
Observations	39	

[a]Significant at the 0.01 level.
[b]Significant at the 0.05 level.

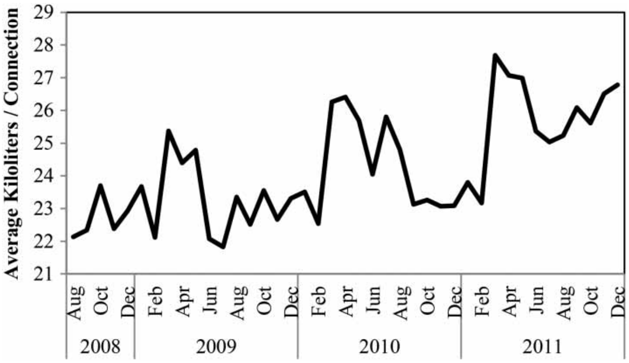

Figure 3 | Non-stationary process: recorded consumption per connection.

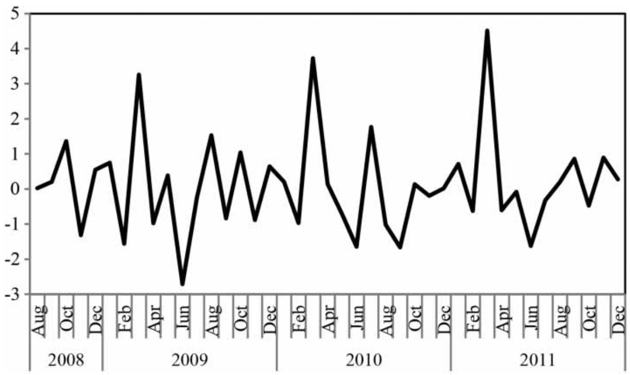

Figure 4 | Stationarity achieved: residuals after a first differencing of recorded consumption per connection.

but significant one at ρ_{12}. The first order of all combinations of the following were tested: an auto regressive (AR (1)) term, seasonal auto regressive (SAR (1)), moving average (MA (1)), seasonal moving average (SMA (1)), and a seasonal differencing of order 12. The five models with the lowest AIC all included a seasonal differencing term and either an SMA (1) or SAR (1) term. The coefficient estimates for these five models along with their respective AIC and Σ^2 estimates are listed in Table 7. The Ljung–Box test statistics for all five models did not allow for the rejection of the null hypothesis of independently distributed residuals.

The $(0,1,1)\times(0,1,1)_{12}$ model happens to have the lowest AIC and the lowest Σ^2 of all the models evaluated. Therefore, this model was used for generating water demand forecasts. Forecasts for bulk demand per connection, along with forecast error, are listed in Table 8.

Forecasting bulk water demand

The forecasts using the MVR and ARIMA methods indicate that bulk demand resulting from scale-up of CWS to the rest of Hubli-Dharwad may outstrip the system's capacity within the first few years of operation. The forecast using the CHM indicates that projected available system capacity is more than sufficient to meet water demand in Hubli-Dharwad after scale-up of CWS. Yet, evaluating the three models using MARE and AARE techniques indicates that the MVR and ARIMA models produce more accurate forecasts. This is concerning; if the system is not able to supply sufficient water to meet demand after scale-up, some sort of rationing or conservation mechanism would be required.

GDP growth is highly uncertain. To account for some of that uncertainty in our MVR forecasts, we estimated three potential water demand paths, assuming three different levels of economic growth. A low, medium, and high estimate for growth has been used when forecasting with the MVR model. The Asian Development Bank (2013) recently downgraded India's GDP growth forecast to 6.0% for the

Table 7 | ARIMA models characterizing Q/C

		Model: $(p,d,q)_1\times(P,D,Q)_{12}$				
Parameter	**Coefficient**	$(0,1,1)\times(0,1,1)_{12}$	$(0,1,0)\times(0,1,1)_{12}$	$(0,1,0)\times(1,1,0)_{12}$	$(0,1,1)\times(1,1,0)_{12}$	$(1,1,0)\times(0,1,1)_{12}$
AR(1)	α_1					−0.25
MA(1)	θ_1	−0.34			−0.31	
SAR(1)	α_{s1}			−0.46	−0.51	
SMA(1)	θ_{s1}	−0.80	−0.55			−0.76
AIC		85.28	85.67	85.90	85.92	85.95
Σ^2		0.7143	0.9333	0.9837	0.8905	0.7600

Table 8 | Comparison of forecasted annual bulk demand with planned system capacity (kiloliters/connection/year)

Year	Actual annual bulk demand (kl/connection) Metered at supply tank	Forecasted annual bulk demand (kl/connection) ARIMA ± (80% CI)	MVR			CHM	Planned system capacity (kl/connection) Planned capacity
2009	280	281		281		346	278
2010	292	293		294		339	273
2011	309	305		306		341	451
			GDP 3% growth	GDP 6% growth	GDP 9% growth		
2012	325	337 ± 25	310	310	310	367	443
2013	–	355 ± 44	315	317	319	348	435
2014	–	372 ± 62	320	327	334	340	427
2015	–	390 ± 81	325	338	351	340	419
2016	–	407 ± 100	330	349	370	341	412
2017	–	425 ± 119	336	361	390	340	404
2018	–	442 ± 139	341	374	412	340	397
2019	–	460 ± 160	347	388	435	340	390
2020	–	477 ± 181	353	402	461	341	382
2021	–	495 ± 202	359	418	490	340	494

near term; therefore, we have taken our low, medium, and high growth estimates to be 3.0, 6.0, and 9.0%. Monte Carlo simulation would have allowed for an estimate of uncertainty in our temperature forecasts, but we did not include this in our analysis in order to make sure our methods might be easily replicated for other Indian water utilities. Projecting temperature as the average for each month, and plugging this and the projected GDPs into the MVR model, gives us a low, medium, and high estimate for water usage for each month of the year. The monthly forecasts were then summed over the course of each year to calculate the annual forecast for the MVR model.

Water consumption had an upward time trend in the demonstration zone. Although there is no reason to believe that this upward trend will stop in the near term, it will not continue indefinitely. Historically, per capita water demand grew along with economic growth in high income countries, but eventually reached a point where it now stays flat during times of economic growth, and has in recent years been reduced in many places due to successful conservation efforts (Gleick 1998). It is impossible to know what level per capita water consumption will reach in Hubli-Dharwad before it no longer grows with increasing incomes. However, Asian countries with higher per capita GDP have experienced this leveling off at consumption levels, which exceed those forecast in this paper. In Osaka, Japan, the per capita domestic water consumption in 2001 was 263 LPCD according to Andrews & Yniguez (2004). For comparison, the highest bulk demand forecast for 2021 that was estimated in this study was 527 kl/connection, which translates to approximately 229 LPCD.

In Table 8, we present annual forecasts of bulk demand per connection, using all three forecasting methods, up until 2021, and compare them with the average system capacity per connection. By the start of the pilot project, all houses in the demonstration zone were connected to the piped water system via a private connection. A significant minority of houses, possibly as many as 10% of all households in the IWS areas of Hubli-Dharwad, may not have legitimate connections (Burt & Ray 2014). The planned scale-up of CWS to the rest of Hubli-Dharwad includes supplying all households with a legitimate, private connection. This implies that the ratio of people per connection for the city overall is currently higher than the ratio found in the demonstration zone. Therefore, our forecasts should not be used to infer information regarding the adequacy of system capacity if scale-up of CWS to the rest of Hubli-Dharwad does not occur.

This was a relatively small data set, and we expect precision to increase as more data are incorporated into these models and they are re-calibrated. The forecasts are based on demand recorded in the demonstration zone of Hubli and it is possible that this area does not perfectly represent the water usage behaviors of the rest of Hubli-Dharwad. Future studies which are able to take a more representative sample from the entire city may improve forecast model accuracy.

Monthly forecasts using the MVR and ARIMA models were plotted, up to December 2018 and December 2019, respectively. The monthly forecasts for the ARIMA model are displayed in Figure 5, along with 80% probability projections and the average planned system capacity per connection. The monthly forecasts for the MVR model are displayed in Figure 6, including 3, 6, and 9% growth scenarios. Using the ARIMA forecasting method the available system capacity per connection under full scale-up of CWS remained larger than the forecasted bulk demand per connection only through the year 2017; using the MVR method it remained larger through the year 2018.

Model performance

The predicted values are close to the actual values for all three models for 2012 data. Based on both the AARE and the MARE, the ARIMA model and the MVR performed better than the CHM method. However, of the two, ARIMA forecast 2012 data slightly more accurately than the MVR model (Table 9).

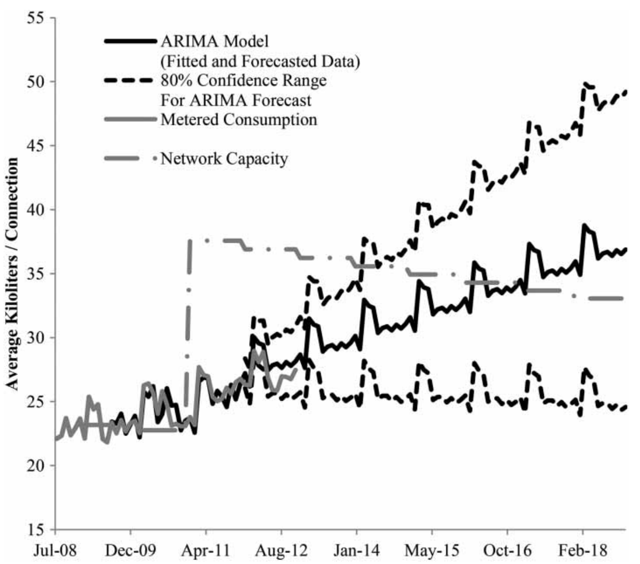

Figure 5 | Monthly forecasts using the ARIMA analysis of bulk demand per connection.

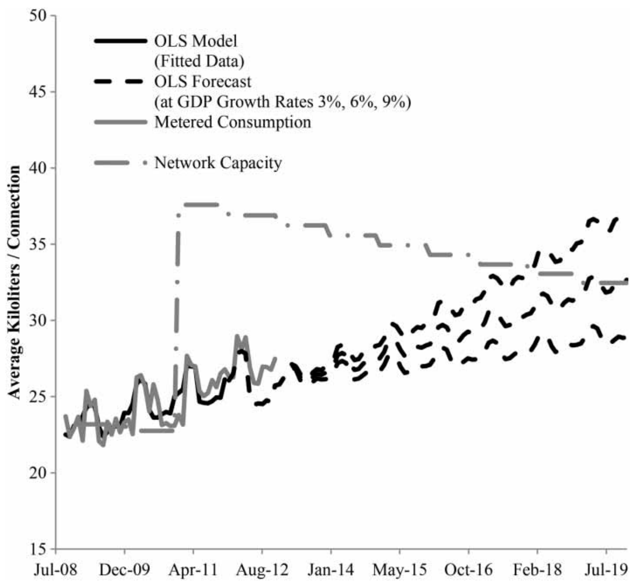

Figure 6 | Monthly forecasts using the MVR model of bulk demand per connection.

As can be seen in Table 8, using CHM (with the CPHEEO standard values of demand) to forecast bulk demand yields forecasts that lie within the planned system capacity. This is a government-issued standard, regularly used by water utilities across India, and so holds considerable weight in the Indian urban water sector. Yet, our forecast models clearly outperformed the CHM method using the MARE and AARE criteria; even by visual inspection, it is clear that the MVR and ARIMA forecasts were closer to actual bulk demand than CHM forecasts (see Table 10). Therefore, we believe that forecasting models using more advanced methods, such as ARIMA or MVR, may be more accurate, and could help utilities in India improve their ability to invest and plan for future demand.

Table 9 | Comparison of AARE and MARE

	ARIMA	MVR	CHM
AARE	0.037862	0.048025	0.129455
MARE	0.08216	0.090124	0.205675

Table 10 | Comparison of metered (actual) bulk demand and forecasted bulk demand for 2012

	Actual monthly demand (kl/connection) Metered at supply tank	Forecasted monthly demand (kl/connection) ARIMA	MVR	CHM
January 12	26	27	26	29
February 12	26	26	26	30
March 12	29	30	28	32
April 12	28	30	28	30
May 12	29	29	28	31
June 12	27	27	25	30
July 12	26	28	24	31
August 12	26	28	25	31
September 12	27	28	25	30
October 12	27	28	25	31
November 12	27	28	25	30
December 12	27	28	26	31
Total	325	337	310	367

CONCLUSION

In this paper, we analyzed the actual consumption pattern in the Hubli demonstration zone. There was a considerable difference, 22.7%, between actual bulk water consumption and average planned system capacity during the start of the project. However, after 4 years, this difference between capacity and demand has decreased to 3.7%. The per capita water consumption at the tap was observed to be increasing over time in the pilot area, a trend that will need to be monitored; thus far it has remained within the design parameters, but it is uncertain whether this will remain true in the future.

Whether currently planned supplies and current planned system capacity are sufficient for scale-up of CWS to the rest of Hubli-Dharwad remains to be seen; the forecasts estimated by the ARIMA and the MVR models indicate that current planned system capacity may need to be expanded. If the system capacity is insufficient to meet bulk demand then some sort of rationing or conservation program would become necessary. Rationing could come in the form of a return to IWS, an increase in the tariffs, both IWS and tariff increases, or some other rationing program. Returning to IWS would have multiple negative repercussions, including customer dissatisfaction, and a potential decrease in willingness-to-pay; customers in Hyderabad were willing to pay Rs 1.92 more per m^3 for an additional hour of supply per day and it is only logical that the reverse should also be true (Echenique & Seshagiri 2009). For these reasons, once CWS is achieved, it is important that it be maintained.

The World Bank claims that conversion to CWS lowers the burden on water resources; empirical data are needed to verify this claim. Unfortunately, we do not have sufficient data on a reasonable comparison group and we therefore cannot determine whether conversion to CWS has contributed to the upward trend in bulk demand, nor if bulk demand is higher than it would have been under IWS. Data presented here from one supply cycle indicate that demand may be lower under CWS (see Table 1).

Improved forecasting methods are crucial to the successful scale-up of CWS to the rest of the city. Based on our results, we recommend that policy-makers consider the following:

1. Further study is warranted, using a larger data set and a more representative sample of households. In particular, a study which is able to quantify the change in demand owing directly to a conversion from IWS to CWS would be useful.
2. Future forecasts should engage more advanced forecasting methods, such as MVR or ARIMA or other modeling techniques, in addition to CHM.
3. Options for expanding system capacity should be explored. If at all possible, rationing should be avoided.

We hope that this analysis might provide new methods and new information to policy-makers, allowing them to better plan for the future water needs in Hubli-Dharwad, as well as other similar urban water utilities throughout India and in developing countries.

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