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Assessing Drinking Water Quality in Karnataka, India: A Comparative Study of Continuous and Intermittent Supply Systems

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ABSTRACT

A comparative assessment of drinking water quality was conducted in the cities of Hubballi-Dharwad, Kalaburagi, and Belagavi, focusing on areas served by continuous and intermittent water supply systems. Water samples were collected from both source and distribution points, including locations where groundwater is delivered by overhead tanks. This analysis was based on selected physico-chemical parameters relevant to potable water standards. In addition to the water samples, household perceptions of water quality were gathered through a primary survey of 4,576 households conducted across the three cities during 2021-22. The survey included questions on access, quantity, costs, and services, alongside perceptions of water quality. The treated water was found to be similar in physico-chemical characteristics, and the variations were likely more linked to the source water (i.e. water resource and treatment) rather than the operation of the piped supply. However, the quality needs to be improved in Kalaburagi City in both CWS and IWS areas. Samples in private and public bore wells showed higher pH levels than those from piped tap connections. Whether the slightly elevated mean concentrations of calcium, magnesium, chloride, fluoride, sulfate, nitrate, and alkalinity observed in a few IWS wards compared to CWS are due to the differences in pipe quality, leakage rates, water pressure, and service efficiency between CWS and IWS, or due to the differences in the source of supply needs to be examined. A further investigation is warranted to confirm this. Based on the analysis of variance (ANOVA) between IWS and CWS, statistically significant differences were found in several physico-chemical parameters of water quality. Total hardness, calcium, magnesium, chloride, fluoride, and nitrates varied significantly ($p < 0.05$), with nitrates showing the most pronounced difference, followed by calcium, magnesium, and chloride. Overall, the water quality supplied under both IWS and CWS being within the permissible limits indicates that the municipal bodies are supplying satisfactory quality water to residents in the majority part of the selected cities.

Keywords: Water Quality; Physico-chemical Parameters; Continuous Water Supply; Intermittent Water Supply**;** Water Distribution Systems

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INTRODUCTION

Water, free of contamination, is essential for human life, the environment, and the development of the economy. Access to clean and potable water improves the quality of life, and its absence results in malnutrition, stress, and the occurrence of preventable diseases. The physical, chemical, and biological characteristics of water determine its quality and its usage for different purposes. The scarcity of potable water necessitates the efficient utilization of available water. Due to contamination of various kinds, water needs to be treated for human consumption by treatment processes that include filtering, chlorination, or several other measures for the removal of dirt, bacteria, detergents, debris, food particles, human/animal waste, algae, etc. Municipal bodies and water utilities across the world, therefore, treat the raw water and provide potable water to their citizens. Despite these efforts, water gets contaminated during distribution and household storage.

Recognizing these challenges, several studies have been conducted by researchers to analyze drinking water quality issues in India. A study by Shivaraju (2012) in Mysuru found that water samples were free from chemical and microbial contamination at their pumping station (i.e., Water Treatment Plant (WTP)), but contamination was detected from household water taps. They found harmful bacteria and other pollutants in many of the samples of drinking water collected from household taps in different areas of Mysuru city. A study on bacterial communities of drinking water supply at water delivery/supply points in Panama in Latin America by Chavarria *et al*. (2023) reveals the presence of several organisms in first flush samples, which were absent after 24 hour of stable supply indicating intrusion and/or growth of microorganisms between supply cycles. And studies by Elala *et al.* (2011) and Eshcol *et al*. (2009) respectively in Nagapur and Hyderabad in India revealed the risks to water quality due to unsafe household storage practices despite the supply of treated piped water. The review by Ayub and Agarwal (2012) indicates continued organic and bacterial contamination in water bodies mainly due to the discharge of untreated domestic wastewater in urban areas of India. A study by Reddy et al. (2022) carried out in Vizianagaram, coastal Andhra Pradesh, assesses the physicochemical and microbiological quality of the water drawn from the reservoir, municipal pipes, and ready to drink bottles. The results indicated that 40% of the water samples had bacterial contamination. A study carried out by Khayum *et al.* (2011) in the Bangalore South Central Zone area, covering 15 samples from houses located within a radius of 5 km, following the standard methods of American Public Health Association, 2005 (APHA) revealed that the concentrations of most of the investigated parameters in the drinking water samples were within the permissible limits of drinking water quality standards and guidelines. The findings show that the water quality supplied by municipal bodies was potable and treated well. However, the sample for this study was too small to generalize on the quality for the entire zone, indicating the inclusion of more samples for a scientific study.

A study by Kumpel and Nelson (2013) conducted in Hubballi-Dharwad, India, compared water quality between intermittent water supply (IWS) and continuous water supply (CWS), with the findings indicating that CWS provided better water quality. The CWS distribution system had fewer samples containing indicators of contamination at consumer taps than the supplies under the IWS system. The bacterial contamination of the tap water drawn from IWS was higher during the rainy season compared to the water samples collected during the summer. Ercumen *et al*. (2015) found intermittently operated piped water systems as a significant transmission mechanism for Salmonella typhi and dysentery-causing pathogens in this urban population of Hubballi-Dharwad, despite centralized water treatment. A review of studies on water contamination in low- and middle-income countries by Bain et al. (2014) reveals that untreated water supplies were more contaminated than the treated piped water supplies.

The studies highlighted that the leakage in distribution network pipes, poor quality materials, and fittings in consumer connections were the reasons allowing contamination in the entire distribution system, leading to poor water quality. This implies that, while several studies in India have highlighted that treated water at the source often meets quality standards at the source, evidence consistently points to contamination risks during distribution, household storage, and uneven water quality across regions. And, there is an absence of comparative analysis of water quality between intermittent and continuous water supply systems between different cities. The water quality may differ due to water being supplied from different sources irrespective of the hours of supply. This highlights the need for a more comprehensive, large-scale assessment of drinking water safety.

RESEARCH CONTEXT

Most cities in India are serviced with intermittent water supply (IWS) rather than continuous water supply (CWS, 24 hours/7 days' service). The transition from IWS to CWS is based on the principle of improvement in the quality of water delivered due to high pressure, leakage proof pipes, and efficiency in services backed by technology. A few wards in Hubballi-Dharwad, Belagavi, and Kalaburagi cities in India were upgraded to CWS services in 2008 through demonstration projects. The demo project for upgrading from IWS to CWS was implemented under the World Bank-funded Karnataka Urban Water Sector Improvement Project (KUWASIP) in Hubballi-Dharwad, Belagavi, and Kalaburagi cities. Eight wards in Hubballi-Dharwad, 10 wards in Belagavi, and 11 wards in Kalaburagi were covered by CWS under this demo project. One of the goals was to improve water quality at the consumer point by the implementation of CWS.

After the success of CWS in pilot areas with observed better quality of water, several areas in Hubballi-Dharwad Municipal Corporation (HDMC) were gradually upgraded to CWS. To assess the impacts of these upgrades on water quality, we collected and tested samples from both consumer taps and public taps in CWS and IWS areas across three cities: Hubballi-Dharwad, Kalaburagi, and Belagavi. While Hubballi-Dharwad included pilot and expanded CWS wards, Belagavi and Kalaburagi had only pilot CWS wards. In all three cities, most households have access to treated piped water. In CWS areas, water supply is managed by a private operator, whereas in IWS areas, it was supplied by the Karnataka Urban Water Supply and Drainage Board (KUWSDB)[1]. While the bulk (raw) water source is the same for both IWS and CWS areas, the distribution networks are different, with variations in the quality of connecting pipes and the operation and management of supply networks. In some locations (i.e. Itigatti and Nuggikere in Ward 18 of Dharwad city), water is provided through public taps or stand posts, requiring households to collect water from such sources. This study examined the physico-chemical and bacteriological quality of water from both CWS and IWS systems, using samples collected from various supply points across the three cities, alongside household-level data on water quality perceptions.

METHODOLOGY

The analysis in this paper is based on two sources of data. First, the information on household perceptions of water quality was drawn from a primary survey of 4,576 households conducted during 2021-2022) in three cities (Hubballi-Dharwad, Kalaburagi, and Belagavi) in Karnataka, an Indian southern state. The objective of the primary survey was to compare continuous water supply (demo zone) with intermittent water supply, based on selected parameters in these cities. Along with questions on access, quantity, costs, and services, the survey captured the perceptions of the household members on water quality. These households are distributed between IWS and CWS wards (Table 1).

Table 1: Type of water supply across selected households

	CWS	IWS	Total
Belagavi	368	647	1015
Hubballi-Dharwad	701	1594	2295
Kalaburagi	439	827	1266
Total	1508	3068	4576

Secondly, water samples were collected at random after the primary survey from some of these households and from public distribution points.

The permission of the residents was obtained to collect water from their household tap in selected areas. 100 ml sterile bottles were used to collect water from the selected household taps for bacteriological indicator tests. Water samples for physico-chemical analysis were collected in clean 500 ml bottles and tested using standard measurements. We collected 2-3 samples randomly from the households in each selected ward: 40 tap water samples from the CWS area (34 from the demo plus 6 from extended wards),

[1] During the survey period (2021-22), CWS areas were maintained by the private operator and the IWS areas were being maintained by Karnataka Urban Water Supply and Drainage Board (KUWSDB). Currently, the entire CWS in three cities (except the supply from Neersagar in Hubballi) is managed by L&T (private operator).

40 samples from the IWS area, one sample from a private open well, 3 samples from private bore wells, 2 samples from public bore wells (tap) in CWS and IWS areas, 4 samples from public bore wells (Mini Water Supply) and 3 raw water samples from the water treatment plant (WTP). During the field visits in Kalaburagi city, the researchers observed that the colour of the water samples was opaque; therefore, three additional water samples from the WTP were collected. Since the surface water from the Bheema River is found to have higher values of TDS, hardness, and nitrate (Yalakpalli, 2012), water samples were collected from households with piped water tap connections, private bore wells, and public bore wells. For other sources, the water samples were drawn in accordance with the availability of the source like open well and bore wells in respective areas. Water samples were collected at the end of the summer season (May, 2022). This resulted in 93 total water samples (Table 2). Since the networking is similar for all the piped water houses, we have restricted the water samples to around 2%, which can be considered as a limitation of the study. Future studies can consider testing based on a larger sample for a better comparison of parameters.

Table 2: Water Samples for Testing of Water Quality

City	Belagavi	Kalaburagi	Hubballi-Dharwad	Total
CWS (24x7)	10	12	12	34
CWS (24x7) P1, P2*	0	0	6	6
CWS Open Well	1	-	0	1
CWS Public Bore well (Tap)	-	1	-	1
IWS	12	12	16	40
IWS Private Bore well (Tap)	0	1	2	3
IWS Public Bore well (Tap)	-	-	1	1
IWS MWS* Bore well (Cistern)	2	1	1	4
WTP (Raw Water)	-	3	-	3
Total	25	30	38	93

*Note: *MWS: Mini Water Supply, P1-P2 (Phase 1 and 2)*

Water quality analysis was performed by ESSAR Laboratories and Research Center in Hubballi, and their instructions for transporting samples to the laboratory in a box within specified hours (6.30 AM to 10 AM) were followed. All the collected samples were tested for physico-chemical and bacteriological parameters as per IS-10500:2012 drinking water standards (Table 3).

Table 3: Parameters for Water Quality

Sl. No.	Physical-Chemical Parameters	Sl. No.	
1.	Colour	9.	Calcium (Ca^{2+})
2.	Odour (Qualitative)	10.	Magnesium (Mg^{2+})
3.	Taste (Qualitative)	11.	Chloride (Cl^{-})
4.	Turbidity	12.	Fluoride (F^{-})
5.	Hydrogen Ion Concentration (pH)	13.	Sulphate (SO_4^{-2})
6.	Electric Conductivity (EC)	14.	Nitrates (NO_3^{-1})
7.	Total Dissolved Solids (TDS)	15.	Iron (Fe)
8.	Total Hardness (TH)	16.	Total Alkalinity
		17.	Total Suspended Solids
	Bacteriological Analysis		
1.	Total Coliform (TC) MPN/100 ml		
2.	Escherichia coli (*E. coli*) MPN/100 ml		

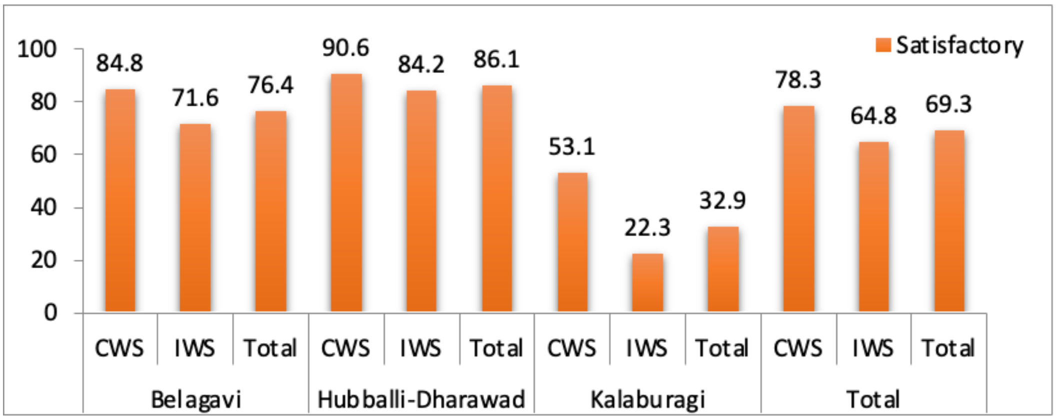
RESULTS AND DISCUSSION

Households' perception of water quality and the results of water samples tested to detect physico-chemical and biological parameters are discussed in this section.

- **Households' Satisfaction with Water Quali**ty

The primary survey of 4,576 households conducted across these three cities revealed that 69.3% of them were satisfied with the quality of water (**Figure 1**). The share of households reporting satisfaction was higher (78.3%) in CWS areas than in IWS (64.8%) areas. The majority of the households with IWS and CWS in Belagavi and Hubballi-Dharwad reported satisfaction with the quality of water supplied during the survey period. However, in Kalaburagi, only 53.1% of households with CWS reported that they were satisfied with water quality, and only 22.3% of households were satisfied with the quality of water in IWS areas. This is because of the green colour of the water and its bad smell. The officials of the City Corporation, KUWSDB, and household members reported that they could easily identify water quality issues by looking at its colour and smell. Some wards frequently received poor-quality water due to sources of water issues (i.e. Bheema River), technical problems, and pipe leakages.

Figure 1: Households' Reporting Satisfaction with Water Quality



- **Physico-Chemical and Bacteriological Parameters**

All the physico-chemical parameters vary from one city to another and also depending on the water source (Table 4). The colour (Hezen), turbidity, and pH were at acceptable levels in Hubballi-Dharwad and Belagavi, but colour and turbidity were identified as elevated in Kalaburagi City.

Two water samples (not shown in Table 4) from CWS areas (Shahabazar Nagar-Ward No. 23 and Dangi Galli- Ward No 33) were detected with high colour values, respectively (8, 12) and both had turbidity of 24 NTU, which was higher than the values observed in IWS areas. As reported by residents and officials, some wards (wards 54, 55, and 57) frequently received green and gray colour water. Residents have frequently staged protests and demonstrations due to water quality issues. When we raised these issues in a dissemination workshop organized by the research team to share the results of the study with different stakeholders, the officers of Kalaburagi Municipal Corporation stated that they were aware of the problem and were trying to resolve it. The qualitative parameters (odour and taste) were at acceptable levels in all cities. Water supply provided in CWS wards showed lower levels of conductivity (EC), total dissolved solids, and total hardness compared to those found in IWS areas; however, the differences were small. Lower values of EC in Belagavi and higher values in Kalaburagi were likely related to the raw water supplied from different sources, but were all within the permissible level. The higher EC in Kalaburagi in IWS areas compared to CWS areas suggests a difference in the quality of water, indicating that conductivity differences are likely due to water coming from different sources and not necessarily due to intermittency. The other parameters, including calcium, magnesium, chlorine, fluoride, sulphate, nitrates, and alkalinity, were higher in IWS wards compared to CWS wards. Iron was notably low or below the detectable limit in all the cities.

Total coliforms or *E. coli,* were not detected in the samples during this study, which may be due to the chlorination of water. Studies (Luvhimbet et al., 2022**,** Kumpel and Nelson, 2013) mention that generally higher bacterial contamination is detected during the wet season (rainy) rather than the dry season. These samples were tested at the end of the dry season (May 2022) when contamination might have been lower, and this could be considered one of the limitations of the study.

Table 4: Water quality results in IWS versus CWS areas in selected cities

Parameters	IS Standard	Belagavi		Hubballi-Dharwad		Kalaburagi		All 3 Cities	
		CWS	**IWS**	**CWS**	**IWS**	**CWS**	**IWS**	**CWS**	**IWS**
Colour (Hazen Units)	5-15	0.2	0.3	0.4	0.3	2.9	1.6	1.1	0.7
Odour	A*	A	A	A	A	A	A	A	A
Taste	A	A	A	A	A	A	A	A	A
Turbidity (NTU)	1-5	0.4	0.5	0.8	0.6	4.6	2.1	1.8	1.0
pH	6.5 - 8.5	7.0	7.0	7.1	7.2	7.2	7.2	7.1	7.1
Electric Conductivity (EC) (µS/cm^2)	--	100.4	105.1	310.3	338.3	457.8	808.5	302.1	409.4
Total Dissolved Solids (TDS) (ppm)	500-2000	60.3	62.9	193.9	202.9	276.2	498.3	185.2	249.5
Total Hardness (TH) (as $CaCO_3$, mg/L)	200-600	41.2	47.3	138.2	137.5	174.0	354.5	124.7	175.6
Calcium (Ca^{2+}) (mg/L)	75-200	11.8	13.5	31.7	38.7	47.6	92.7	31.5	47.3
Magnesium (Mg^{2+}) (mg/L)	30-100	4.9	5.6	13.2	16.2	19.8	38.5	13.1	19.7
Chloride (Cl^-) (mg/L)	250-1000	27.4	27.8	40.0	41.8	55.4	120.4	41.5	61.2
Fluoride (F^-) (mg/L)	1-1.5	0.3	0.3	0.3	0.4	0.4	0.8	0.3	0.5
Sulphate (SO_4^{-2}) (mg/L)	200	4.9	5.8	7.1	9.3	12.4	24.3	8.1	12.8
Nitrates (NO_3^-) (mg/L)	45	3.1	3.2	1.6	3.3	5.2	11.6	3.1	5.8
Iron (Fe) (mg/L)		BDL**	BDL	0.034	0.028	0.081	0.1	0.053	0.058
Alkalinity (as $CaCO_3$, mg/L)	200	29.1	29.3	114.7	119.4	126.3	232.3	96.8	126.3
Total Suspended Solids (mg/L)		BDL	BDL	BDL	BDL	125	60	125	60
Bacteriological Parameters									
Total Coliforms (MPN/ 100mL)		ND***	ND	ND	ND	ND	ND	ND	ND
E. coli (MPN/ 100mL)		ND	ND	ND	ND	ND	ND	ND	ND

Source: *IS-10500:2012 drinking water standards and CMDR survey, 2022*
*Note: *A: Agreeable, **BDL: Below Detectable Level, ***ND: Not Detected*

Table 5: ANOVA Results for Water Quality Parameters (IWS vs CWS)

Parameter	F-Value	Sig. (p)	Significance (p < 0.05)
Total Hardness (TH)	4.49	0.04	Significant
Calcium (Ca++)	6.22	0.02	Significant
Magnesium (Mg++)	6.25	0.02	Significant
Chloride (Cl–)	6.18	0.02	Significant
Fluoride (F–)	4.23	0.04	Significant
Nitrates (NO_3–)	10.80	0.00	Strongly Significant
Electric Conductivity (EC)	3.72	0.06	Borderline (NS)
Total Dissolved Solids	3.55	0.06	Borderline (NS)
Alkalinity	3.48	0.07	Borderline (NS)
Others (Colour, pH, etc.)	2.0	0.05	Not Significant

Table 5 explains the analysis of variance (ANOVA) between IWS and CWS, statistically significant differences were observed in several physico-chemical parameters of water quality. Total hardness, calcium, magnesium, chloride, fluoride, and nitrates showed significant variation ($p < 0.05$), with nitrates exhibiting the strongest difference ($F = 10.798$, $p = 0.002$, $\eta^2 = 0.122$), followed by calcium, magnesium, and chloride ($\eta^2 \approx 0.074$ each). Fluoride ($p = 0.043$) and total hardness ($p = 0.037$) also differed significantly between the two supply systems. In addition, electrical conductivity, total dissolved solids, and alkalinity were close to significance (p values between 0.058 and 0.065), suggesting a trend towards higher levels in IWS compared to CWS. On the other hand, turbidity, pH, iron, total suspended solids, and microbial indicators (total coliforms and E. coli) did not show significant differences, with the latter displaying no variation across groups. Overall, the results highlight that CWS water samples generally had lower mineral loads than IWS samples, indicating that continuous supply systems are associated with better chemical water quality stability, while bacteriological parameters did not differ across supply types.

- **Water Supply by Corporation Tap versus Alternative Water Sources**

Water sources are assumed to be the key components in determining water quality. Improved sources, including piped water, stand posts, bore wells, and protected dug wells, are less likely to be contaminated than unimproved sources like unprotected wells, springs, and surface waters (Bain et al., 2014). In water samples collected from different sources, the average values of all physico-chemical measurements were lower in treated piped water supplies from IWS and CWS areas compared to other water sources like public and private bore wells and public cisterns, except for privately (households') owned open wells (Table 6).

A few households reported public bore well and Mini Water Supply (MWS) stand posts as their source of drinking water. This service is provided by the HDMC in Ward 18 of Hubballi-Dharwad city (Itigatti and Nuggikeri of Dharwad) and in some areas in Kalaburagi. Higher physico-chemical concentrations were found in bore well water sources (private and public) compared to the water at household taps (IWS/CWS) in all three cities. The physico-chemical parameters for colour, turbidity, TDS, and fluoride are given in Annexure I.

Table 6: Corporation tap water versus other drinking water sources in 3 cities –(Mean value)

Parameters	CWS	IWS	Bore well-Public (Tap)	MWS Bore well-Cistern	Open well (*Bhavi*)	Bore well-Private (Tap)
Colour (Hazen Units)	1.1	0.7	1.2	1.0	0.1	3.6
Turbidity (NTU)	1.8	1.0	1.6	2.0	0.4	2.8
pH	7.1	7.1	7.2	7.2	7.1	7.5
Electric Conductivity (EC) ($\mu S/cm^2$)	302	409	1108	750	360	1010
Total Dissolved Solids (TDS) (ppm)	185	250	665	450	216	606
Total Hardness (TH) (as $CaCO_3$, mg/L)	125	176	435	307	122	220
Calcium (Ca^{2+}) (mg/L)	31	47	124	88	35	63
Magnesium (Mg^{2+}) (mg/L)	13	20	52	37	15	26
Chloride (Cl^-) (mg/L)	41	61	168	102	32	174
Fluoride (F^-) (mg/L)	0.3	0.5	1.0	0.7	0.4	0.5
Sulphate (SO_4^{-2}) (mg/L)	8.1	12.8	33.6	22.7	2.0	36.0
Nitrates (NO_3^-) (mg/L)	3.1	5.8	14.8	8.5	2.0	14.0
Alkalinity (as $CaCO_3$, mg/L)	97	126	304	223	32	270

Belagavi: Out of 25 water samples collected in Belagavi City, two were from public tap (MWS), one from an open well, and the remaining (22) from corporation piped water supply (Table 7). The comparison of water in other sources to water from IWS/CWS revealed that all the examined parameters were found to be within the limits set by the Bureau of Indian Standard (BIS). Although, within the permissible limits, conductivity, TDS, total hardness, calcium, magnesium, and chloride were all higher in the alternative water sources than the tap water provided by the corporation, reflecting the water quality of groundwater sources.

Table 7: Corporation tap water versus other drinking water sources in Belagavi (Mean-value)

Parameters	CWS	IWS	MWS Bore well-Public Tap	Open Well (Bhavi)
Colour (HU)	0.2	0.3	1.5	0.1
Turbidity (NTU)	0.4	0.5	2.8	0.4
pH	7.0	7.0	7.2	7.1
Electric Conductivity (EC) (µS/cm^2)	100	105	575	360
Total Dissolved Solids (TDS) (ppm)	60	63	345	216
Total Hardness (TH)(as $CaCO_3$, mg/L)	41	47	232	122
Calcium (Ca^{2+}) (mg/L)	12	14	66	35
Magnesium (Mg^{2+}) (mg/L)	5	6	28	15
Chloride (Cl^-) (mg/L)	27	28	67	32
Fluoride (F^-) (mg/L)	0.3	0.3	0.5	0.4
Sulphate (SO_4^{-2}) (mg/L)	4.9	5.8	17.0	2.0
Nitrates (NO_3^-) (mg/L)	3.1	3.2	7.3	2.0
Alkalinity (as $CaCO_3$, mg/L)	29	29	196	32

Hubballi- Dharwad: Water samples were collected from bore wells (private and public) used by households for drinking water in Hubballi Dharwad city. Measurements of EC, TDS, TH, calcium, magnesium, chloride, fluoride, sulphate, nitrates, and alkalinity were higher in IWS and CWS areas than in other water sources (Table 8) reflective of expected differences in groundwater (from bore wells) compared to surface water (supplied in CWS and IWS areas). However, all values were within the permissible levels.

Table 8: Corporation tap water versus other drinking water sources in Hubballi-Dharwad – (mean value)

Parameters	CWS	IWS	Bore well-Corporation	MWS Bore well-Tap	Own Bore well-Tap
Colour (HU)	0.4	0.3	0.4	0.2	0.2
Turbidity (NTU)	0.8	0.6	0.6	0.5	0.5
pH	7.1	7.2	7.3	7.1	7.3
Electric Conductivity (EC) (µS/cm^2)	310	338	973	1100	800.0
Total Dissolved Solids (TDS) (ppm)	194	203	584	660	480.0
Total Hardness (TH) (as $CaCO_3$, mg/L)	138	138	421	456	432.0
Calcium (Ca^{2+}) (mg/L)	32	39	120	130	123.4
Magnesium (Mg^{2+}) (mg/L)	13	16	50	54	51.4
Chloride (Cl^-) (mg/L)	40	42	148	174	114.0
Fluoride (F^-) (mg/L)	0.3	0.4	0.9	1.0	0.9
Sulphate (SO_4^{-2}) (mg/L)	7.1	9.3	30.7	34.0	26.0
Nitrates (NO_3^-) (mg/L)	1.6	3.3	14.0	11.0	18.0
Alkalinity (as $CaCO_3$, mg/L)	115	119	281	278	238.0

Kalaburagi: The majority of the households were not satisfied with the quality of water in Kalaburagi city, and water samples tested for the parameters given in Table 3 showed higher values for some of the parameters compared to the values in the other two cities (Belagavi and Hubballi-Dharwad). Kalaburagi district is known for having high fluoride (Choudhary and Naik, 2017; Majagi et al., 2008), due to the geological strata. Earlier studies (Vijay Kumar et al., 2005; Yalakpalli, 2012) in Kalaburgi city revealed that water sources in the city were heavily contaminated, including Bheema River water (The Times of India (2015) with higher values of TDS, hardness, and nitrate. Bennetoora, Bheema, and Bhosga WTPs are the main water sources of the city. Bheema WTP (Table 9) has higher values of the parameters measured compared to the other two water sources and piped water at the tap. Notably, the turbidity was higher at the treatment plant, with the measured 12 NTU at the Bheema River WTP far above recommended values internationally. While physico-chemical parameters were within the permissible limits in both public and private bore well samples, the values were higher than those for surface water sources. Colour and turbidity mean values of CWS were higher in 2 water samples (Shahabazar Nagar-ward 23 and Dangi Galli-ward 33), which showed high values for colour (actual value 8, 12) and turbidity (actual value 24).

Table 9: Corporation tap water versus other drinking water sources in Kalaburagi –(mean value)

Parameters	CWS	IWS	Bore well-Public	Own Bore well-Tap	RWS*-Bennithora WTP	RWS-Bheema River WTP	RWS-Bhosga WTP
Colour (HU)	2.9	1.6	2.4	3.6	4.9	9.0	4.0
Turbidity (NTU)	4.6	2.1	3.0	2.8	6.6	12.0	5.0
pH	7.2	7.2	7.2	7.5	6.9	7.1	6.9
Electric Conductivity (EC) (µS/cm^2)	458	809	1310	1010	350	712	320
Total Dissolved Solids (TDS) (ppm)	276	498	786	606	228	463	208
Total Hardness (TH) (as $CaCO_3$, mg/L)	174	355	456	220	196	390	188
Calcium (Ca^{2+}) (mg/L)	48	93	130	63	44	87	42
Magnesium (Mg^{2+}) (mg/L)	20	39	54	26	18	36	17
Chloride (Cl^-) (mg/L)	55	120	197	174	40	118	36
Fluoride (F^-) (mg/L)	0.4	0.8	1.0	0.5	0.5	1.1	0.4
Sulphate (SO_4^{-2}) (mg/L)	12	24	38	36	8	36	6
Nitrates (NO_3^-) (mg/L)	5	12	16	14	3	14	2
Alkalinity (as $CaCO_3$, mg/L)	126	232	338	270	136	180	118

Note: * RWS= Raw Water Supply

CONCLUSION

Overall, measured values of turbidity, colour, and pH were generally similar in samples from CWS wards and IWS wards. While IWS areas had old GI pipes, there was laying of new high-density polyethylene (HDPE) pipes in CWS areas resulting in lower leakage rates, quick identification of leakage through new technology, and targeted implementation of 24 x7 focusing on demo zones. However, the treated water being similar in physico-chemical characteristics between CWS and IWS indicates its likely linkage to the source water rather than the operation of the piped supply. In Kalaburagi, Bheema River water has issues of high turbidity at the outflow of the treatment plant compared to other water sources like Bhosga and Bennithora. This river belt has been reported to have higher hardness, turbidity, TDS, and colour values. The old pipelines with small cracks and leakages were also the reasons for poor water quality.

All samples from groundwater (bore wells) revealed hard water (>180 as $CaCO_3$ mg/L) content, while moderately hard water was found in some cases of surface water (>60 as $CaCO_3$ mg/L). Overall, the water quality was found to be satisfactory in CWS and IWS areas of two cities (Belagavi and Hubballi-Dharwad), but needs to be improved in Kalaburagi City in both CWS and IWS areas. Water sources from bore wells (private and public) had higher pH levels than the piped water tap connections. The analysis of variance (ANOVA) between IWS and CWS water samples highlights that the CWS water samples generally had lower mineral loads than IWS samples, indicating that comparatively continuous supply systems were associated with better chemical water quality stability, while bacteriological parameters did not differ across both the supply types. However, as per the measured parameters, the water supplied under both IWS and CWS is potable, and none of the parameters are above the permissible limit, indicating that the municipal bodies are supplying acceptable quality water (within permissible limit) to residents in the majority of the selected cities. But, the differences in bacteriological parameters and the higher presence of typhi and dysentery-causing pathogens in IWS areas, as indicated by some studies in the region, call for large- scale studies including rainy season to validate the findings as the justification for CWS over IWS in the light of public health. In conclusion it can be said that while water quality may not be a major issue in most of the cities being served with IWS, the demand for CWS can be justified on the grounds of convenience, comfort, savings in collection time, the reduced need for storage, and overall wellness.

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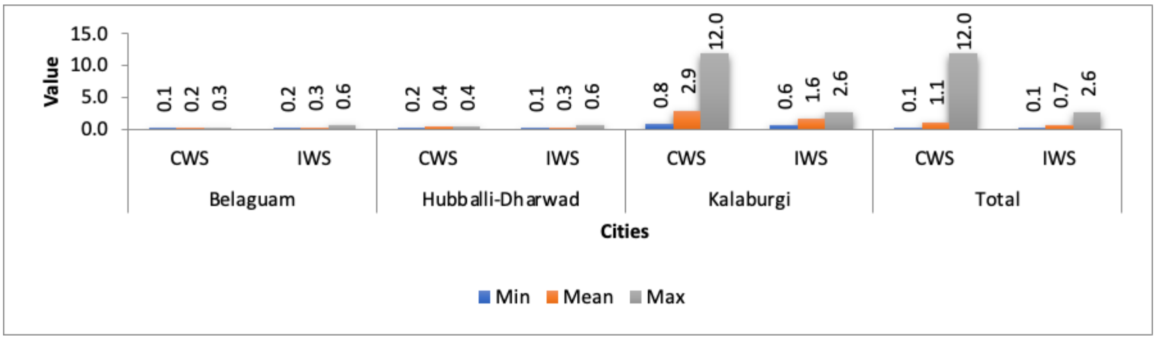
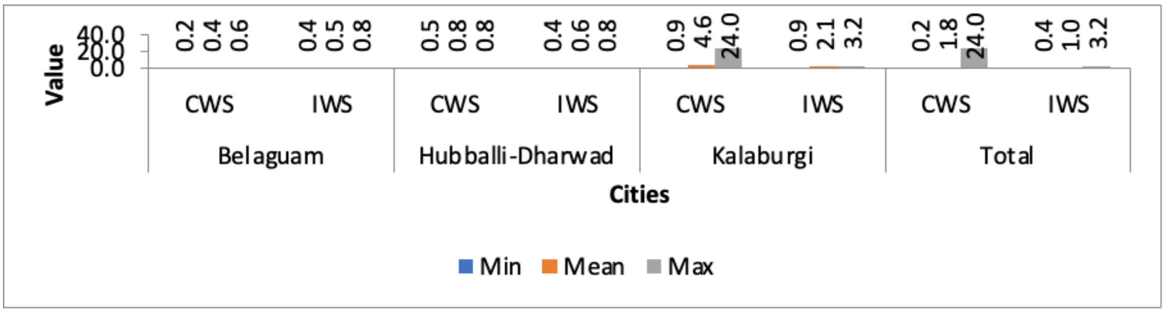
Annexure I (Figures)

Comparison of physico-chemical parameters in CWS and IWS at consumer taps

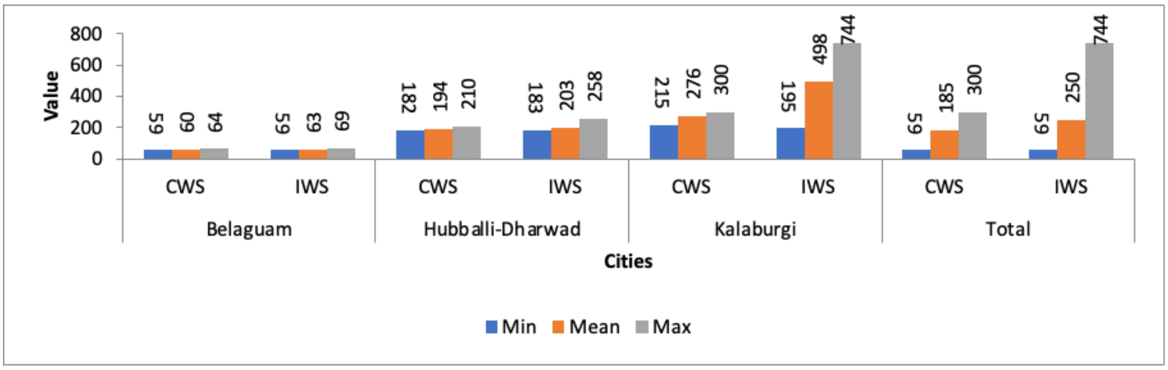
1. **Colour (HU)**



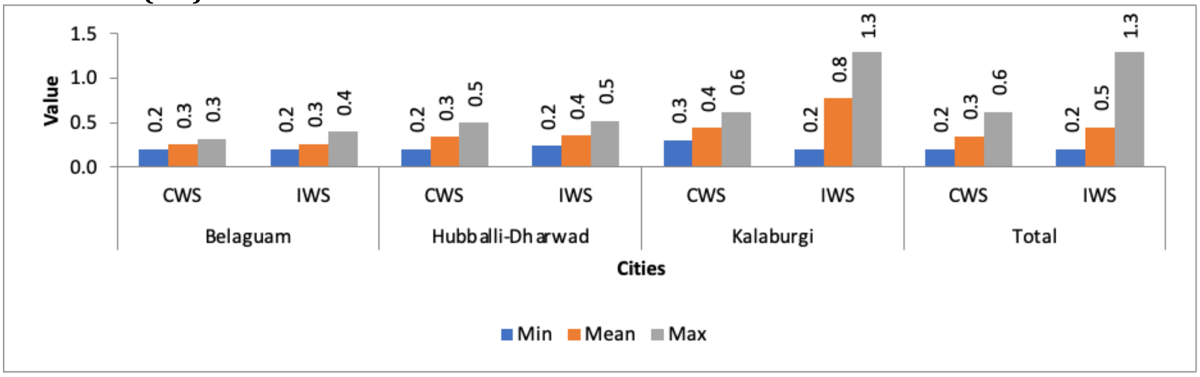
2.Turbidity (NTU)



3. Total Dissolved Solids (TDS)



4. Fluoride (F-1)



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