Change in drinking water quality from catchment to consumers: a case study

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Abstract The study was conducted on the status of water supply at Indore through SDWQ. The performance of the Narmada and Devdharan WTPs was assessed from catchment to consumer for consecutive 7 days during three seasons. No significant change in raw water quality was observed on day-to-day basis. During monsoon, the turbidity of raw water was 690–1530 NTU which was reduced to 0.3–3.7 NTU after treatment. TC and FC were not detected in filtered water. The treated water quality was found within CPHEEO guidelines. At ESR, the residual chlorine was 0.1–0.6 mg/l. During winter, the water from ESR and from consumer ends was free from FC, whereas TC counts at consumer ends were 7–607 CFU/100 ml. During summer, on one occasion, TC and FC counts were found in ESR, whereas at the consumer ends, most of the samples were positive for TC and FC. The variation in bacterial counts amongst the different service reservoirs and consumer ends was due to poor maintenance of ESRs and enroute contamination. The proper maintenance of the distribution network, awareness about the hygienic and sanitary conditions around the public taps and proper storage of water are prerequisites in maintaining safe water supply in the city.

Keywords Surveillance of drinking water quality (SDWQ) · Water treatment plant (WTP) · Total coliforms (TC) · Fecal coliforms (FC) · Colony-forming units (CFU) · Permissible limit

Introduction

Drinking water supply and sanitation are critical water uses for human survival, health and prosperity (WHO 2004; Marobhe et al. 2007). Almost 900 million people lack access to an improved water supply and 2.6 billion to basic sanitation (WHO and UNICEF 2010). The adverse impacts on public health from poor water supply have long been recognized in both developing and developed countries and take the form of disease outbreaks (Esrey et al. 1991; Ford 1999; Payment and Hunter 2001). Water supply access in most developing countries is complex compared to those in developed countries (WHO and UNICEF 2010; Howard and Bartram 2005) resulting in change in water quality from treatment plant to the distribution system. Initiatives to manage the safety of water do not only support public health, but often promote socioeconomic development and well-being as well (WHO 2013). In spite of significant achievements in water supply and sanitation coverage, many factors render good-quality water unsafe by the time it reaches the consumer. The main problems related to drinking water quality are associated with the conditions of the water supply network (Lehtola et al. 2004; Karavoltsova et al. 2008; Farooq et al. 2008; Proto et al. 2014), during collection and storage (Andrew et al. 2005), poor operation management and unsatisfactory sanitary practices; so it becomes obligatory to monitor water quality at each stage of delivery (Khadse et al. 2011a, b, c). Water quality management and surveillance practices ensure safe water supply to consumers.

It is essential that the service provider and the consumers shoulder combined responsibility to see that needed programs and policies are taken up to achieve objectives and missions of “providing safe and sufficient water to one and all at minimum cost in terms of optimum utilization of

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available resources, adequate maintenance of existing infrastructures, self sustenance, reduction and loss due to leakage and environmental protections from degradation and pollutions” (WSSP 2004). Surveillance of drinking water quality (SDWQ) is the continuous and vigilant public health assessment and overview of the safety and acceptability of drinking water supplies (WHO 1993). SDWQ at drinking water treatment plant is necessary to avoid risk from chemical and bacteriological pollutants and to assure consumers that drinking water is safe and can be consumed without any risk (Leeuwen 2000). The elements of surveillance include water quality surveillance, study of institutional setup and examination of water for physico-chemical and bacteriological parameters. Analysis of these parameters constitutes a risk to human health, others affect the aesthetic quality of the water supplied and others relate to treatment issues (Ratnayaka et al. 2009). SDWQ programs identify those interventions that will result in improvements in water supply that will be protective of public health (Lloyd and Bartram 1991; Lloyd et al. 1991, WHO 1997; Howard 2002) and should identify those communities where water supply improvements will deliver the greatest health gain (Lloyd et al. 1991). Public health protection aspects of waterworks should ensure that each component of the system, viz. source, treatment, conveying main, storage and distribution, functions without risk of failures.

The SDWQ also involves inspection of site and sanitary condition of installations. The activities of SDWQ include assessment of design, commissioning and O&M of source, treatment, storage and distribution. The sampling and analysis of water from source to distribution are the main components of SDWQ. The water analysis laboratories of water supply agency, financial and manpower structure are in the purview of SDWQ. The SDWQ is to seek the answer to the question—is the water supply agency in a position to give the specified quality of water to total population within reasonable cost? The SDWQ includes all the

activities to seek answer to these questions. It is necessary to ascertain the present status of drinking water quality being supplied in urban areas and to evolve a suitable strategy for future planning for SDWQ. In view of these, in the present paper, the intake water quality of treatment plants, at different treatment stages and at consumer end, was monitored for three different seasons to assess the drinking water quality status of Shimla city which may help in taking appropriate measures for safe drinking water supply to the city.

Study area

Indore city is the commercial capital of Madhya Pradesh in India and lies at latitude 22°44'N and longitude 75°50'E. There are two water treatment plants (WTPs) viz. Narmada and Devdharan, which supply treated water to the city. Public Health Engineering Department (PHED) is responsible for O&M of Narmada WTP, and Municipal Corporation is looking after Devdharan WTP and water distribution network of the city. The capacity details of the WTPs are provided in Table 1. Both the plants follow the conventional method of treatment like addition of coagulant, flash mixing, flocculation, sedimentation, filtration and chlorination. Salient features of WTPs are given in Table 1 and the flow sheets of WTPs are given in Figs. 1 and 2. The cases of gastroenteritis (296), hepatitis (165), diarrhea (9), jaundice (35) and typhoid (9) were reported during the year 2000–2002 in the city. The water-supplying authority takes the preventive measures in a routine manner. No epidemic due to water-born diseases was reported during the recent past.

Methodology

Criteria for selecting sampling locations are envisaged with a view to examine water quality starting from raw water at source to consumers end including all the intermediate

Table 1 Salient features of WTPs

Treatment plant	Location	Raw water source	Distance (km)	Design capacity (MLD)
Narmada WTP, phase I & phase II	Jalud	Narmada river	70	171
Devdharan WTP	Pitru Parbat	Yashwant Sagar Dam	12	54

Fig. 1 Flow diagram of Narmada WTP

Fig. 2 Flow diagram of Devdharan WTP **Table 2** Water quality at WTPs

S. no.	Parameters	Winter				Summer		Monsoon		IS:10500:1991	
		Narmada WTP		Devdharan WTP		Narmada WTP		Narmada WTP		Desirable limit	Permissible limit
		Raw water	Sump water	Raw water	Sump water	Raw water	Sump water	Raw water	Sump water		
1	pH	7.8–8.2	8.1–8.3	7.8–8	7.3–7.4	8.3–8.4	8.2–8.3	7.4–7.6	7.7–7.9	6.5–8.5	No relaxation
2	Temperature (°C)	19–20	19–20	18–20	18–20	29–30	29–30	30–31	–	–	–
3	Turbidity (NTU)	0.6–1.0	0.4–0.7	3–5.2	1.4–2.8	0.7–1.8	0.56–1.3	690–1530	0.3–3.7	5	10
4	Cond. (mS/l)	230–235	240	235	235	242–246	243–246	150–200	155–185	–	–
5	TDS (mg/l)	140	145	135–140	140	146	146–148	90–120	95–115	500	2000
6	T. alk (mg/l)	113–117	117–120	92–97	84–90	136–144	140–148	75–96	70–85	200	600
7	T. hard (mg/l)	104–107	106–110	87–92	87–90	100–104	100–104	78–112	82–104	300	600
8	Ca (mg/l)	26	26–28	21–22	21–22	19–21	19–21	22–30	21–30	75	200
9	Mg (mg/l)	9.5–10.1	9.5–9.9	8.3–8.9	7.8–8.6	10.8–12.7	11.6–13.7	5–10	6–8	30	100
10	Cl (mg/l)	12	12	16	16	12–14	12–16	10	12	250	1000
11	SO ₄ (mg/l)	5	5	12	16–18	6	5–7	12–17	15–20	200	400
12	NO ₃ (mg/l)	2	2–3	3	2	1.7–2.7	1.1–2.9	3–4	3–4	45	100
13	PO ₄ (mg/l)	ND	ND	ND	0.02	ND–0.06	0.5–0.7	ND–0.03	ND	–	–
14	F (mg/l)	0.01	0.01	0.02	0.02	0.17–0.18	0.18	0.2	0.2	1.0	1.5
15	Na (mg/l)	15	15	16–17	17	17	17	6	6	–	–
16	K (mg/l)	1–2	1	5	5	2	2	2	2	–	–
17	DO (mg/l)	8.6–9.1	–	6.2–7.6	–	7.1–7.4	–	7.0–7.2	–	–	–
18	Residual Cl (mg/l)	–	0.4–0.15	–	1.5–2	–	0.2–0.8	–	0.8–2.0	0.2	–
19	TC (CFU/100 ml)	30–73	ND	13–310	ND	ND–60	ND	120–250	ND	Nil	Nil
20	FC (CFU/100 ml)	ND	ND	ND	ND	ND–8	ND	10–140	ND	Nil	Nil

ND not detected; not done

stages of treatment unit, distribution network and consumer ends (from household tap during water supply) (Tables 2, 3). The city has intermittent water supply for 2–4 h daily. To examine the performance of WTPs, the samples of raw, settled, and filtered water were collected during summer, monsoon and winter seasons for 7 consecutive days from Narmada WTP, whereas Devdharan WTP was assessed during winter only due to non-functioning of WTP during summer and monsoon.

The raw water and treated water samples were collected and analysed for physicochemical parameters and bacteriological quality. The settled water was collected from the overflow of the clariflocculator/settling tank of

the WTPs and examined for turbidity and sulphate. The filtered water was collected from the combined channel of the filters after filtration and analysed for turbidity, sulphate, and bacteriological quality. Final treated water after chlorination was collected from the sump of each WTP. To assess the enroute bacteriological contamination in distribution network, water samples were collected from service reservoirs and distribution network for bacteriological analysis. The samples were also collected from consumer end to see the quality of water supplied to the consumer. To monitor the water quality at consumer end, samples from 21 ESR and 21 representative consumer ends were evaluated.

Table 3 Water quality at ESR

S. no.	Sample ID	Location	Winter			Summer			Monsoon		
			Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)	Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)	Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)
1	T-1	Sadar Bazar	Nil-0.2	ND	ND	Nil-0.8	ND	ND	Nil-0.6	ND-12	ND
2	T-2	Subhash Chowk	0.1-0.2	ND-10	ND	Nil-0.4	ND-12	ND	0.2-0.8	ND-12	ND
3	T-3	Gandhi Hall	Traces-0.1	ND-20	ND	Traces-0.4	ND	ND	0.2-0.8	ND-160	ND
4	T-4	Raj Mohalla	Traces-0.2	ND-10	ND	Nil-0.4	ND	ND	Nil-0.4	ND-24	ND
5	T-5	B.S.F. Tank	0.3-1	ND-10	ND	Nil-0.2	ND-80	ND-18	Traces-0.8	ND-36	ND
6	T-6	Yashwant Club	0.1-0.4	ND-20	ND	NWS-0.8	NWS-ND	NWS-ND	Traces-0.4	ND-196	ND-4
7	T-7	Cotton Adda	Traces-0.2	ND-50	ND	Nil-0.6	ND-28	ND-6	Traces-0.8	ND-20	ND
8	T-8	Vijay Nagar	0.1-0.4	ND-50	ND	Nil-0.2	ND-20	ND	Traces-1.5	ND-104	ND-NWS
9	T-9	P.W.D	0.1-0.3	ND	ND	Nil-1	ND-20	ND	Traces-1.5	24-60	ND-NWS
10	T-10	Radio Colony	0.1-0.4	ND-10	ND	Nil-0.5	ND-20	ND	Nil-0.2	8-20	ND-NWS
11	T-11	Khajarana	0.1-0.3	ND-20	ND	NWS-0.2	NWS-ND	NWS-ND	Nil-0.2	80-580	ND-NWS
12	T-12	Ambedkar Nagar	Traces-0.3	ND	ND	NWS-0.8	NWS-ND	NWS-ND	0.2-0.6	ND-12	ND
13	T-13	Gadi Adda	0.1-0.2	ND-20	ND	Nil-0.1	ND	ND	0.5-1	ND-4	ND
14	T-14	Khandwa Road	Nil-0.4	ND	ND	Nil-1.5	ND-16	ND	Traces-1	NWS-8	ND-NWS
15	T-15	Biloali	Nil-0.6	ND	ND	Nil-2	ND-20	ND	0.2-1.5	64-264	ND
16	T-16	Annapura	0.1-0.3	ND	ND	Nil-0.5	ND-8	ND	Traces-1	ND-72	ND
17	T-17	Paganis Paga	0.1-0.9	ND	ND	Traces-0.1	ND-68	ND	0.2-1	ND-12	ND
18	T-18	Narmada Control Room	Traces-0.2	ND-20	ND	Nil-1	ND	ND	Traces-1	12-40	ND
19	T-19	Maharana Pratap Nagar	Traces-Nil	ND	ND	Traces-Nil	ND-20	ND-2	0.2-Nil	ND52	ND
20	T-20	Bajrang Nagar	Nil-0.1	ND-10	ND	Traces-0.6	ND-48	ND-10	Traces-0.8	ND-20	ND
21	T-21	Bhagirathpura	Nil	ND-400	ND	Nil	ND-60	ND-14	Nil-0.1	8-60	ND

TC and FC should not be present in ESR water as per BIS standards
 ND not detected, NWS no water supply

The water quality parameters such as temperature ($^{\circ}\text{C}$), pH, conductivity (EC) and dissolved oxygen (DO) were measured in the field. For other parameters, samples were preserved by adding appropriate reagents. Samples were filtered and stored in plastic bottles and analysed for major cations (Ca, Mg, Na, K) and major anions (SO_4 , Cl, PO_4 , NO_3) as per standard methods (APHA, AWWA, WPCF 1998, 2005). Sodium and potassium were determined by flame photometry. Chloride, total hardness, and total alkalinity were analysed by volumetric methods. Sulphate, nitrate and phosphate were estimated by spectrophotometric technique. Bacteriological tests for total coliform and fecal coliform were undertaken by membrane filter (MF) technique. Knowledge, Attitude and Practice (KAP) survey was conducted which pertains to defined specific and measurable campaign objectives based on the problems identified by the agency. The KAP survey objectives have been achieved separately through a set of questionnaires designed separately for general public, health agencies and managers of water supply agencies. People from different economic and literacy levels comprising various age groups and gender from slum area, civil area, market area were covered during the survey. About 100 people were surveyed for their opinions about drinking water supply in the city.

Results and discussions

Water quality at WTPs

The analytical results for the physicochemical and bacteriological parameters of the water samples collected during three seasons are reported in Tables 2, 3 and 4.

Narmada WTP

During winter, it was observed that phase I and phase II units of the WTP were overloaded to the extent of 20 %. The performances of both the units were satisfactory as the raw water quality was fairly good. Alum/PAC addition was discontinued due to low turbidity of raw water. Bacteriological quality of raw water showed the presence of TC in the range of 30–73 CFU/100 ml, while FC was not detected (Table 2). TC in the filtered water samples of phase I and phase II units was up to 27 CFU/100 ml and up to 113 CFU/100 ml, respectively, and FC was not detected (Table 2).

During summer, the turbidity of raw water was 0.7–1.8 NTU. As the raw water quality was fairly good, Alum/PAC addition was not practised. In raw water, TC and FC were up to 60 CFU/100 ml and up to 8 CFU/100 ml, respectively, (Table 2). TC in the filtered water sample of phase I and phase II units was up to 44 and 16 CFU/100 ml, respectively (Table 2). FC was not detected in the filtered water.

During monsoon, the river was flooding and the turbidity of raw water was 690–1530 NTU. Primary settling tank brought down the turbidity of raw water to some extent. The applied PAC dose was @20 mg/L and supplemented with 0.1 mg/L dose of catflock. Finished water turbidity was 0.3–3.7 NTU. TC and FC in raw water were in the range of 100–250 and 10–140 CFU/100 ml, respectively (Table 2). In filtered water of phase I unit, TC and FC counts were 50–300 CFU/100 ml and up to 80 CFU/100 ml, respectively. In filtered water of phase II unit, TC was up to 20 CFU/100 ml and no FC was observed (Table 2). The treated water quality of the plants during all the seasons was found within the desirable limit as per BIS standards (BIS 1991).

Devdharan WTP

The raw water turbidity during winter was in the range of 3.0–5.2 NTU, whereas the turbidity of settled and filtered water was in the range of 1.2–3 NTU and 2.4–2.8 NTU, respectively. Settled and filtered water turbidity indicated poor settling of the flocks after alum dosing and malfunctioning of filter beds which may be due to improper back washing. The alum dose was not properly regulated, and the overall maintenance of the plant was not satisfactory. In raw water, TC counts were in the range of 13–310 CFU/100 ml and FC was not detected (Table 2). In filtered water, TC was up to 80 CFU/100 ml and FC was not detected (Table 2). The finished water quality was within the desirable limit as per BIS standards. During summer and monsoon, the Devdharan WTP was found closed due to non-availability of raw water in Yashwant Sagar Dam.

Water quality of distribution system

After conventional treatment, water from WTP is pumped to elevated service reservoirs (ESR) for distribution. The water quality of 21 ESR (Table 3) and 21 consumer ends (Table 4) were tested for residual chlorine and samples were analysed for bacteriology. The chlorine solution is added in all the ESR before distribution, and the residual chlorine was found in the range of 0.1–0.6, 0–1 and 0–1.0 mg/l during winter, summer and monsoon, respectively.

During winter, FC was not detected in any water sample from ESR and consumer end, while TC count at consumer ends was 7–607 CFU/100 ml. During summer, on one occasion, TC and FC counts in ESR (T-5) were 80 and 18 CFU/100 ml, respectively. The TC counts present in T-7 and T-20 samples were in the range of 28–48 CFU/100 ml and FC counts were in the range of 4–10 CFU/100 ml. At the consumer ends, out of 21 samples, most of the samples were positive both for TC and FC as 76 and 12 CFU/100 ml, respectively. In monsoon, it was observed

Table 4 Water quality at consumer ends

S. no.	Location	Winter			Summer			Monsoon		
		Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)	Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)	Res-Cl (mg/l)	TC (CFU/100 ml)	FC (CFU/100 ml)
1	PSP near garden, opp. Sanjay traders sadar bazar	0.1–Nil	ND-13	ND	0.1–0.5	ND-8	ND-4	0.2–Nil	4–108	ND
2	Subhash chowk, PSP near Mr. Mangelal Hazar's house	Traces	ND-13	ND	Tracer-0.4	ND	ND	0.6–Traces	ND-72	ND
3	Gandhi hall, PSP-Mr. Satyasai Cement Industry	Traces-0.1	ND-13	ND	Traces-0.3	ND-76	ND-6	0.1–0.5	ND-200	ND
4	Raj Mohalla, PSP-Near Anand uphar gruha	Nil-0.2	ND	ND	0.2–Nil	ND-20	ND	Traces-0.2	8–64	ND
5	B.S.F. H. No. 12-Man Pasand Colony	0.2–0.5	ND	ND	Traces-0.4	ND	ND	1–Nil	ND-16	ND
6	Yashwant Club, H/O Mr. R.C. Goyal opp. tank	0.1	ND-167	ND	0.2–0.6	12–20	2–4	0.1–0.2	ND-4	ND
7	Mr. Radheshyam Yadav near tasty centre, cotton adda	0.2–Nil	ND-320	ND	0.1–Nil	ND-4	ND	0.2–Traces	24–200	ND-30
8	Vijay Nagar, H/O—Mr. Khandwekar	Nil-0.1	30–273	ND	Nil-NWS	8-NWS	ND-NWS	Nil-Traces	20–600	10-ND
9	Mr. RC Khandelwal, 2/2 old Palasiya besides twin tower	Nil-03	ND-580	ND	NWS-Nil	NWS-ND	NWS-ND	Nil-0.2	28-ND	ND
10	Mr. Harshawardhan Nahar, 23, Radio colony	Nil	ND-110	ND	NWS-0.2	NWS-44	NWS-2	Nil-Traces	ND-320	ND
11	PSP Opp. Ajay tyre service near Shiv temple, Khajarana	0.2	ND-20	ND	Nil-NWS	ND-NWS	NWS-ND	Nil-NWS	8–16	ND-NWS
12	Ambedkar nagar, H. No. 308 opp. Dr. Shyam Prasad Mukherjee garden	0.1–Nil	ND-607	ND	Nil-NWS	8-ND	ND-NWS	0.1–0.5	ND-184	ND-4
13	PSP near Mr. Omkarlal Mone's house Gadi Adda	0.1	ND-10	ND	Nil	8-ND	ND	0.1–1	ND-28	ND-4
14	Khandwa road, Mr. V.S. Sangar, 407, Indrapuri	0.2–Nil	ND-170	ND	0.1–0.5	ND	ND	Nil-Traces	36–96	4ND
15	Biloali, Dr. Bina Goyal. H.No. 34, Vishnupuri colony	0.1–Nil	260-ND	D	Traces-0.5	ND-16	ND	0.1–0.5	60–160	ND
16	Annapurna, Mirram Traders Co. Annapurna road	0.2	ND	ND	0.2–Nil	ND	ND-NWS	Nil-1	ND-200	ND
17	Paganis Paga, Allapura mone complex, near Bank of MS	0.2–Traces	ND-320	ND	Nil-Traces	ND-26	ND	0.2–1	ND-380	ND
18	Narmada control room, Rupa's house, Agra-Mumbai road, Bijalpur	0.1–0.2	ND-10	ND	0.2–1	ND	ND	Traces–Nil	4–180	ND
19	Mr. Mangelal Pratap nagar, opp. Sunil cycle service	Nil	ND	ND	0.2–Nil	ND-52	ND	0.2–Traces	ND-84	ND
20	Mr. Rajendra Tomar, 301 “Babli” villa Bajrang nagar	0.2–Nil	ND	ND	0.2–Nil	ND-8	ND-12	0.1–0.6	ND-180	ND-4
21	Mr. Monahar Yadav, 1004, new basti Bhagirathpura	Nil	30-ND	ND	Traces-Nil	ND-48	ND-10	Nil-0.2	36–76	ND

TC and FC should not be present in water at consumer ends as per BIS standards

ND not detected, NWS no water supply, Nil absent

that in samples T-6, T-8, T-11 and T-15, TC was up to 196, 104, 580 and 264 CFU/100 ml. At consumer ends, it was observed that TC was up to 700 CFU/100 ml and FC was 48 CFU/100 ml. Presence of TC and FC indicated occasional enroute contamination in the ESR and distribution system.

KAP survey

Perceived state of drinking water pollution

The water quality is good in the opinion of 60 % of consumers. There is a regular water quality control program conducted by the field staff of the water supply agency by carrying out random water sampling of ESR and consumer ends.

Awareness of the SDWQ and information on drinking water standards

Awareness of the SDWQ program amongst general public is 20 %; in water works personnel, it is 35 %, and in health agencies, it is 30 %. Awareness of information on drinking water quality standard was 40 % amongst general public, 80 % amongst waterworks personnel and 90 % amongst health agency staff.

Information on private water supplies

A total of 20 % of the consumer amongst general public informed that they use private water supply through tube wells to meet their additional water demand.

Accountability for the efficient and effective delivery of water supply

10 % of the consumers amongst general public have indicated the satisfaction towards water supply, while 90 % supply efficiency and effective delivery of finished water were reported by 60 % waterworks personnel.

Knowledge of individuals/institution with water supply agency services

A total of 50 % of the consumers amongst general public, especially educated people, were aware of water supply agency services.

Procedure for the complaints against drinking water supply

45 % of the consumers indicated prompt action of waterworks personnel towards the lodged complaint regarding drinking water supply.

Knowledge of sanitary survey

About 80 % of the respondents amongst general public were found aware of cleaning practices and health aspects related to sanitary practices.

Knowledge of preventive measures and health education

65 % of the respondents were aware about the preventive measures to be taken to prevent the water-borne diseases. Yet, there is a need to impart health education to common people, especially illiterates and women.

Status of quality control and surveillance

The raw water sources were well protected from pollution in catchments. Alum bricks are kept in the raw water inlet channel. The dose of chlorine is arbitrary due to absence of dose regulating system, and dosing is done based on experience of the operator. The O&M of Narmada WTP is satisfactory, whereas Devdharan WTP is lacking in O&M. The staff of IMC looks after leakages and maintenance of distribution network. PHED laboratory undertakes the water analysis for the samples sent by the Municipal Corporation who is having well-equipped central water testing laboratory. Laboratory facilities are provided at Narmada WTP, but laboratory at Devdharan WTP did not have adequate equipment/instruments. Raw and treated water quality for pH, alkalinity, hardness, sulphate and residual chlorine are analysed at Narmada WTP and records are maintained properly.

Regular water quality control program is practised by water supply agency by carrying out random water sampling of ESRs and consumer ends. There is no organized leak detection program, and the leakages are repaired on the basis of public complaints and as noticed by water supply personnel. SDWQ program was not in practice. During the study period, 40–50 % water samples for TC and about 20 % water samples for FC were found positive from distribution system; hence, there exists an urgent need to create the infrastructural facility to carry out SDWQ.

Conclusion

The drinking water supply at Indore was assessed at raw water sources, treatment stages, distribution network and consumer ends. From the present study, it is observed that water supplied through the distribution network is of good physicochemical quality; however, 40–50 % water samples for TC and about 20 % water samples for FC were found positive from consumer ends. No significant change in physicochemical parameters of raw water quality was

observed on a day-to-day basis. The city had an intermittent water supply. Therefore, during non-supply hours, due to back suction through leakages/damages/faulty joints in the supply lines, some insanitary material might be entering into the pipelines and carried up to the consumer ends, when supply resumes. In the places where the fecal contamination was present at the consumer end, the necessary precautionary measures need to be undertaken to avoid any adverse impact on health. The proper maintenance of the distribution network, awareness about the hygienic and sanitary conditions around the public taps and proper storage of water will definitely help in maintaining water quality within the limits of potable water standards. Thus, the surveillance of water supply and in-time measures to control the contamination along with people's participation will lead to safety and better health of the community.

Recommendations

- Instruments/equipments for flow measurement and head loss indicator need to be repaired and maintained.
- Monitor coagulant dosing to avoid carryover of micro-flocs.
- Improve backwash to avoid scum formation in settling tank, filter beds.
- Ensure requisite quantity of residual chlorine with proper chlorine dose.
- Upgradation of water testing laboratories at treatment plant.
- O&M aspects of WTPs need due attention.

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