Drinking water contamination from peri-urban Bengaluru, India

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The presence of diarrhoeagenic bacteria such as *Escherichia coli* in drinking water indicates faecal and sewage contamination. Testing the microbial quality of drinking water at source (*n* = 29) and households (*n* = 43) of 29 peri-urban villages of Bengaluru city, indicated that 80% and 93% of samples respectively were unfit for human consumption as per WHO standards, i.e. nil *E. coli* in 100 ml sample. This also indicated that water gets contaminated further at the point-of-use when compared to the source. Forty-one per cent of the source drinking water samples had high *E. coli* counts which in turn means that the residing population face moderate to high risk of diarrhoea. A longitudinal study of the microbial quality of drinking water at source of supply (*n* = 45) was undertaken five times over an eight-month period in a subset of eight villages. Only around 18% of the total samples were microbially safe with nil *E. coli*/100 ml. Microbial contamination was found to be lower in January and March (<30 CFU/100 ml *E. coli*) when compared to December, May and September (>150 CFU/100 ml). Samples from Chikkakuntanahalli and Kodiyalakeranahalli had ≥1000 CFU/100 ml *E. coli*. Total dissolved solids, calcium, magnesium, alkalinity and hardness in source drinking water of eight selected villages were beyond acceptable levels. The nitrate levels were consistently high and beyond WHO permissible levels. Alarming levels of microbial and chemical contamination of drinking water from the sites press for appropriate remedial measures to reduce health threats, particularly among vulnerable population.

Keywords: Microbial contamination, peri-urban Bengaluru, Vrishabhavathi–Byramangala reservoir, water quality.

WATER, sanitation and hygiene (WASH) are crucial for a healthy life. The United Nations General Assembly has declared safe drinking water as a human right[1]. In developing countries, a majority of water quality problems related to health are due to microbiological contamination. Globally, significant improvement was achieved through the millennium development goals (MDG) strategy[2]. However, 1.1 billion people still lack access to safe drinking water and 2.4 billion lack access to basic sanitation[3]. Of the 3.4 million water-related deaths every year, diarrhoea accounts for 2.2 million, and a majority of these are children under the age of 5 years (U5) from developing countries[4]. Diarrhoeal disease (88%) worldwide is attributed to drinking water contaminated with microbial pathogens[5]. Diarrhoea is the second highest cause of mortality among U5 children[6]. Meanwhile, chemical contamination also poses health risk.

With such devastating effects on infants, there is a dire need to focus on interventions that can prevent diarrhoea. According to the Center for Disease Control and Prevention (CDC), improved sanitation can reduce diarrhoea morbidity by 37.5% and improved water supply alone can reduce it by 21% (ref. 7). WASH has now become one of the sustainable development goals (SDGs) of the United Nations[8]. Environmental pollution is another major cause affecting drinking water quality. Globally, 2 million tonnes of waste from sewage, industries and agriculture get discharged into water bodies leading to contaminated water with faecal matter and chemical pollutants. Pollutants also contaminate the water table affecting around 1.8 billion people whose drinking water source is ground water[9]. In India, nearly 85% of drinking water supplies depend on ground water[10].

Periodical water quality assessment and surveillance are vital to guide action on improving the quality of water. Counts of coliforms and *Escherichia coli*, which are present in faeces, are used as indicators to assess the microbial quality of drinking water. The presence of coliforms indicates microbial contamination and *E. coli* indicates faecal contamination of drinking water. Coliforms of faecal origin can be differentiated from other coliforms in the laboratory as they can grow at 44 or 44.5°C and ferment lactose to produce acid and gas[11]. The faecal coliforms are therefore increasingly being used as a water quality indicator and are referred to as thermotolerant coliforms (TTC), with *E. coli* forming 95% of TTCs. As per WHO standards, potable water should not have any TTC or *E. coli* in 100 ml of drinking water sample. Risk of diarrhoea from drinking water is determined based on TTC load in water as low (1–10 TTC/100 ml), moderate (11–100 TTC/100 ml), high (101–1000 TTC/100 ml) and very high (>1000 TTC/100 ml)[12]. Apart from microbial quality, physicochemical parameters like total dissolved

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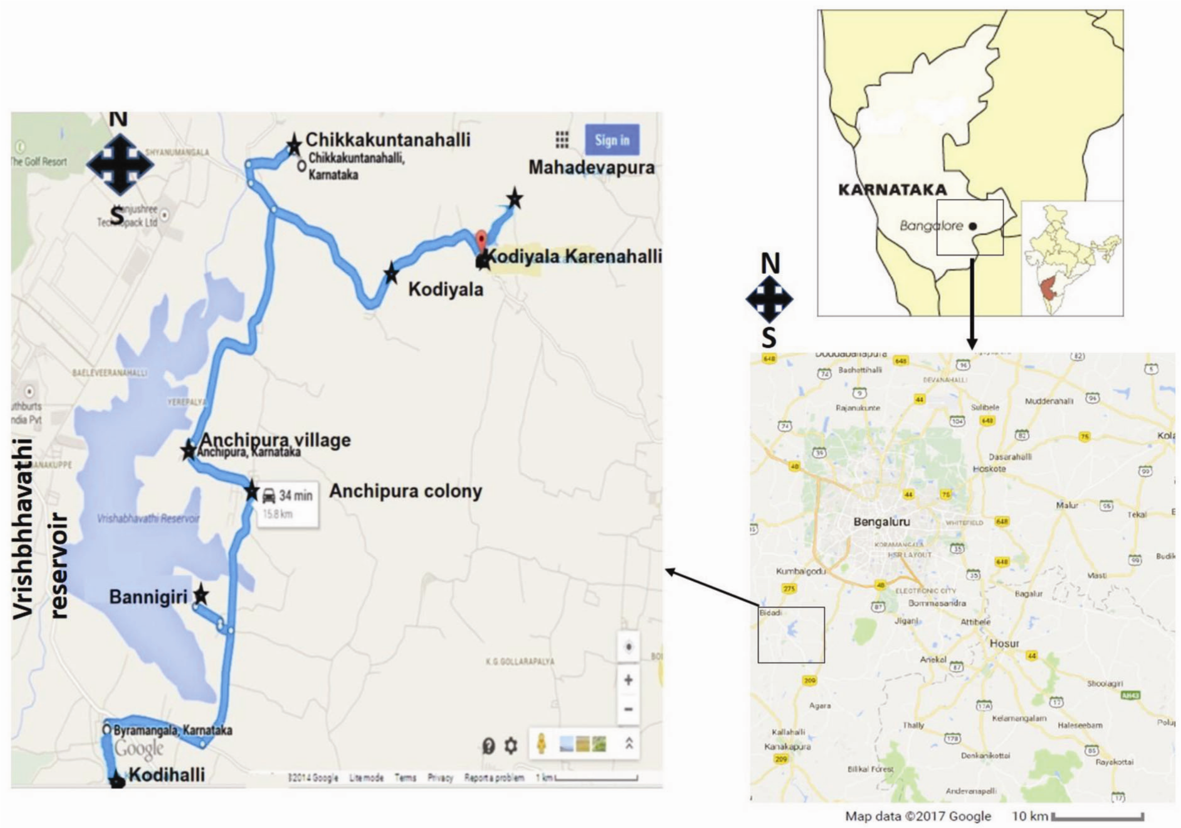

Figure 1. Map of selected study villages in Byramangala Panchayat, Ramnagara district in Karnataka.

solids, hardness, etc. also form a part of drinking water quality assessment[13,14].

Earlier water quality assessments from selected sites in and around Bengaluru have reported that drinking water is unsuitable for domestic consumption based on microbial contamination[15–17]. Physicochemical and bacteriological analyses of water from Vrishabhavathi valley and Byramangala reservoir reported the water to be extremely polluted[18,19]. More importantly progressive deterioration of ground water quality is a serious health hazard in surrounding areas. The current study was undertaken between July 2014 and September 2015 to analyse drinking water from source of supply and from households in peri-urban sites near Bengaluru. The main objective of the study was to determine bacteriological contamination at source and household level and analyse the physicochemical quality of source drinking water samples with a special focus on villages close to Vrishabhavathi–Byramangala reservoir.

Methodology

Ethical approval

The present study was part of a larger field study of safe drinking water intervention. The study protocol was approved by the Institutional Ethics Committees of SRM University, Chennai and of the Institute of Ayurveda and Integrative Medicine (I-AIM), Bengaluru. Written consent was obtained from households for information and collection of samples, after explaining the purpose of the study. The study was registered with the Indian National Clinical Trial Registry (CTRI/2014/07/004747).

Cross sectional study

A cross-sectional study was conducted to test the microbial quality of drinking water at source and households from selected peri-urban sites in and around Bengaluru city.

Selection of sites

Sites were selected based on at least one or more fits with the following criteria: (i) densely populated areas; and (ii) proximity to known contaminated water body, as evidenced from published literature. Distance of the site from the testing laboratory being <2 h was a practical requirement for selection of sites.

Sampling of drinking water

One-time sampling of source drinking water was conducted for assessing the microbial quality of drinking

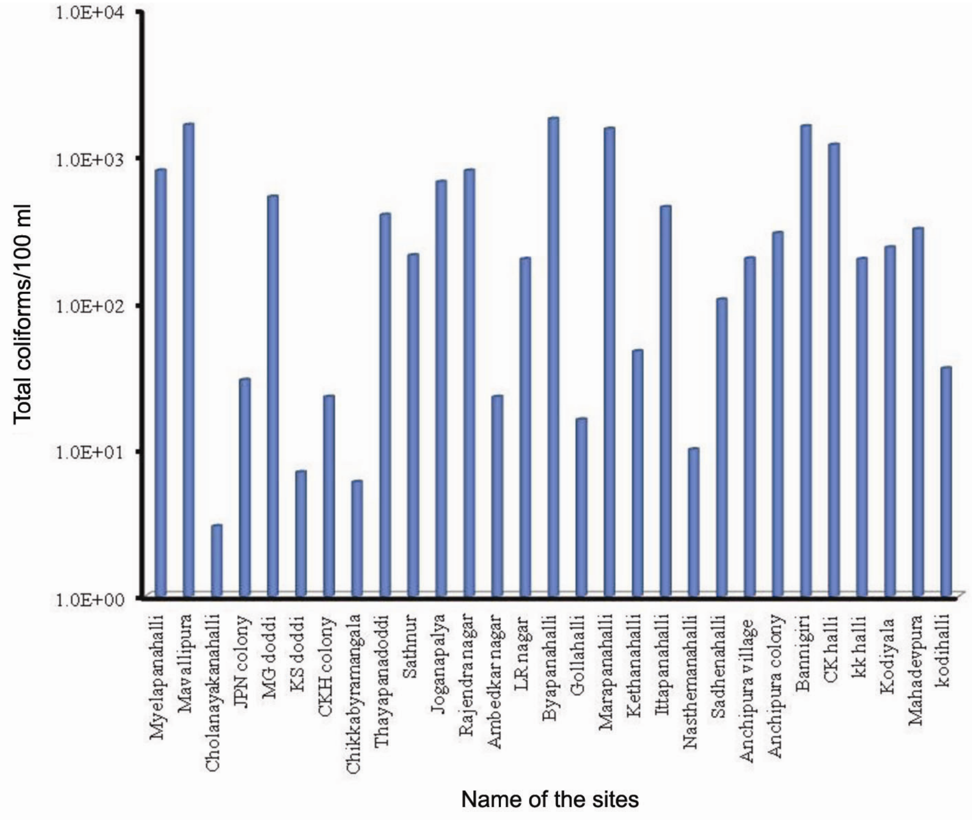

Figure 2. Sites screened for total coliforms contamination of source drinking water in Bengaluru city and peri-urban villages. All the samples were coliform positive. The number of total coliforms ranged from 3 to 1802/100 ml.

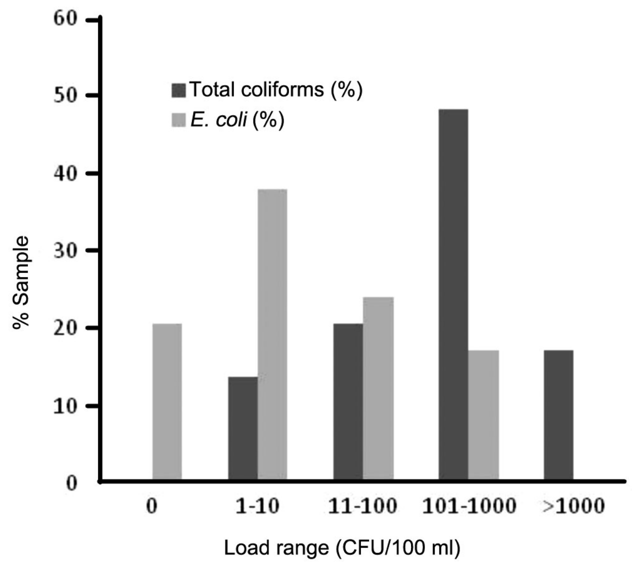

Figure 3. Cross-sectional water quality assessment of source drinking water. All samples were positive for total coliforms, while 80% of the samples were positive for *E. coli*.

water samples collected from the source of water supply during July–August 2014 from 29 sites in peri-urban Bengaluru, Karnataka. Of the 29 sites screened, a cluster of eight villages from Byramangala panchayat, Ramnagara district was selected to assess the microbial quality of drinking water. These villages were: Anchipura village, Anchipura colony, Bannigiri, Chikkakuntanahalli, Kodiyala Keranahalli, Kodiyala, Mahadevpura and Kodihalli. A reservoir called Vrishabhavathi, is in the vicinity of around 5 km from all selected villages (Figure 1). This is known to be contaminated with sewage and industrial wastes mainly from Bengaluru and Bidadi industrial areas[20]. Borewells supplying water through tanks was the source of drinking water for all villages. Household drinking water samples ($n = 43$) were collected from at least five randomly selected households from each of these eight villages to assess the microbial water quality[12,13].

Physicochemical analysis was done on source drinking water samples collected[13,14] from Anchipura village, Anchipura colony, Bannigiri and Chikkakuntanahalli villages which are close to Vrishabhavathi–Byramangala reservoir (Figure 1).

Longitudinal study

In order to understand the variability in microbial quality in source drinking water over different months, a longitudinal study was undertaken by periodic sampling from the cluster of eight selected villages of the Byramangala

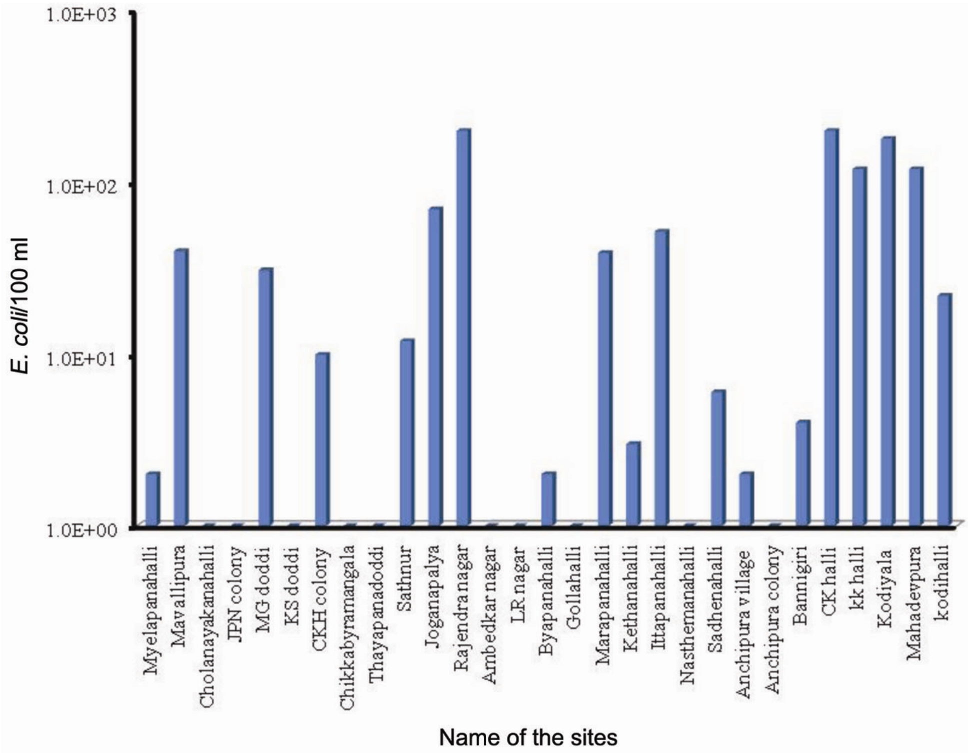

Figure 4. Sites screened for *E. coli* contamination of source drinking water in Bengaluru city and peri-urban villages. The number of *E. coli* ranged from 0 to 200/100 ml.

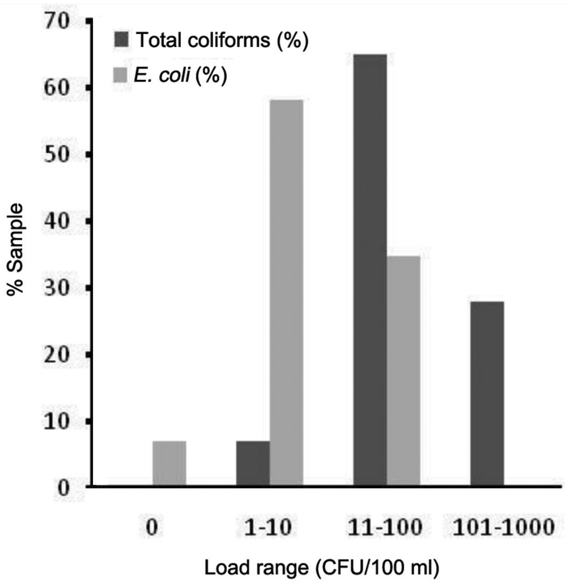

Figure 5. Cross-sectional water quality assessment of household drinking water. All samples were positive for total coliforms while 93% of the samples were positive for *E. coli*.

panchayat as mentioned above. Water samples ($n = 45$) intended for drinking purpose were collected from the source through public taps from each of the eight villages at five different months namely December 2014 and January, March, May and September of 2015.

Collection and testing of water samples

Water samples (250 ml) were collected in sterile 3M sample bags (BP 115S, Minnesota, USA) and transported on ice to the laboratory within 2 h.

The samples were tested for total coliforms and *E. coli* using 3M EC plates (6404/6414/6444, Minnesota, USA), followings the instruction provided in the kit. All samples were tested in duplicates for verification and the results were the mean of two values if similar. If the difference between duplicates was >0.5 log, the sample was re-tested. Total coliforms and *E. coli* in 100 ml were quantified for the samples tested.

Water for assessing physicochemical parameters was collected in sterile plastic cans (10L). Twenty-six physicochemical parameters were tested as per BIS guidelines, IS: 3025.

Statistics

Data was compiled using Microsoft Excel and analysed for frequency using SPSS v.17 software.

Results

Cross-sectional study

Forty-one per cent of the screened sites were under moderate to high risk category for diarrhoea: The cross-sectional study of source drinking water quality from 29

Table 1. Physicochemical analysis of source drinking water collected from four different villages in Byramangala Panchayat near Vrishabhavathi reservoir

Physicochemical parameter	Acceptable limits as per IS:10500-2012	Permissible limits as per IS:10500-2012	Bannigiri	Anchipura colony	Anchipura village	Chikkakuntanahalli
Turbidity (NTU)	Maximum 1	Maximum 5	<0.01	<0.01	0.3	0.1
pH	6.50 to 8.50	No relaxation	7.41	7.48	7.37	7.38
Total dissolved solids (mg/l)	Maximum 500	Maximum 2000	1062	1032	1230	1156
Aluminum as Al (mg/l)	Maximum 0.03	Maximum 0.2	0.015	0.02	0.02	0.03
Ammonia as NH_3 (mg/l)	Maximum 0.5	No relaxation	<0.05	<0.05	<0.05	0.05
Anionic detergents as MBAS (mg/l)	Maximum 0.2	Maximum l.0	<0.2	<0.2	<0.2	0.2
Barium as Ba (mg/l)	Maximum 0.7	No relaxation	<0.1	<0.1	<0.1	0.1
Boron as B (mg/l)	Maximum 0.5	Maximum l.0	<0.1	<0.1	<0.1	0.1
Calcium as Ca (mg/l)	Maximum 75	Maximum 200	122.6	122.6	163.5	147.2
Chloramines as Cl_2 (mg/l)	Maximum 4.0	No relaxation	<0.05	<0.05	<0.05	<0.05
Chorides as Cl (mg/l)	Maximum 250	Maximum 1000	196.8	179.5	250	240
Copper as Cu (mg/l)	Maximum 0.05	Maximum l.5	<0.05	<0.05	<0.05	<0.05
Fluorides as F (mg/l)	Maximum l.0	Maximum l.5	0.4	0.6	0.45	0.4
Free residual chlorine (mg/l)	Minimum 0.2	Minimum 1.0	<0.05	<0.05	<0.05	0.4
Iron as Fe (mg/l)	Maximum 0.3	No relaxation	0.03	0.05	0.05	0.05
Magnesium as Mg (mg/l)	Maximum 30	Maximum 100	67	54.6	79.4	64.5
Manganese as Mn (mg/l)	Maximum 0.1	Maximum 0.3	<0.1	<0.1	<0.1	<0.1
Nitrate as no 3 (mg/l)	Maximum 45	No relaxation	50	97.8	172	109
Phenolic compounds as C_6H_5OH (mg/l)	Maximum 0.001	Maximum 0.002	Absent	Absent	Absent	Absent
Selenium as Se (mg/l)	Maximum 0.01	No relaxation	<0.01	<0.01	<0.01	<0.01
Silver as Ag (mg/l)	Maximum 0.1	No relaxation	<0.01	<0.01	<0.01	<0.01
Sulphates as SO_4 (mg/l)	Maximum 200	Maximum 400	81.2	54.5	75.2	58.3
Sulphides as H_2S (mg/l)	Maximum 0.05	No relaxation	<0.05	<0.05	<0.05	<0.05
Total alkalinity as $CaCO_3$ (mg/l)	Maximum 200	Maximum 600	462	440	385	451
Zinc as Zn (mg/l)	Maximum 5	Maximum 15	0.05	0.01	0.06	0.03
Total hardness as $CaCO_3$ (mg/l)	Maximum 200	Maximum 600	581.4	530.4	734.4	632.4

sites in peri-urban Bengaluru showed that all water samples had coliforms with 17.24% of the sites having >1000 CFU/100 ml (Figures 2 and 3). Only 20.6% of the source water samples tested complied with WHO permissible limits with respect to *E. coli* (Figures 3 and 4) count (i.e. nil count/100 ml). Based on *E. coli* counts in drinking water collected at source, 37.93% of source drinking water samples presented a low risk (<10 CFU/ml), 24.14% (11–100 CFU/ml) moderate risk, and 17.24% high risk of diarrhoea to the residing population.

Only 7% of household drinking water samples complied with WHO permissible limits: All drinking water samples from households ($n = 43$) were found to be contaminated with coliforms. As shown in Figure 5, ~28% of samples had contamination loads of 101–1000 coliforms/100 ml. While 20% of drinking water samples at source complied with WHO standards for *E. coli* (no risk category), the percentage of samples complying at household level was only 7%. This indicates further contamination of drinking water at the household level. Around 58% of samples were found to be under low risk and 35% of samples were under moderate risk category for diarrhoea, based on *E. coli* count.

High levels of chemical pollution of source water samples: Total dissolved solids, calcium, magnesium and total alkalinity were found to be beyond acceptable levels and within permissible levels in the source water samples tested from villages namely Anchipura village, Anchipura colony, Bannigiri, Chikkakuntanahalli. Total hardness was beyond permissible levels for Anchipura and Chikkakuntanahalli. Nitrate levels were beyond permissible levels in all the source samples ranging from 50 to 172 mg/l, when the permissible level should actually be 45 mg/l as per BIS and 50 mg/l as per WHO standards (Table 1).

Longitudinal study of microbial quality of source drinking water samples

Of the cluster of eight selected sites in Byramangala Panchayat that were taken up for longitudinal study, a total of 45 source drinking water samples were analysed at five time points. All the source water samples collected at all sampling times were contaminated with coliforms and 33.3% of the samples had >1000 coliforms/100 ml (Table 2).

Only 17.78% of total samples ($n = 45$) collected from the source at all 5 time points complied with WHO permissible limits (0 *E. coli* count/100 ml; no risk category). 29% of the water samples put people under high to very high risk for diarrhoea because they contained 101 to >1000 *E. coli*/100 ml (Table 3).

Table 2. Longitudinal water quality assessment of source drinking water for total coliforms/100 ml from selected villages in Byramangala Panchayat

	Total coliforms/100 ml of drinking water/name of the village							
Sampling months	Anchipura	Anchipura colony	Bannigiri	Chikkakuntanahalli	Kodiyalakeranahalli	Kodiyala	Mahadevpura	Kodihalli
December 2014	1800	1800	80	400	1100	2800	3000	10800
January 2015	138	2800	48	14	18	223	1	7
March 2015	12	50	31	88	230	39	23	40
May 2015	8	456	2400	920	12600	49	2440	1290
September 2015	20	400	26	9006	35000	103	2500	210

Table 3. Longitudinal water quality assessment of source drinking water for *E. coli*/100 ml from selected villages in Byramangala Panchayat

	E. coli/100 ml of drinking water/name of the village							
Sampling months	Anchipura	Anchipura colony	Bannigiri	Chikkakuntanahalli	Kodiyalakeranahalli	Kodiyala	Mahadevpura	Kodihalli
December 2014	520	520	62	80	600	720	320	800
January 2015	37	200	0	1	2	3	0	1
March 2015	0	33	1	2	20	27	0	8
May 2015	1	56	100	200	1000	3	40	4
September 2015	0	300	6	1006	600	3	500	10

The contamination levels in drinking water at source varied quite a bit over the different months tested. Contamination levels of total coliforms (64–406 CFU/100 ml) and *E. coli* (<30 CFU/100 ml) in drinking water in January and March months were lower in all the eight village sites when compared to that from other months (>2000 CFU/100 ml coliforms and >170 CFU/100 ml *E. coli*). During December, May and September months, the *E. coli* counts in samples collected from Chikkakuntanahalli and Kodiyalakeranahalli were far from safe with ≥1000 CFU/100 ml. Anchipura colony had consistently high levels (33–200 CFU/100 ml) of *E. coli* in source drinking water samples collected during all months. Of the sites tested, microbial quality of drinking water at source of Bannigiri village was somewhat better when compared to that of other villages, even though in May, September and December months there was *E. coli* ranging from 1 to 100 CFU/100 ml (Table 3).

Discussion

Surveillance of microbial quality of drinking water is an important activity of public health systems. Previous studies reported coliform contamination of drinking water from source and households at various sites in and around Benglauru[17,21,22]. In the present study, source drinking water samples from selected Bengaluru peri-urban villages were analysed. The cross-sectional study of source microbial quality of drinking water of the sites screened showed that 80% of samples were unfit for consumption as per WHO standards.

The groundwater of the region around Vrishabhavathi reservoir was considered a serious environmental issue with respect to microbial contamination[23]. The present water surveillance study at Byramangala Panchayat, indicated that source drinking water which drew water from borewells were contaminated with coliforms and *E. coli.* This indicates that possibly the groundwater of areas around the reservoir is contaminated with faecal contamination. The primary reasons for contamination could be the sewage inflow from Bengaluru city and industrial effluents into the reservoir. Previous studies[18,24] of ground water samples around Vrishabhavathi valley basin found that 50% of samples showed bacterial contamination. In another study, continuous flow of sewage and industrial effluents were reported to be the contributing factors for worsening of the quality of water and air around Byramangala reservoir[20]. This reservoir has become the cesspool of various pathogenic microbes especially multidrug resistant emerging superbugs[25] along with chemical pollutants including heavy metal and toxic chemical contamination which makes it unsuitable for drinking as well as irrigation[19]. Previous studies reported that 29% of ground water samples analysed in and around Bengaluru were found to have nitrate contamination[15]. Majority of water samples analysed from Vrishabhavathi valley basin were found to be non-potable due to nitrate and total hardness[18,26]. Similarly, in this study we found that the nitrate levels were greater than the permissible levels (50 mg/l) consistently in all source drinking water analysed from the villages surrounding Vrishabavati–Byramangala reservoir. This further confirms progressive deterioration of ground water quality of villages surrounding Vrishabhavathi reservoir. High level of nitrates is a known cause for methaemoglobinaemia in bottle fed infants and causes gastric and prostrate cancers in adults[27].

In the longitudinal study conducted at five different time points between December 2014 and September 2015, from a cluster of eight villages in Byramangala Panchayat water was found to be contaminated with coliforms, beyond permissible limits. The samples collected in January and March were less contaminated compared to other months. The samples collected in September showed maximum contamination level in all the sites. This indicates a possible influence of seasons on the load of microbial contamination as reported previously[28,29].

The level of contamination at household level was higher than that in source samples. The increased level of contamination of water at household level could be due to poor sanitation and sociocultural practices. A recent update from WHO revealed that nearly 60% of those practicing open defeacation live in India. Open defeacation along with many other environmental and anthropogenic activities pertaining to WASH make water unfit for drinking[30].

Simple, sustainable interventions at community as well as household level would tremendously improve water quality to reduce water-borne diseases and deaths. One such feasible approach is to adopt point-of-entry (PoE)/point-of-use (PoU) interventions. Several studies are available on cost-effective sustainable PoU intermentions such as solar disinfection[31], chlorine tablets[32], copper[33], etc. that can reduce diarrhoea causing pathogens in drinking water thereby reducing diarrhoea morbidity. Nevertheless, only a combined approach integrating improvement in WASH practices along with better governance to control environment pollution can provide safe drinking water on a sustainable basis[30].

Conclusion

In developing countries, approximately half the population suffers from health problems due to inadequate water supply and sanitation. The ground water quality threatened by a combination of chemical pollution and microbial contamination, causes additional health risks. Microbial contamination of drinking water was observed in samples collected from peri-urban areas of Bengaluru. Of all source and household drinking water samples tested, only 16.5% and 6.9% complied respectively with WHO standards for *E. coli*. The longitudinal study results of drinking water quality in villages around Byramangala, Vrishabhavathi reservoir at Ramnagara district indicate that these sites have potential health risks due to high level of contamination observed both in source and household drinking water samples. The seasonal factor had a vital role on the level of drinking water contamination with somewhat lower contamination in January and March months. High levels of nitrates observed might cause hazardous health effects. Interventions to purify drinking water need to be supported by sustained efforts to improve WASH behaviour as well as governance to control environmental pollution, particularly of water bodies.

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