Research Paper

Assessment of microbiological and physico-chemical characteristics of water samples in households of Bangalore city, Karnataka, India

Jessen George, Siri Karthiyayani Nagaraja and Ajisha A.

ABSTRACT

Access to safe drinking water is one of the basic human rights and is essential to human health. The present study investigated the concentration of pathogenic microbial flora and health risk in drinking water samples in households of Bangalore city, Karnataka, India. The samples were analysed for microbiological and physico-chemical parameters. In this study, most probable number and heterotrophic plate count were used to assess the microbial load. The results of the study show that most of the household water samples were contaminated with the presence of coliform bacteria. The dominant bacterial species are *Escherichia coli, Salmonella, Shigella, Klebsiella* and *Enterobacter*. The bacteria belonging to the family *Enterobacteriaceae* showed maximum occurrence in water samples. The overall results of the study showed that the consumption of such contaminated drinking water at the end-user point may cause potential health hazards to the inhabitants.

Key words | coliforms, *Enterobacteriaceae*, health hazard, HPC, MPN, water quality

Jessen George (corresponding author)
Rev. Jacob Memorial Christian College,
Ambilikkai 624612, Oddanchatram, Dindigul (Dist),
Tamilnadu,
India
E-mail: *georgejessen@gmail.com*

Siri Karthiyayani Nagaraja
SGS Lanka (Pvt) Ltd,
140, Vauxhall Street,
Colombo 00200,
Sri Lanka

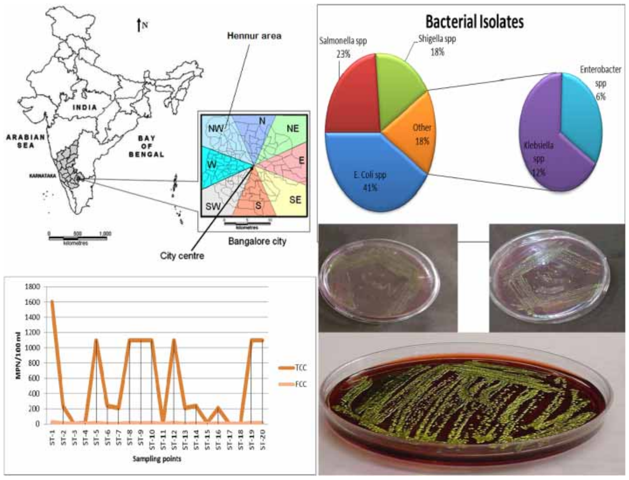
Ajisha A.
IQVIA,
Bangalore,
India

HIGHLIGHTS

- Study investigated the concentration of pathogenic microbial flora and health risk in drinking water samples in households of Bangalore city, Karnataka, India.
- The result of the study shows that most of the household water samples were contaminated with coliform bacteria.
- This study indicates that continuous consumption of such contaminated water could pose health risks to water consumers.

doi: 10.2166/washdev.2021.222

GRAPHICAL ABSTRACT



INTRODUCTION

Access to safe drinking water is one of the basic human rights and is essential to human health (Hall *et al.* 2013). The quality of drinking water is an essential factor for better human health (Francis *et al.* 2015). An adequate supply of safe drinking water is one of the most challenging tasks in many developing countries (Ouf *et al.* 2018). Many people must confront every day the situation of an inadequate supply of water and the very serious consequences (Cosgrove & Loucks 2015).

According to the estimation of the UN (2018), more than 55% of the population is living in an urban area. With the increasing urban population and expansion of urban areas, many city managers are facing the problem of providing an adequate quantity and quality of water (McDonald *et al.* 2011). Proper sewerage systems also remain challenging tasks for many in urban areas (Wankhade 2015). Consequently, this situation could be a potential threat to the health of citizens. This problem is more serious in India where the rate of urban growth is higher (George 2015).

The rapid growth of the urban population has resulted in increases in the need for basic services and the access to appropriate water supply and sanitation (Satterthwaite *et al.* 2010). The rapid growth of urban areas has further affected water quality due to the increase of the urban population, over-exploitation of resourses and improper waste disposal practices (McGrane 2016).

Many researchers (Edokpayi *et al.* 2018; Irda Sari *et al.* 2018) from different parts of the world have reported the status of drinking water quality in urban areas. The status of water supply and sanitation services in urban areas of India is generally poor and with a limited continuity of water supply (George *et al.* 2015). In India, no major city is known to have a continuous water supply and it is only available for a few hours per day (McKenzie & Ray 2009). In Bangalore city, the incidence of waterborne infections is consistently high due to a limited supply of drinking water (Sheeba *et al.* 2017). Many studies have been reported on the physico-chemical quality of drinking water in Bangalore but the hazard identification and health risk-associated assessments have not yet been reported.

This study was based on two aspects of water quality: one is the microbial contamination and the other is focused on physico-chemical parameters. The microbial contamination is mainly due to waterborne pathogens, especially from the members of *Enterobacteriaceae*. Generally, most of the microbial pathogens are transmitted via contaminated food, but waterborne transmission has been well documented for recreational and contaminated drinking water (Ashbolt 2015). Contaminated drinking water serves as an important vehicle for transmitting both chemical and microbial agents to cause diseases in humans (Hurst 2018). Increasing incidents of waterborne diseases via contaminated drinking water have become a public health problem in both developed and developing countries (Pandey *et al.* 2014).

The main objective of this research is to assess the microbial health risk generated in the households of Bangalore city and to determine the physico-chemical and microbiological quality of drinking water supply for the end-user. In view of this, an attempt was made to carry out microbiological hazard identification from the households of Bangalore city, Karnataka, India.

METHODS

This study was carried out in and around Bangalore, Karnataka, India, located at 13.0320°N, 77.6360°E. The city population mainly depends on bore well and Cauvery water sources for drinking purpose.

A total of 20 sampling points were randomly selected and water samples were collected from households of Bangalore, Karnataka, India. The samples were designated as SSW-1, SSW-3, SSW-5, SSW-7 to SSW-11, SSW-14, SSW-15, SSW-17, SSW-19 to SSW-20 and the samples were collected from surface water source (Cauvery water). The samples SGW-2, SGW-4, SGW-6, SGW-12, SGW-13, SGW-16 and SGW-18 were collected from groundwater sources (Table 1).

A survey was conducted during the study period to determine the type of water consumption (Cauvery water, bore well and bottled water). The samples were collected in pre-cleaned, sterilized polyethene bottles. They were analysed by following microbiological and physico-chemical parameters. Microbiological parameters were examined within 2 hours of sample collection. All the measurements were done in triplicate and values were expressed as mean ± standard deviation.

The water samples were analysed for the microbiological parameters heterotrophic plate count (HPC), total coliform count (TCC), faecal coliform count (FCC) and *Escherichia coli* using standard methods. The total coliform count was determined by most probable number (MPN) technique using a set of three tubes inoculated with 10 mL of lactose broth of different strengths with samples of 10 mL, 1 mL and 0.1 mL. The faecal coliform and *E. coli* were detected by subculture of all presumptive positive tubes of the coliform test at the end of 48 hours in BGLB medium and incubation at 44.5 °C for 24 hours in a water bath. Bacterial pathogens related to gastroenteritis isolated on respective media were identified on the basis of their morphological and biochemical properties following *Bergey's Manual of Determinative Bacteriology* (Holt 1994). Biochemical tests such as indole, MR-VP and urease were performed for phenotypic identification of enteric isolates.

On-site analyses of pH, conductivity, turbidity and temperature were carried out at the site of sample collection following the standard protocols and methods of the American Public Health Agency. Total hardness was measured according to the standard methods (APHA 2005). Winkler's method (APHA 2005) was used for determination of the dissolved oxygen (DO) using azide modification. All the measurements were done in triplicate and values were expressed as mean ± standard deviation.

Table 1 | Key details of sampling points and water sources

S. No	Source of water	Drinking water access and storage	Type of water consumption
SSW-1	Cauvery	Pot	Cold water
SGW-2	Bore well	Canned	Bottled water
SSW-3	Cauvery	Tap water	Cold tap water, hot water
SGW-4	Bore well	Canned	Bottled water
SSW-5	Cauvery	Pot	Hot water
SGW-6	Bore well	Canned	Hot water
SSW-7	Cauvery	Tap water	Cold, hot water
SSW-8	Cauvery	Pot	Cold tap water
SSW-9	Cauvery	Tap water	Cold tap water
SSW-10	Cauvery	Tap water	Hot water
SSW-11	Cauvery	Tap water	Hot water
SGW-12	Bore well	Canned	Hot water
SGW-13	Bore well	Canned	Bottled water
SSW-14	Cauvery	Tap water	Cold, hot water
SSW-15	Cauvery	Pot	Cold, hot water
SGW-16	Bore well	Canned	Bottled water
SSW-17	Cauvery	Tap water	Hot water
SGW-18	Bore well	Canned	Hot water
SSW-19	Cauvery	Tap water	Cold tap water
SSW-20	Cauvery	Tap water	Cold tap water

RESULTS AND DISCUSSION

The microbiological and physico-chemical parameters of water samples were compared to the water quality guidelines of CPHEEO (2009), BIS (2012) and WHO (2017). Microbiological and physico-chemical characteristics of water samples are presented in Table 2.

Microbiological water quality

The results of the study show that most of the household water samples were contaminated with coliform bacteria (Figure 1). The SSW-1 sample showed the highest count (1,600 MPN/100 mL) among other samples. Sampling stations SSW-5, SSW-8, SSW-9, SSW-10, SGW-12, SSW-19 and SSW-20 showed a similar pattern of TCC (1,100 MPN/100 mL). The water samples SGW-2, SGW-6, SSW-7, SGW-13 and SGW-16 have a similar pattern of TC count (210–240 MPN/100 mL). The sampling points SSW-4 and SGW-15 are less contaminated in terms of TC count (13 MPN/100 mL). The water samples SSW-3, SSW-11, SSW-17 and SGW-18 showed TC count within the permissible ranges of WHO (2017) and BIS (2012).

The faecal coliform count (FCC) was higher for SSW-1, SSW-5, SSW-8, SSW-10, SGW-12, SSW-19 and SSW-20 (11–24 MPN/100 mL). The water samples SGW-2, SSW-7, SSW-9, SGW-13, SSW-14 and SGW-16 were moderately

Table 2 | Microbiological and physico-chemical parameters of water samples from the households of Hennur area of Bangalore city

	TCC (MPN/100 mL)[a]			FCC (MPN/100 mL)[a]								
S. No	Min	Max	Avg	Min	Max	Avg	HPC (CFU/mL)	PH	EC (μS/cm)	DO (Mg/L)	TH (Mg/L)	Turbidity (NTU)
SSW-1	210	1,600	905	4	24	14	2.9×10^6	8.1 ± 0.1	400 ± 2	6.8 ± 0.1	130 ± 0.5	4.2 ± 0.2
SGW-2	0	240	120	0	4	2	5.4×10^5	7.7 ± 0.3	770 ± 2	6.9 ± 0.1	200 ± 1	1 ± 0.3
SSW-3	0	0	0	0	0	0	ND	7.5 ± 0.3	1,120 ± 4	7.4 ± 0.2	275 ± 1.5	0.5 ± 0.1
SGW-4	0	13	6.5	0	0	0	1.6×10^5	7.6 ± 0.3	554 ± 1.5	6.3 ± 0.3	240 ± 1.5	0.6 ± 0.1
SSW-5	210	1,100	655	2	15	8.5	ND	8 ± 0.1	400 ± 1	6.2 ± 0.2	130 ± 0.6	3.6 ± 0.2
SGW-6	93	240	166.5	0	0	0	5×10^5	7.7 ± 0.3	773 ± 3	6.4 ± 0.2	180 ± 0.8	0.8 ± 0.1
SSW-7	28	210	119	0	2	1	4×10^5	7.7 ± 0.3	680 ± 2	6.3 ± 0.1	150 ± 0.5	0.7 ± 0.1
SSW-8	93	1,100	596.5	6	12	9	3.0×10^6	7.9 ± 0.2	400 ± 2	6.1 ± 0.1	130 ± 0.5	2.8 ± 0.2
SSW-9	75	1,100	587.5	2	8	5	2.1×10^6	7.9 ± 0.2	400 ± 2	6.2 ± 0.2	130 ± 0.5	3 ± 0.3
SSW-10	75	1,100	587.5	2	12	7	2.8×10^6	8 ± 0.1	400 ± 1	6.1 ± 0.1	275 ± 2.5	2.8 ± 0.2
SSW-11	0	0	0	0	0	0	ND	7.5 ± 0.3	1,120 ± 5	7.4 ± 0.2	130 ± 0.5	0.4 ± 0.1
SGW-12	150	1,100	625	2	11	6.5	1.8×10^6	7.9 ± 0.1	400 ± 2	6.1 ± 0.1	160 ± 0.6	3.6 ± 0.2
SGW-13	21	210	115.5	0	2	1	7×10^5	7.6 ± 0.1	554 ± 2	6.2 ± 0.3	240 ± 0.5	0.8 ± 0.2
SSW-14	28	240	134	0	4	2	6.2×10^5	7.7 ± 0.3	773 ± 3	6.6 ± 0.2	200 ± 0.8	1.1 ± 0.1
SSW-15	4	13	8.5	0	0	0	1.4×10^5	7.6 ± 0.3	554 ± 3	6.3 ± 0.1	240 ± 2	0.5 ± 0.1
SGW-16	21	210	115.5	2	6	4	5.4×10^5	7.9 ± 0.2	400 ± 1	6.1 ± 0.1	130 ± 1	0.7 ± 0.1
SSW-17	0	0	0	0	0	0	ND	7.6 ± 0.3	554 ± 2	6.3 ± 0.1	240 ± 2	0.4 ± 0.1
SGW-18	0	0	0	0	0	0	ND	7.5 ± 0.2	1,120 ± 6	7.3 ± 0.1	275 ± 2.5	0.4 ± 0.1
SSW-19	210	1,100	655	2	12	7	2.2×10^6	8 ± 0.1	400 ± 2	6.2 ± 0.2	130 ± 0.5	2.6 ± 0.1
SSW-20	210	1,100	655	2	11	6.5	2.1×10^6	8 ± 0.1	400 ± 2	6.1 ± 0.1	130 ± 0.4	2.8 ± 0.2

Avg, average; Min, minimum; Max, maximum; CFU, colony forming unit; ND, not detected.

[a]MPN values per 100 mL of sample and 95% confidence limits for various combinations of positive and negative results (when three 10-mL, three 1-mL, and three 0.1-mL test portions are used).

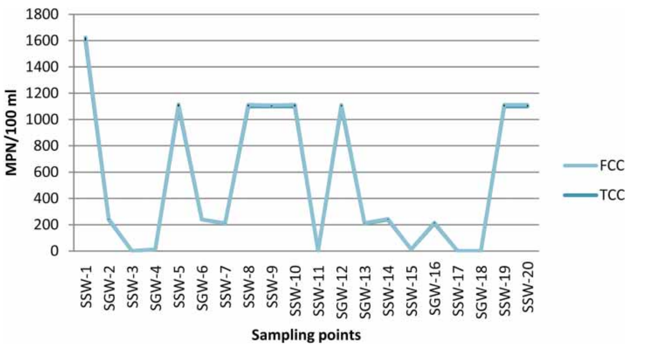


Figure 1 | Microbiological results of drinking water from the households of Hennur area of Bangalore city.

contaminated with faecal coliforms. The water samples SSW-3, SSW-4, SSW-11, SSW-15, SSW-17 and SGW-18 showed FC count within the permissible range of WHO (2017) and BIS (2012).

The bacteria belonging to the family *Enterobacteriaceae* showed a greater percentage of bacterial population isolated from the household water samples of Bangalore city (Figure 2). These *Enterobacteriaceae* members are associated with gastroenteritis, salmonellosis and bacillary dysentery. The dominant bacterial species are *E. coli, Salmonella, Shigella, Klebsiella* and *Enterobacter*. The pathogenic species of *E. coli* is divided into six groups based on serological and virulence characteristics.

The heterotrophic count of water samples SSW-1, SSW-8, SSW-9, SSW-10, SSW-19 and SSW-20 showed higher values from 2.1×10^6 to 3.0×10^6 CFU/mL. The higher value of such samples may be due to prolonged storage of water in a pot. Microbiological assessment of the drinking water from the households of Bangalore city demonstrates its vulnerability due to indicator and enteric bacteria. The overall results showed that the consumption of such contaminated

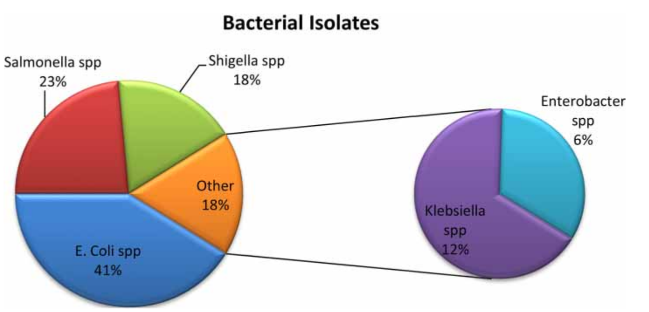


Figure 2 | Percentage of bacterial population isolated from the household water samples of Hennur area of Bangalore city.

water at end-user point may cause potential health hazards to the inhabitants.

Physico-chemical water quality

The hydrogen ion concentration in all water samples remained alkaline throughout the study period. The average pH of water samples showed a maximum of 8.1 and minimum of 7.5. The pH values of water in all samples were within the permissible limit recommended by WHO (6.5–8.5).

The conductivity of all water samples showed ranges from 400 (μmho) to 1,120 (μmho). Dissolved oxygen (DO) concentration water samples observed were a maximum 7.4 and minimum 6.1. For all water samples, the DO values were within the permissible limit.

The total hardness was found to be 130 mg/L to 275 mg/L. For all water samples, the total hardness is within the permissible limit recommended by CPHEEO (2009), BIS (2012) and WHO (2017).

During the study period, temperature varied from 26 °C to 29 °C. The minimum temperature was recorded with water sample SGW-12 and the maximum with SSW-1, SGW-4, SSW-8 and SSW-20.

In this present study, the water samples contain turbidity value ranges of 0.4 NTU (SSW-11, SSW-17 and SGW-18) to 4.2 NTU (SSW-1). Drinking water is considered to be good quality when it contains turbidity values of 1 or below (Cotruvo 2017). In this study, some sampling stations exceeded the limit of turbidity value WHO (2017).

Correlation between physico-chemical and microbiological quality

For the correlation study, a few physico-chemical parameters with microbial parameters to check the interrelationship of each parameter were used. Statistically, using Pearson's correlation coefficient TCC was found to be positively and significantly related to pH and turbidity. The pH was found to be significantly and positively related to turbidity. Electrical conductivity was found to be significantly and positively related to DO and TH. TCC was negatively correlated to EC, DO and TH. The pH was negatively correlated with EC, DO and TH. EC, DO and TH were negatively correlated with turbidity. The rest of the

Table 3 | Pearson's correlation between physico-chemical and microbiological quality

	TCC	pH	EC	DO	TH	Turbidity
TCC	1					
pH	0.927[a]	1				
EC	−0.692	−0.808	1			
DO	−0.430	−0.582	0.893[a]	1		
TH	−0.564	−0.604	0.424[b]	0.290[b]	1	
Turbidity	0.981[a]	0.890[a]	−0.673	−0.402	−0.524	1

[a]Correlation is significant at the 0.01 level (two-tailed).
[b]Correlation is significant at the 0.05 level (two-tailed).

combinations were not significantly related to each other (Table 3).

CONCLUSIONS

In terms of microbial risk, most of the households (80%) are prone to contamination with waterborne pathogens. This clearly indicates the microbial risk of gastroenteritis. Hence, the water is not suitable for drinking purposes without proper treatment or boiling. The study highlighted that certain physico-chemical parameters are within the permissible range of the regulatory authorities, but most of the microbiological parameters of water samples exceeded the permissible limit. The WHO guidelines for bacteriological quality of drinking water require that all water intended for drinking must contain no *E. coli* or thermotolerant coliforms in any 100 mL sample. In this study, it was concluded that the water to the end-user point is highly contaminated with coliform bacteria.

In this assessment, people are consuming water from two major sources; bore well water and Cauvery water source. Mostly contamination is greater in prolonged storage in containers or pots. The storage practices and handling the water from storage containers at home caused the quality deterioration, posing a potential risk of infection to consumers. Poor personal and domestic hygiene can increase the incidence of waterborne infection. This study concluded that the drinking water to the end-user point is contaminated with the presence of coliform bacteria. The study also revealed that the microbial quality of water from the households was not suitable for drinking purposes without proper treatment or boiling.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

APHA 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association, Washington DC, USA.

Ashbolt, N. J. 2015 Microbial contamination of drinking water and human health from community water systems. *Current Environmental Health Reports* **2** (1), 95–106. https://doi.org/10.1007/s40572-014-0037-5.

Bureau of Indian Standards 2012 *Indian Standard Drinking Water-Specification (Second Revision)*. Available from: http://cgwb.gov.in/Documents/WQ-standards.pdf

Cosgrove, W. J. & Loucks, D. P. 2015 Water management: current and future challenges and research directions. *Water Resources Research* **51**, 4823–4839. https://doi.org/10.1002/2014WR016869.

Cotruvo, J. A. 2017 WHO guidelines for drinking water quality: first addendum to the fourth edition. *Journal of the American Water Works Association* **109**, 44–51. https://doi.org/10.5942/jawwa.2017.109.0087.

CPHEEO 2009 *Manual on Water Supply and Treatment*. Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, New Delhi, India.

Edokpayi, J. N., Odiyo, J. O., Popoola, E. O. & Msagati, T. A. M. 2018 Evaluation of microbiological and physicochemical parameters of alternative source of drinking water: a case study of Nzhelele River, South Africa. *The Open*

Microbiology Journal **12**, 18–27. https://doi.org/10.2174/1874285801812010018.

Francis, M. R., Nagarajan, G., Sarkar, R., Mohan, V. R., Kang, G. & Balraj, V. 2015 Perception of drinking water safety and factors influencing acceptance and sustainability of a water quality intervention in rural southern India. *BMC Public Health* **15**, 731. https://doi.org/10.1186/s12889-015-1974-0.

George, J. 2015 *Microbial Risk Assessment and its Implications of Risk Management in Urban Water Systems of Mysore, Karnataka, (India)*. Ph.D. thesis. JSS University, Mysore, India. Available from: https://shodhganga.inflibnet.ac.in/handle/10603/129218?mode=full

George, J., An, W., Joshi, D., Zhang, D., Yang, M. & Suriyanarayanan, S. 2015 Quantitative microbial risk assessment to estimate health risk in urban drinking water systems of Mysore, Karnataka, India. *Exposure and Health* **7** (3), 331–338. https:/doi.org/10.1007/s12403-014-0152-4.

Hall, R. P., Van Koppen, B. & Van Houweling, E. 2013 The human right to water: the importance of domestic and productive water rights. *Science and Engineering Ethics* **20** (4), 849–868. https://doi.org/10.1007/s11948-013-9499-3.

Holt, J. G. 1994 *Bergey's Manual of Determinative Bacteriology*. Lippincott Williams and Wilkins, Philadelpia, PA, USA.

Hurst, C. J. 2018 Understanding and estimating the risk of waterborne infectious disease associated with drinking water. In: *The Connections Between Ecology and Infectious Disease* (C. Hurst, ed.). Advances in Environmental Microbiology, vol. 5. Springer, Cham, Switzerland. https://doi.org/10.1007/978-3-319-92373-4_3

Irda Sari, S. Y., Sunjaya, D. K., Shimizu-Furusawa, H., Watanabe, C. & Raksanagara, A. S. 2018 Water sources quality in urban slum settlement along the contaminated river basin in Indonesia: application of quantitative microbial risk assessment. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2018/3806537

McDonald, R. I., Green, P., Balk, D., Fekete, B. M., Revenga, C., Todd, M. & Montgomery, M. 2011 Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences of the United States of America* **108** (15), 6312–6317. https://doi.org/10.1073/pnas.1011615108.

McGrane, S. J. 2016 Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review. *Hydrological Sciences Journal* **61** (13), 2295–2311. https://doi.org/10.1080/02626667.2015.1128084.

McKenzie, D. & Ray, I. 2009 Urban water supply in India: status, reform options and possible lessons. *Water Policy* **11**, 442–460.

Ouf, S. A., Yehia, R. S., Ouf, A. S. & Abdul-Rahim, R. F. 2018 Bacterial contamination and health risks of drinking water from the municipal non-government managed water treatment plants. *Environmental Monitoring and Assessment* **190**, 685. https://doi.org/10.1007%2Fs10661-018-7054-z.

Pandey, P. K., Kass, P. H., Soupir, M. L., Biswas, S. & Singh, V. P. 2014 Contamination of water resources by pathogenic bacteria. *AMB Express* **4**, 51. https://doi.org/10.1186/s13568-014-0051-x.

Satterthwaite, D., McGranahan, G. & Tacoli, C. 2010 Urbanization and its implications for food and farming. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* **365** (1554), 2809–2820. https://doi.org/10.1098/rstb.2010.0136.

Sheeba, G., Jalagam, A. & Venkatasubramanian, P. 2017 Drinking water contamination from peri-urban Bengaluru, India. *Current Science* **113** (9), 1702–1709. Available from: https://www.currentscience.ac.in/Volumes/113/09/1702.pdf

UN-Water 2018 Available from: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html (accessed 26 April 2019).

Wankhade, K. 2015 Urban sanitation in India: key shifts in the national policy frame. *Environment and Urbanization* **27** (2), 555–572. https://doi.org/10.1177/0956247814567058.

WHO 2017 *Guidelines for Drinking Water Quality*. World Health Organization, Geneva, Switzerland.

First received 4 November 2020; accepted in revised form 11 January 2021. Available online 8 March 2021