

## Surveillance of bacteriological quality of drinking water in Chandigarh, northern India

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### ABSTRACT

The study was carried out in Chandigarh, India with the following objectives: (1) to monitor the bacteriological quality of drinking water; (2) to collect data on bacteriological contamination of water collected at point of use; (3) to test both groundwater being supplied through hand pumps and pre-treated water; and (4) to determine the pattern of seasonal variations in quality of water. The community-based longitudinal study was carried out from 2002 to 2007. Water samples from hand pumps and tap water were collected from different areas of Chandigarh following a simple random sampling strategy. The time trends and seasonal variations in contamination of water according to area and season were analysed. It was found that the contamination of water was higher during the pre-monsoon period compared with the rest of the year. The water being used in slums and rural areas for drinking purposes also had higher contamination levels than urban areas, with highest levels in rural areas. This study found that drinking water supply in Chandigarh is susceptible to contamination especially in rural areas and during pre-monsoon. Active intervention from public health and the health department along with raising people's awareness regarding water hygiene are required for improving the quality of drinking water.

**Key words** | Chandigarh, surveillance, variations, water quality

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### INTRODUCTION

Access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection (WHO 2011). One of the most serious problems humanity is facing today is the global water crisis. Development of sustainable and safe drinking water supplies is a global challenge. According to the United Nations third World Water Development Report, more than 600 million people in many parts of the world are forced to live without safe water and sanitation services. The per capita water availability depends on storage capacity. Developed nations are much further ahead in storage capacity than the developing nations. India's per capita storage capacity is 213 m<sup>3</sup> as against 4,733 m<sup>3</sup> and 1,964 m<sup>3</sup> in Australia and the USA, respectively (Mahanti 2010). In most developing cities, population growth precedes the development of an infrastructure capable of handling

water and waste water, which tends to lead to widespread contamination of the groundwater by domestic and industrial effluents (Cheema 1994). Thus, ensuring safety of public water supply systems in the municipal towns and rural areas has remained (posed) the greatest challenge to public health engineers and municipal authorities. While meeting the demands for adequate quantity of water, it is also essential to ensure the quality of water.

The interactions of quality of drinking water with health are multiple. On the most direct level, water can be the vehicle for the transmission of a large number of pathogens leading to various diseases such as diarrhoea, cholera, typhoid, infectious hepatitis and enteric diseases. Epidemics of such diseases have become an annual event in urban, peri-urban and rural areas particularly among low-income groups of people (Lal 1997). Even in the metropolitan

areas and megacities, the operation, maintenance and quality monitoring of drinking water supply systems are extremely inadequate. The service pipes leading to individual houses in India most often have leaking joints leading to the contamination of the water supply. In the rural areas even the rudimentary facilities of water quality monitoring and surveillance are not available.

Despite the fact that India is one of the wettest countries, it is in the midst of a serious water problem. The major reasons are high population density, time and variability of rainfall and increasing depletion and contamination of its surface water and groundwater. Climate change is also affecting the hydrological cycle (Mahanti 2010).

Similar to most cities in India, the public water supply in Chandigarh, Union Territory is managed by a municipal body. The quantity of water supply has increased but to improve its quality a system of monitoring and surveillance for drinking water quality is imperative. Against this background, this study was carried out with the following objectives: (1) to monitor the bacteriological quality of drinking water in Chandigarh, India; (2) to collect information on bacteriological contamination of water collected at point of use in Chandigarh; (3) to test both groundwater and pre-treated water supplied in Chandigarh; and (4) to determine the pattern of seasonal variations in quality of water.

## MATERIAL AND METHODS

### Study area and study design

This was a community-based longitudinal study conducted in Chandigarh, northern India over a period of 5 years (from July 2002 to December 2007). Water samples were collected from tap water and hand pumps covering different areas of Chandigarh to represent the different sources of water used by all sections of society residing in urban, rural and slum areas. A simple random sampling strategy was followed to select representative sites from different areas of Chandigarh. Thus, the drinking water samples were collected from randomly selected taps of houses, commercial establishments and institutional settings, hand pumps, community taps and tube wells in urban, rural and slum areas.

### Collection of water samples

Collection of water samples was carried out by a team comprising postgraduate students in Community Medicine, medical officers/demonstrators along with sanitary inspectors and trained health workers in accordance with the methods described in the WHO *Guidelines for Drinking Water Quality* (WHO 2011). Sampling was carried out bimonthly during May–October and once every month during November–April. A total of 662 drinking water samples were collected from the study area during early morning hours (0700–0900 hours). Samples were collected in wide-mouthed sterile flasks. Samples were sent to the laboratory for examination within 2 hours of collection.

### Laboratory analysis of samples

The water samples were tested for bacteriological contamination by coliform organisms using presumptive coliform count employing the method described by Mackie and McCartney (Senior 1996). The most probable number (MPN) of these bacteria was determined from McCrady's probability tables. Detection of growth of *Vibrio cholerae* was also done using the concentration technique described by Mackie and McCartney (Collee et al. 1968). The samples of tap water which were found contaminated (on first visit) were repeated in the next visit.

### Data analysis

Samples with MPN more than three were considered unfit for drinking purposes. Time trend and variations in contamination in different areas were studied. To explore the seasonal variations in quality of drinking water, the months March–June were considered as the pre-monsoon, July–October as the monsoon and November–February as the post-monsoon season.

On bacteriological examination, if the water sample was found to be contaminated, the Director Health Services Chandigarh Administration was informed so that he could take remedial action as soon as possible. All the hand pumps which were found to supply contaminated water were either marked unfit for drinking or these hand pumps were removed.

## RESULTS

### Level of contamination of water

A total of 662 drinking water samples, 309 from hand pumps and 353 from taps, were collected from the study area. Of the total samples, 140 (21.1%) were found to have MPN more than three and therefore were not fit for drinking purposes. Overall 36.9% (114/309) of the hand pump samples and 7.4% (26/353) of tap water samples surveyed were found to be contaminated (Table 1). The number of contaminated samples was 29% in 2002 followed by 34% in 2003. After that a downward trend in the level of contamination was observed over the study period with the highest in 2003, i.e. 34% followed by 19% and 11% in 2005 and 2007, respectively. On examining the contamination of water samples collected from different sources, it was observed that the level of contamination of tap water reduced over the period from 11% in 2002 to 2% in 2007. Similar observations were recorded in samples collected

from hand pumps. Contamination of such samples was as high as 43% in 2002, decreasing to 26% in 2007. The level of contamination of tap water samples was lower than that of samples collected from hand pumps throughout the study period (Figure 1).

### Contamination of water from different areas and sources

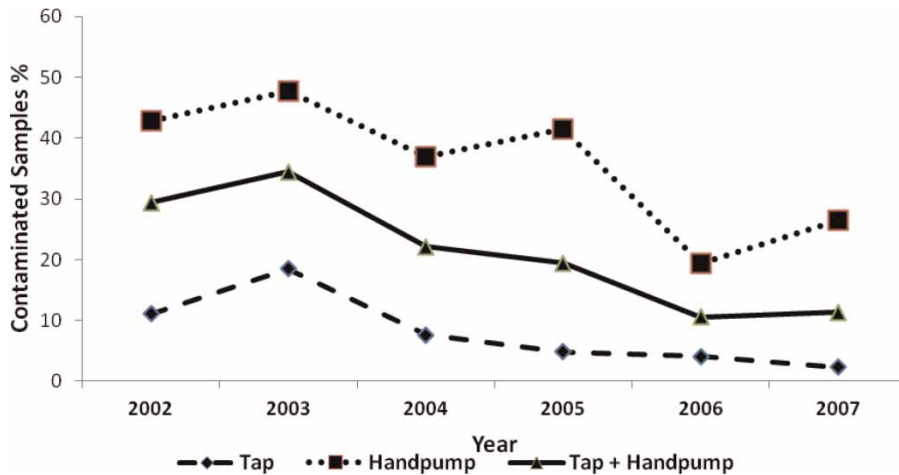
It was seen that incidence of bacteriological contamination of water from all sources was the highest in rural areas (26.7%) followed by 21.0% in urban areas and 18.2% in slums (Figure 2). Five water samples were also detected to be positive for *Vibrio cholerae* during the study period. All these samples were taken from hand pumps.

The extent of contamination of water samples in rural areas remained high over the study period varying from 35% in 2003 to 21% in 2007. Overall contamination level was lower in samples drawn from tap water and slightly varied from 14% in 2002 to 9% in 2007. The samples

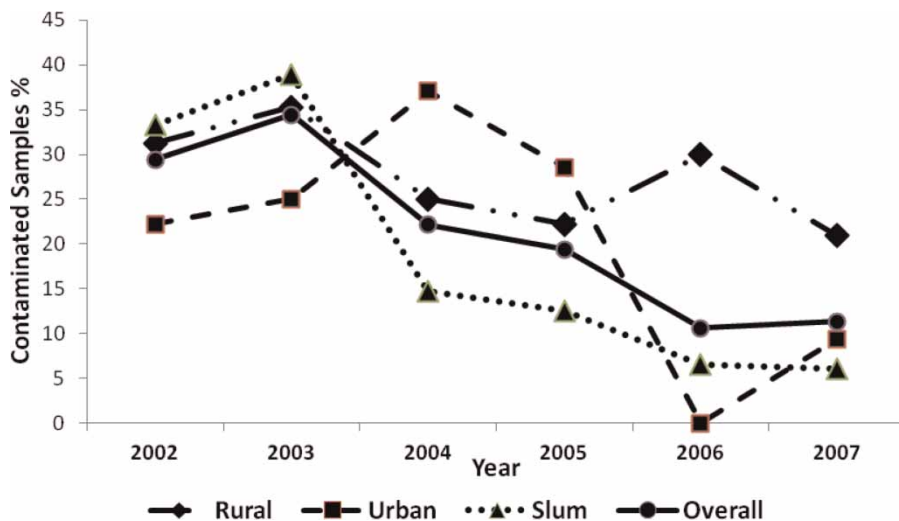
**Table 1** | Distribution of water samples according to area of collection, source and contamination

Area	Source	Water samples	Pre-monsoon N (%)	Monsoon N (%)	Post-monsoon N (%)	Total N (%)	Chi-sq. (p)
Rural	Tap	Collected	23	44	20	87	1.57 (0.46)
		Contaminated	4 (17.4)	6 (13.6)	1 (5.0)	11 (12.6)	
	Hand pump	Collected	22	41	26	89	6.45 (0.04)
		Contaminated	13 (59.1)	17 (41.5)	6 (23.1)	36 (40.4)	
	Total	Collected	45	85	46	176	5.93 (0.05)
		Contaminated	17 (37.8)	23 (27.1)	7 (15.2)	47 (26.7)	
Urban	Tap	Collected	20	47	31	98	1.35 (0.51)
		Contaminated	0	3 (6.4)	2 (6.5)	5 (5.1)	
	Hand pump	Collected	17	24	18	59	2.88 (0.23)
		Contaminated	11 (64.7)	10 (41.7)	7 (38.9)	28 (47.5)	
	Total	Collected	37	71	49	157	2.21 (0.33)
		Contaminated	11 (29.7)	13 (18.3)	9 (18.4)	33 (21.0)	
Slum	Tap	Collected	42	75	51	168	0.48 (0.78)
		Contaminated	2 (4.8)	4 (5.3)	4 (7.8)	10 (6.0)	
	Hand pump	Collected	41	76	44	161	2.99 (0.22)
		Contaminated	17 (41.5)	22 (28.9)	11 (25.0)	50 (31.1)	
	Total	Collected	83	151	95	329	1.69 (0.43)
		Contaminated	19 (22.9)	26 (17.2)	15 (15.8)	60 (18.2)	
Overall	Tap	Collected	85	166	102	353	0.10 (0.95)
		Contaminated	6 (7.1)	13 (7.8)	7 (6.9)	26 (7.4)	
	Hand pump	Collected	80	141	88	309	10.86 (0.00)
		Contaminated	41 (51.3)	49 (34.8)	24 (27.3)	114 (36.9)	
	Total	Collected	165	307	190	662	8.15 (0.02)
		Contaminated	47 (28.5)	62 (20.2)	31 (16.3)	140 (21.1)	

Significant results are shown in bold, taking  $p \leq 0.05$  as level of significance.



**Figure 1** | Variations in level of contamination of water samples by source, collected during 2002–2007 in Chandigarh (N = 662).



**Figure 2** | Variations in level of contamination of water samples by area, collected during 2002–2007 in Chandigarh [N = 662; p (rural) = 0.76, p (urban) = 0.02, p (slum) = 0.00, p (overall) = 0.00].

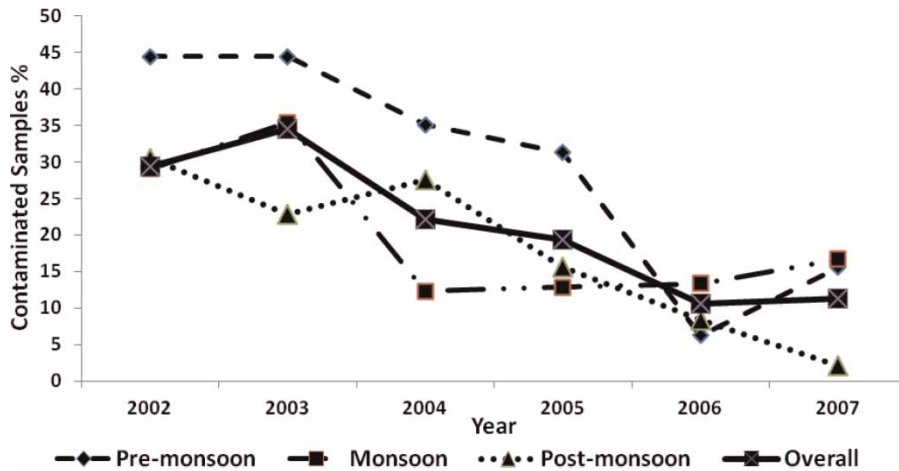
collected from hand pumps in rural areas were found to be highly contaminated. Though no definite pattern in contamination level was observed over the years it decreased markedly from 67% in 2004 to 33% in 2005.

There was a marked reduction in the levels of water contamination in slums over the study period. It reduced to 6.1% in 2007 from 33.3% in 2002. The tap water samples collected from this area showed great improvement in the level of contamination, falling to 0% in 2007 from a high of 33% in 2002. The number of contaminated samples collected from hand pumps also reduced to 12% in 2007 from 33% in 2003.

In urban areas, the extent of contamination decreased from 22% in 2002 to 0% in 2006. There was an absolute reduction in the level of contamination of tap water after 2003. The water samples obtained from hand pumps in these areas were found to be highly contaminated throughout the study period.

#### Seasonal variation in contamination of water samples

It was observed that the level of contamination of water was uniformly high in pre-monsoon season (Figure 3). Monsoon



**Figure 3** | Seasonal variations in level of contamination of water samples collected during 2002–2007 in Chandigarh ( $N = 662$ ).

seasons showed great variation in level of contamination though no definite pattern was observed: 29% in 2002 increasing to 35% in 2003, followed by a decrease to 12% in 2004 and remaining steady after that. Post-monsoon season was observed to have the minimum number of contaminated samples (Table 1, Figure 3). It was noticed that tap water samples showed a marked reduction in the level of contamination with no contamination in pre-monsoon and post-monsoon periods of 2006. In monsoon, the level of tap water contamination was 7% and 6% in 2006 and 2007, respectively. Water from hand pumps, which represents groundwater, was observed to be clearly more contaminated in pre-monsoon and monsoon seasons compared with the post-monsoon period.

Five water samples were also detected to be positive for *Vibrio cholerae* during the study period. All these samples were taken from hand pumps. But no case of cholera was reported during the study period from the study area. No major diarrhoeal epidemic was recorded during the study, although a few sporadic cases were noted during the rainy season.

## DISCUSSION

The United Nations General Assembly (2010) explicitly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realization of all human rights (Resolution A/RES/64/292). Water is essential to sustain life and a

satisfactory (adequate, safe and accessible) supply must be available to all. Improved access to safe drinking water can result in tangible benefits to health as much of the ill health that affects humanity, especially in developing countries, can be traced to lack of safe and wholesome water supply. There can be no state of positive health and well-being without safe water. The WHO guidelines place a great emphasis on the microbiological quality of drinking water (WHO 2011). In India, water quality monitoring is now considered as an important part of government programmes. Since 2000, water quality monitoring has been accorded a high priority and institutional mechanisms have been developed at national, state, district, block and *panchayat* levels. The government has also outlined requisite mechanisms to monitor the quality of drinking water. Bacterial contamination of water continues to be a widespread problem across the country and is a major cause of illness and deaths with 37.7 million affected by water-borne diseases annually. Central pollution control board monitoring results obtained during 2005 indicate that organic pollution continues to be predominant in aquatic resources. The bacteriological examination of drinking water is a sensitive method to assess its quality, though it does not detect contamination with protozoa, virus and fungi. Enumeration of coliforms has been recommended by the Indian Council of Medical Research and has been the main method adopted by many workers (Mehta & Dass 1990; Bandopadhyay *et al.* 1992; Manjula *et al.* 1993; Strauss *et al.* 2001; Brick *et al.* 2004; Wright *et al.* 2004; Marisa *et al.* 2005; Anstiss & Ahmed 2006; Rao *et al.*

2006; Goel *et al.* 2007; Shankar *et al.* 2008; Tambe *et al.* 2008; Eshcol *et al.* 2009). Faecally contaminated water is usually the vehicle for transmission of cholera, either directly or through the contamination of food.

The results of this prospective study showed that the drinking water supply system in Chandigarh is susceptible to contamination. We found that 29% of the drinking water samples were contaminated with coliforms sufficient to exceed the current standards for safe drinking water. This prevalence is much lower compared with other studies conducted in Indian cities such as Madurai (47%), Delhi (43%), Vellore (93%), Bangalore (50%), Hyderabad (4%) and Chandigarh (30%) (Mehta & Dass 1990; Bandopadhyay *et al.* 1992; Brick *et al.* 2004; Shankar *et al.* 2008; Eshcol *et al.* 2009). A community-based study in Maharashtra reported the contamination of water samples to be as high as 49.8%, of which 45.9% of the samples were from piped water supply (Rao *et al.* 2006). However, studies from Mirzapur, Shimla and other parts of Asia and Africa have documented much fewer samples with MPN more than 3 (Manjula *et al.* 1993; Strauss *et al.* 2001; Wright *et al.* 2004; Marisa *et al.* 2005; Anstiss & Ahmed 2006; Tambe *et al.* 2008). The bacteriological analysis of samples of groundwater from district Nainital (Uttarakhand, India) does not show any sign of bacterial contamination in hand pump and tube-well water samples. However, in the case of spring water, six samples exceeded the permissible limit of 10 coliforms per 100 ml of sample (Jain *et al.* 2010).

During five consecutive years the incidence of contamination has shown a downward trend. However, the contamination level is still 21.1%, which needs immediate attention to avoid ill health. Disinfection and proper storage methods must be employed at household level with environmental and engineering measures at community level. Contamination was higher (28%) in water samples obtained from hand pumps indicating contamination of groundwater. It reveals that the upper level of groundwater has been infiltrated with coliforms due to indiscriminate open field defecation and inadequate facilities for human excreta disposal. From 2002 to 2007, the reduction in contamination was greater in tap water than for hand pumps indicating an improvement in the water distribution system in the areas.

The maximum contamination was observed in water samples collected from rural areas. In these areas, over the

years, no change was observed in level of contamination indicating that water supply in rural areas needs to be improved. A study to determine the bacterial contamination in drinking water samples collected from some rural habitations in northern Rajasthan showed that the bacteria belonging to the family Enterobacteriaceae (coliforms) showed the maximum occurrences in water samples (Suthar *et al.* 2009). Contrary to the normal belief that the water sources are maximally infected during monsoon season, it was observed that contamination of water samples was greater in pre-monsoon period compared with monsoon and post-monsoon. This might be because this time of year (March–June) is the hottest requiring greater consumption (quantity) of water which could be more easily met by hand pumps than tap water in slums and rural areas. In slums and urban areas, the tap water supply is available for a limited period of the day only. Thus, increased demand and short supply of water also forced public health authorities to allow people to use hand pumps that were marked unfit for drinking. Although these hand pumps were only permitted to be used for purposes other than drinking, the inhabitants were using these for all purposes including drinking. Other authors have also observed that *Escherichia coli* count was higher in the summer than in the rainy season (Marisa *et al.* 2005). It is well known that *E. coli* are mostly of human and animal faecal origin; hence their increase in water can be correlated with increased human and animal activity.

During the study period, the Government of India took the initiative in February 2006 by launching the National Rural Drinking Water Quality Monitoring and Surveillance Programme that aims towards improving the quality of drinking water (Lal 2009). This led to an increase in the per capita supply of water and was probably one of the leading reasons for the reduction in number of contaminated water samples in the later part of the study period, i.e. 2006 and 2007. On analysing the pattern of contamination of water in the months of monsoon over the period of 5 years, no reduction was observed during this part of the year. The rains during July–September act to amplify contamination of ground and surface water in the insanitary conditions prevailing in the study area. Similar observations have been made by several authors (Mehta & Dass 1990; Bandopadhyay *et al.* 1992; Manjula *et al.* 1993; Strauss *et al.* 2001; Brick *et al.* 2004; Wright *et al.* 2004; Marisa *et al.* 2005; Anstiss & Ahmed 2006; Rao

*et al.* 2006; Goel *et al.* 2007; Shankar *et al.* 2008; Tambe *et al.* 2008; Eshcol *et al.* 2009). Investigation of samples of water and beach sand from the four fish landing centres of Thoothukudi, Tamil Nadu, showed that total coliform bacteria, faecal coliform bacteria and *E. coli* were isolated from all four landing centres from undetectable to the maximum detectable level of over 140 MPN throughout the year with no obvious seasonal variation (Sugumar *et al.* 2008).

Five water samples collected from hand pumps were detected positive for *Vibrio cholerae* during the study period. But no case of cholera or major diarrhoeal epidemic was recorded during the study period from the study area.

## CONCLUSION

Improved access to safe drinking water will help to improve quality of life as most of the communicable illnesses, especially in developing countries, are due to lack of safe and wholesome water supply. To improve quality, it is essential to improve the monitoring mechanisms at all levels of the system. This study found that drinking water supply in Chandigarh is susceptible to contamination. Contamination was greater in rural and slums areas than urban areas, with highest levels reported in rural areas. It was also observed that contamination level was higher in pre-monsoon season rather than monsoon season, with significant annual variations except in rural areas. Increased demand and short supply during hot weather increased the use of hand pumps for drinking water purposes. Hence, the present paper strongly advocates a more intensive and active intervention from public health engineering and the health department to reduce the problem of water contamination in order to combat rampant water-borne and water-related diseases in these areas. Education level, increased public awareness and their participation are also paramount prerequisites for better water management.

## REFERENCES

- Anstiss, R. G. & Ahmed, M. 2006 A conceptual model to be used for community-based drinking water improvements. *J. Health Popul. Nutr.* **24** (3), 262–266.
- Bandopadhyay, S., Banerjee, K., Khanna, K. K., Sharma, R. S. & Verghese, T. 1992 Drinking water quality and diarrhoea in Delhi. *J. Com. Dis.* **24**, 156–158.
- Brick, T., Primrose, B., Chandrasekhar, R., Roy, S., Muliylil, J. & Kang, G. 2004 [Water contamination in urban south India: household storage practices and their implications for water safety and enteric infections](#). *Int. J. Hyg. Environ. Health* **207**, 473–480.
- Cheema, G. S. 1994 Priority urban management issues in developing countries: the research agenda for the 1990s. In: *Mega City Growth and the Future* (R. J. Fuchs, E. Brennan, J. Chamie, F. C. Lo & J. I. Uitto, eds). United Nations University Press, Tokyo, pp. 412–428.
- Collee, J. G., Fraser, A. G., Marmion, B. P. & Simmons, A. 1968 In: *Practical Medical Microbiology*, 11th edn (Mackie & McCartney, eds). Churchill Livingstone, Edinburgh, p. 268.
- Eshcol, J., Mahapatra, P. & Keshapagu, S. 2009 [Is fecal contamination of drinking water after collection associated with household water handling and hygiene practices? A study of urban slum households in Hyderabad, India](#). *J. Water Health* **7** (1), 145–154.
- Goel, N. K., Bhatnagar, T., Sharma, M. K., Verma, A., Agarwal, N., Chander, J., Gupta, V. & Swami, H. M. 2007 Surveillance of quality of drinking water. *Bahrain. Med. Bull.* **29** (2), 53–56.
- Jain, C. K., Bandyopadhyay, A. & Bhadra, A. 2010 [Assessment of ground water quality for drinking purpose, District Nainital, Uttarakhand, India](#). *Environ. Monit. Assess.* **166** (1–4), 663–676.
- Lal, S. (ed.) 1997 Investing in safe drinking water in rural areas. *Indian J. Commun. Med.* **22**, 91–95.
- Lal, S. 2009 National rural water supply and sanitation programme. In: *Textbook of Community Medicine: Preventive and Social Medicine*, 2nd edn (S. Lal, ed.). CBS Publishers, New Delhi, pp. 238–241.
- Mahanti, S. 2010 Challenges of water management in the 21st century. *Dream 2047* **12** (5), 22, 35.
- Manjula, S., Rajendran, P., Balakrishnan, P., Kannan, I. & Thyagarajan, S. 1993 Assessment of bacteriological quality of potable water from Madras city. *Indian J. Med. Microbiol.* **11** (4), 234–237.
- Marisa, M. H., Yolanda, L. V., Sergio, P. L., Juan, J. C., Francisco, R. C. & Gonzalo, C. R. 2005 [Longitudinal study of microbial diversity and seasonality in the Mexico City metropolitan area water supply system](#). *Appl. Environ. Microbiol.* **71** (9), 5129–5137.
- Mehta, M. & Dass, A. V. 1990 Study on water quality: bacteriological aspect. *Health Popul. Perspect Issues.* **13**, 140–148.
- Rao, P. N. S., Suresh, K. & Basavarajappa, K. G. 2006 Bacteriological quality of potable water in Davangere City. *J. Commun. Dis.* **38** (4), 381–384.
- Senior, B. W. 1996 Examination of water, milk, food and air. In: *Mackie and McCartney Practical Medical Microbiology*, 14th edn (J. G. Collee, J. P. Duguid, A. G. Fraser & B. P. Marmion, eds). Churchill Livingstone, Edinburgh, pp. 883–921.
- Shankar, B. S., Balasubramanya, N. & Reddy, M. T. 2008 Hydrochemical assessment of the pollutants in waters of

- Vrishabhavathi Valley Basin in Bangalore (India). *J. Environ. Sci. Eng.* **50** (2), 97–102.
- Strauss, B., King, W., Ley, A. & Hoey, J. R. 2001 **A prospective study of rural drinking water quality and acute gastrointestinal illness.** *BMC Public Health* **1**, 8.
- Sugumar, G., Chrisolite, B., Velayutham, P., Selvan, A. & Ramesh, U. 2008 Occurrence and seasonal variation of bacterial indicators of faecal pollution along Thoothukudi Coast, Tamil Nadu. *J. Environ. Biol.* **29** (3), 387–391.
- Suthar, S., Chhimpa, V. & Singh, S. 2009 **Bacterial contamination in drinking water: a case study in rural areas of northern Rajasthan, India.** *Environ. Monit. Assess.* **159** (1–4), 43–50.
- Tambe, P. V., Daswani, P. G., Mistry, N. F., Ghadge, A. A. & Anita, N. H. 2008 A community based bacteriological study of quality of drinking water and its feedback to a rural community in Western Maharashtra, India. *J. Health, Popul. Nutr.* **26** (2), 139–150.
- United Nations General Assembly 2010 *The Human Right to Water and Sanitation.* Resolution A/RES/64/292, United Nations General Assembly, 28 July 2010. [www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E](http://www.un.org/es/comun/docs/?symbol=A/RES/64/292&lang=E) (accessed 31 March 2014).
- WHO 2011 *Guidelines for Drinking Water Quality*, 4th edn. World Health Organization, Geneva.
- Wright, J., Gundry, S. & Conroy, R. 2004 **Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use.** *Trop. Med. Int. Health* **9** (1), 106–117.

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