

The bacteriological quality of drinking water in Haldwani Block of Nainital District, Uttarakhand, India

Vinita Rawat, Sanjay Kumar Jha, Arundhati Bag, Monil Singhai and Chandra Mohan Singh Rawat

ABSTRACT

A cross-sectional study was conducted to assess the bacteriological quality of water in Haldwani block, Nainital District, India. Stratified random sampling was used to categorize water sources and consumer points. In total, 108 samples were collected: 15 from the Gola river, 51 from water taps, 24 from water treatment plants and 18 from tube wells. Samples were tested for coliforms by the most probable number technique. Identification of species was done by standard procedures. Of 108 water samples, 58.8% were found to be polluted. All samples of water ($n = 15$) from different sites of the Gola river were found to be highly contaminated. Out of 24 water treatment plant samples, four samples were found unsatisfactory, while more than half (51.6%) of its supplies to water taps were polluted. From tube wells and their water taps, 88.8 and 60% samples were found safe for drinking respectively. Bacterial contamination of water treatment plants and their supplies indicates significant disparities in the efficiency of water treatment processes. Contamination of water taps of tube wells suggests leakage of pipes. There is an urgent need to improve these services to ensure the supply of safe water for consumers.

Key words | bacteriological analysis, coliform, *Escherichia coli*, most probable number

Vinita Rawat (corresponding author)
Sanjay Kumar Jha
Arundhati Bag
Monil Singhai
Chandra Mohan Singh Rawat
Govt. Medical College,
Haldwani,
District Nainital,
Uttarakhand,
India
E-mail: drvinitarawat31@rediffmail.com

INTRODUCTION

Water is essential to sustain life, and every effort should be made to provide satisfactory supplies of drinking water to all (WHO 2011). The microbiological contamination of water is a significant global problem. It is estimated that unsafe water and a lack of basic sanitation led to at least 1.6 million deaths in children under the age of 5 years in 2004, and 1.8 million deaths, including adults, occur from diarrhoeal diseases every year (WHO 2006). A significant amount of disease could be prevented, especially in developing countries, through access to improved water sources.

The World Health Organization (WHO) and United Nation Children's Fund (UNICEF) Joint Monitoring Program (2008) defines improved water sources as piped water, public taps, stand pipes, tube wells, boreholes,

protected dug wells, protected springs and rainwater collection. However, microbial contamination between the source and point of consumption is widespread; this can be due to contamination of water during collection, transport and storage.

Haldwani town is a gateway of Kumaun region of Uttarakhand with a population of 129,015 (Government of India 2001). Minimum temperature varies from 5 to 10 °C and maximum from 38 to 40 °C. Average annual rainfall is approximately 1,505 mm. Residents of Haldwani are served with water through a piped water supply system obtained from two different sources, the River Gola and tube wells. The present study aimed to assess bacteriological quality of water of Haldwani town.

MATERIALS AND METHODS

This cross-sectional study was undertaken in Haldwani Block of Nainital district from December 2008 to June 2009. In Haldwani town, the Gola river contributes nearly half (44%) of current total water production. The raw water intake for this source is about 1 km downstream of the Gola canal head works. The design discharge is 930 million litres per day (mld), out of which only 28 mld is allowed for drinking purposes. Water is taken through a grit chamber from where it flows by gravity about 1 km through pipelines up to the main waterworks located at Kathgodam for treatment. Clean water is stored in a ground level service reservoir (GLSR) at this waterworks and distributed to six more GLSRs for supply in the distribution network. Another source of water is Shitlahat spring. However, this source has been depleted to a negligible level. In addition to the river, 28 tube wells have also been constructed in different part of Haldwani. These tube wells are directly connected with the existing distribution network and contribute more than half (about 56%) of present total water production. Some communities in the outskirts, having no access to piped water, obtain it from the river.

Number of samples tested

Bacteriological analysis of water was done from the source to the common tap (referred to as a standpost). Water samples were taken as follows: 15 from the Gola river (five samples from different sites of the river, once per 2-month period over 6 months); 24 from water treatment plants (one from each GLSR per 2-month period over 6 months); 31 from water taps of treatment plants (samples from 12 pipelines of the six main GLSRs, once per 2-month period over 6 months; however, five samples could not be taken in the last month of study due to ongoing repair work on five pipelines), 18 from tube wells and 20 from water taps of tube wells. Since pipelines from tube wells are directly connected to the existing distribution network of the town and there is mixing of both tube well water and water from GLSRs (Gola river

water), water from one zone travels freely to other zones. Therefore, samples were taken only from those tube wells where distribution was clearly defined (Figure 1).

Bacteriological analysis

Water samples of 100 ml from each source were collected in 500 ml capacity sterilized bottles, containing 0.1 ml of fresh 1.8% (w/v) aqueous solution of sodium thiosulfate, using standard water collection techniques (Senior 1996). These samples were labelled and transported to the Laboratory of the Microbiology Department, Government Medical College, Haldwani, within 4 h of collection.

In the laboratory, all the samples were subjected to the Multiple Tube Test for determination of most probable number (MPN) of coliforms and faecal *Escherichia coli*. Aseptically, one 50 ml volume and five 10 ml volume of water were added to bottles and tubes containing 50 and 10 ml each of double-strength MacConkey broth. Additionally five 1 ml volume of water sample were added to tubes containing 5 ml of single strength MacConkey broth. All the bottles and tubes contained inverted Durham tubes and were pre-sterilized in an autoclave. All the bottles and tubes were incubated at 37 °C for 48 h. The bottles or tubes which showed acid and gas production were considered positive for coliforms. From the distribution of these positive bottles and tubes, MPN of total coliforms was determined by referring to McCarty's probability table for estimation of total coliforms. All the bottles and tubes positive for total coliforms were subcultured into 10 ml of single strength MacConkey broth with inverted Durham tubes and 5 ml of peptone water to determine presence of faecal *E. coli*. These tubes were incubated at 44 °C for 24 h. The tubes showing acid and gas and indole production, were taken as positive for faecal coliforms (Ejikman Test positive). All the bottles and tubes positive for total coliforms were also subcultured on blood agar and MacConkey agar. Colonies from these plates were identified by conventional biochemical methods according to standard microbiological techniques (Colle et al. 1996).

Samples with 0 coliform/100 ml of original water are to be considered excellent, with 1–10 coliform(s) as acceptable and above 10 coliforms as polluted (Bureau of Indian Standards 1991). For simplicity, samples with 0–10 coliform(s)/

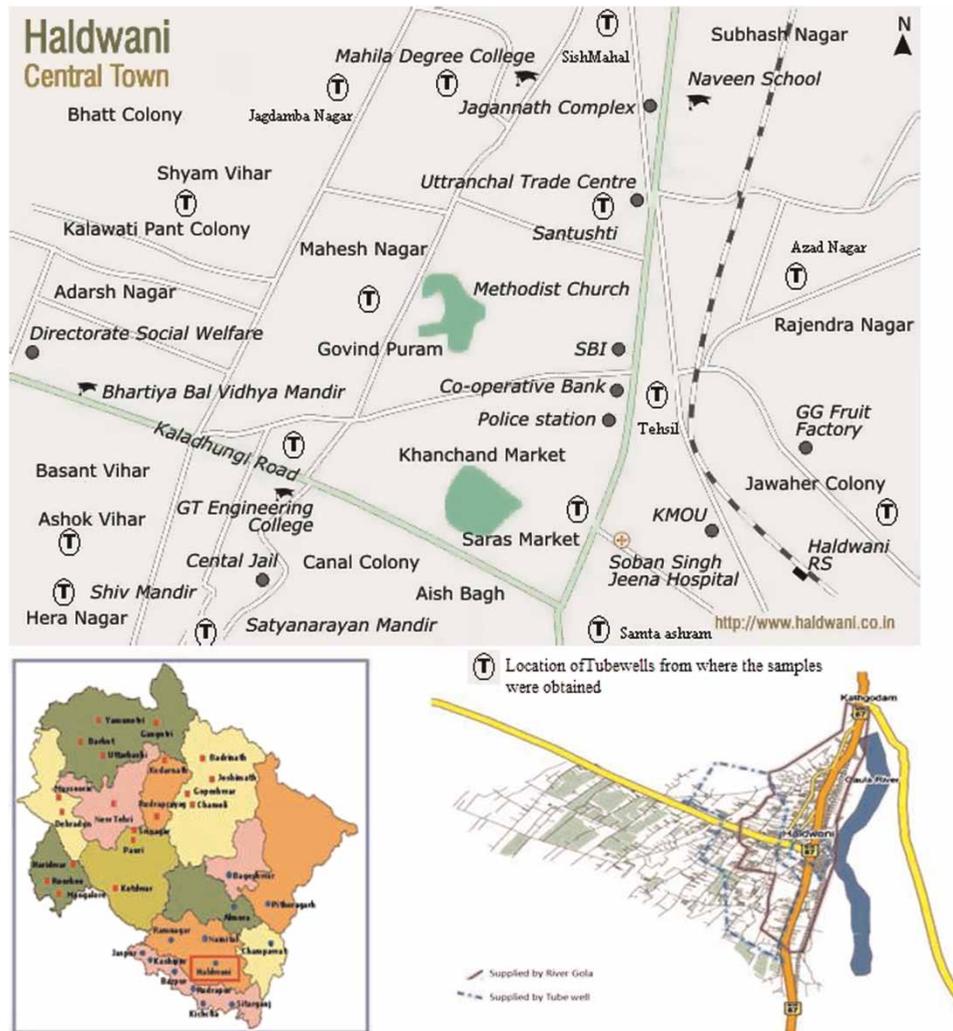


Figure 1 | Uttarakhand map showing location of Haldwani town (left, below), area of Haldwani town supplied by River Gola and tube wells (right, below).

100 ml of original were considered to be acceptable and above 10 as polluted. SPSS v 16 was used to process and analyse the data. The chi-square test and Fisher's exact test were used to determine whether statistically significant differences existed in the contamination levels between different sources.

Bacteriological analysis for the presence of specific-pathogen-like *Salmonella* sp. and *Vibrio cholerae*

Selective media were used. For *Salmonella*, an equal volume of water was added to double-strength selenite broth followed by incubation and subculture on deoxycholate citrate agar. For isolation of *Vibrio*, alkaline peptone water

was mixed with nine times its volume of water, incubated and subcultured on thiosulfate citrate bile salt sucrose agar (Senior 1996).

RESULTS

The distribution of water resources of Haldwani town according to presumptive coliform count is presented in Table 1. All samples of water ($n = 15$) from Gola river sites were found to be highly polluted as MPN counts were up to 1,600/100 ml. Of 24 samples of water at water treatment plants, one-third were recorded as excellent, half as acceptable and the others as polluted. Of 31 samples of tap water

Table 1 | Analysis of water from different sources of Haldwani

Sources of water	Excellent MPN (0) No. (%)	Acceptable MPN (1–10) No. (%)	Unsatisfactory MPN (>10) No. (%)	Total No. (%)	Statistical tests
Gola river	0	0	15 (100)	15 (100)	$\chi^2 = 35.4$, $df = 4^a$ $p = 0.001$
Treatment plant	8 (33.3)	12 (50.0)	4 (16.6)	24 (100)	
Water taps of treatment plant	9 (29.0)	6 (19.3)	16 (51.6)	31 (100)	
Tube well	8 (44.4)	8 (44.4)	2 (11.1)	18 (100)	
Water taps of tube well	2 (10.0)	10 (50.0)	8 (40.0)	20 (100)	
Total	27 (25.0)	36 (33.3)	45 (41.7)	108 (100)	

^aColumns of excellent and acceptable water have been combined for chi-square test.

supplied by water treatment plants, more than half were found to be unsatisfactory, almost one-third were excellent and six remained satisfactory. Of 18 water samples from tube wells eight were excellent, eight were acceptable and two were unsatisfactory. Of 20 samples from water taps of tube wells, eight were unsatisfactory, 10 acceptable and only two excellent. Statistical analysis showed that significant ($\chi^2 = 35.4$, $p = 0.001$) differences exist among the five different types of water with regard to microbial quality measures.

The tube well water was superior to the tube well tap water in bacteriological quality. The number of positive samples for bacterial growth was significantly higher in the tube well tap water samples (90%) (Fisher's exact test $p = 0.02$) in comparison to samples directly taken from tube wells (55.6%) (Table 2) and growth of *E. coli* was significantly greater in the tap water samples. Other bacteria isolated from tube well water were *Pseudomonas* sp. (11%) and *Citrobacter* sp. (4.5%). *Klebsiella* sp. (5%) was also isolated from tube well tap water samples, but *Pseudomonas* sp. and *Citrobacter* sp. were not detected.

Table 3 showed the diversity of faecal bacterial contaminants isolated from Gola river as follows: *E. coli*, *Klebsiella* sp., *Pseudomonas* sp. and *Citrobacter* sp. in 100% of samples ($n = 15$) while of all samples ($n = 24$) at water treatment plants, bacteria isolated were *E. coli* in 66%, *Pseudomonas* sp. in 16.6% and *Citrobacter* sp. in 16.6% of the samples. *V. cholerae* and *Salmonella* sp. were not detected from any sample of water. The number of positive samples for bacterial growth and *E. coli* was significantly higher in Gola river and water taps of filtration plants in comparison to water of treatment plant ($\chi^2 = 6.2$, $p = 0.04$). There was also statistically higher level of *Pseudomonas* sp. and *Citrobacter* sp. in river water and water treatment plant in comparison to water taps.

DISCUSSION

In the present study, Gola river water was found to be highly unsatisfactory with MPN counts up to 1,600/

Table 2 | Frequency distribution of bacterial species isolated in water samples from tube wells and their taps in different localities of Haldwani supplied by tube wells

Microorganism	Total ($n = 38$) No. (%)	Tube wells ($n = 18$) No. (%)	Water taps ($n = 20$) No. (%)	Statistical tests
Growth present	28 (73.7)	10 (55.6)	18 (90.0)	Fisher's exact test $p = 0.02$
<i>Escherichia coli</i>	25 (68.5)	08 (44.4)	17 (85.0)	Fisher's exact test $p = 0.01$
<i>Klebsiella</i> sp.	1 (02.6)	0	1 (05.0)	
<i>Pseudomonas</i> sp.	2 (05.2)	2 (11.0)	0	
<i>Citrobacter</i> sp.	1 (02.6)	1 (4.5)	0	
<i>Salmonella</i> sp.	0	0	0	
<i>Vibrio cholerae</i>	0	0	0	

Table 3 | Frequency distribution of different bacterial species isolated in water samples from Gola river, Kathgodam water treatment plant and tap water

Microorganism	Total (n = 70) No. (%)	Gola river (n = 15) No. (%)	Treatment plant (n = 24) No. (%)	Water taps (n = 31) No. (%)	Statistical tests
Growth present	53 (75.7)	15 (100)	16 (66.6)	22 (70.9)	$\chi^2 = 6.2$, df = 2 $p = 0.04$
<i>Escherichia coli</i>	53 (75.7)	15 (100)	16 (66.6)	22 (70.9)	$\chi^2 = 6.2$, df = 2 $p = 0.04$
<i>Klebsiella</i> sp.	18 (29.7)	15 (100)	0	3 (9.7)	$\chi^2 = 55.8$, df = 2 $p = 0.001$
<i>Pseudomonas</i> sp.	20 (28.6)	15 (100)	4 (16.6)	1 (3.2)	$\chi^2 = 48.9$, df = 2 $p = 0.001$
<i>Citrobacter</i> sp.	20 (28.6)	15 (100)	4 (16.6)	1 (3.2)	$\chi^2 = 48.9$, df = 2 $p = 0.001$
<i>Salmonella</i> sp.		0	0	0	
<i>Vibrio cholerae</i>		0	0	0	

100 ml. It was noticed that there are many animals and humans trespassing, along with defecation surrounding the Gola river. Goel *et al.* (2007) in their study from Kangra also found the river and spring was highly contaminated with MPN counts in some places up to 1,600/100 ml. In our study, 33% of samples from water treatment plants were polluted with an average MPN count of 50, suggesting inadequate treatment of water. To ensure a safe and potable water supply, water should pass through three stages: storage, filtration and disinfection. Storage removes 90–95% of the physical impurities by sedimentation. It also allows penetration of light which results in oxidation of organic matter by aerobic bacteria, thus decreasing free ammonia content of water. It also decreases total bacterial count by as much as 90%. Filtration is the second stage of water purification and results in 98–99% drop in bacterial count apart from other impurities. Disinfection is the final stage of purification and results in destruction of all pathogenic organisms left after storage and filtration. All these stages are required in series for purification of water. If even one stage is bypassed, the water may not be rendered fit for drinking purposes. Contaminated water should be treated before public distribution to reduce contaminants and thus make it suitable for human consumption.

The old, dilapidated water distribution network in Haldwani town develops leaks in pipes, most of which are buried under roads and remain undetected. This results in entry of polluted water into the pipes when the supply is closed. Pioneer work has been done by scientists in the field of water supply engineering and expert systems have been developed to address such issues (Chau *et al.* 2002; Muttil & Chau

2007). As also observed in the present study, water quality further deteriorated in tap water, pumped by water treatment plants, indicating that overall engineering aspects of laying pipelines from treatment plant to common taps is not satisfactory. The emphasis hitherto had been on supplying an adequate quantity of piped water with little attention to quality. However, no diarrhoeal epidemic was recorded during the study period, although sporadic cases were noted. The relation between prevalence of diarrhoea and quality of drinking water is more complex (Tambe *et al.* 2008). Most water treatment/storage interventions, sanitation practices and health education in several other studies have been shown to be effective, and yet high indicator bacteria counts were seldom associated with diarrhoea (Gundry *et al.* 2004). Factors such as the immune status of the community and interplay of bacterial species in the water sources (Tambe *et al.* 2008), along with approaches towards improved sanitation and handling practices at the household level and using filtered and/or boiled water could possibly impact the level of diarrhoeal diseases in the community.

Furthermore, the present study suggests that groundwater samples in Haldwani are better than found in a study conducted by Goel *et al.* (2007) who found that in their study area groundwater was highly contaminated with faecal material. However, in the present study, 40% of samples from tube well water taps and 51% of samples of tap water from treatment plants were polluted; this is a matter of concern, and might lead to outbreaks in the future. Independent monitoring of the quality of drinking water by the Department of Microbiology or Community Medicine needs to be done on a regular basis. Further, as

MPN count is a relatively simple and sensitive test for detection of coliform bacteria and henceforth an indicator of water quality, this can be used at sub-centre levels after imparting adequate basic training to health workers.

Limitations of our study were that our sample size was small; if we could have included several similar towns in the survey, some general conclusions about water quality in such regions could have been reached. Bacteriological analysis was only done from main sources and common taps; water from households was not tested due to technical and logistical problems. Outcome of testing may not reflect the quality of water actually consumed at home.

CONCLUSIONS AND RECOMMENDATIONS

The water sources (Gola river water and tap water) of the study areas were highly bacteriologically contaminated and so not fit for drinking. Bacterial contamination of treated water plants and its supplies indicates significant disparities in the efficiency of water treatment processes. After filtration at a treatment plant, water should be chlorinated properly. Tube well water was found to be satisfactory, whereas contamination of water taps of tube well supplies suggests leakage of pipes. There is an urgent need to improve these services to ensure safe water for consumers. Although Uttarakhand Peya Jal Nigam certify water quality regularly, independent monitoring of drinking water needs to be done on a regular basis with a system of feedback and corrective measures.

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