Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.903863

54 (2015) 2422–2431
May

Taylor & Francis
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Study of water quality improvements at a riverbank filtration site along the upper course of the River Ganga, India

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Received 3 June 2013; Accepted 27 February 2014

ABSTRACT

Along the upper course of the River Ganga, at Haridwar (India), production wells (PWs) (each of 10 m diameter), located at a distance of 4–250 m from the bank of either river or canal, are being used to abstract mixture of groundwater and river/canal water after passage through the soil. Water samples from river/canal and 16 PWs were analyzed in monsoon and non-monsoon periods from 2005 to 2006. A comparison of water quality clearly differentiates PW water from the surface water. TDS, conductivity, alkalinity, and hardness were found to be more in water from the PWs. During monsoon, surface water exhibited increased turbidity by 100–150 times, bacterial count by around 10 times, and conductivity by around 1.2 times compared to non-monsoon samples. The bacteriological quality of the bank filtrate was not found to vary significantly. The conductivity, however, was reduced by 20% in non-monsoon period. In monsoon months, riverbank filtration resulted in reduction of turbidity and total coliform by 2.9 and 2.6 logs, respectively. Removal of turbidity and coliform in non-monsoon was more than 0.4 and 4.2 logs, respectively. UV absorbance measured in non-monsoon period was found to be reduced by 0.4 log.

Keywords: Water supply; River bank filtration; Groundwater/surface water interaction; Production wells; India

1. Introduction

The existing water supply systems are under tremendous stress to meet the increasing water demand due to increasing population. Surface water has been the primary source of drinking water for major metropolitan cities in India augmented with groundwater. Nowadays, the development of a new township is mostly based on groundwater resources. Decreasing level of groundwater and increasing cost of pumping groundwater are not in tune with the environmental obligations for future generation. The preservation of the environment without compromising with the quality and quantity of water required to sustain the growing population has become a challenge of the day. It is time, perhaps, to revive traditional technologies of water supply. A traditional method of drawing surface water is through the column of bed and bank material. This natural filtration process wherein surface water is filtered

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through the bank or bed of a river is referred as river bank filtration (RBF).

The process of RBF is initiated by lowering of a groundwater table below that of an adjoining surface water table. If no artificial (e.g. brick- or concrete-lined bed) or natural (e.g. a low-hydraulic-conductivity layer such as clay) barriers exist, the difference in water levels causes the surface water to infiltrate through the permeable riverbed and bank and/or lakebed and/or bank into the aquifer. The production may be the direct result of an influent river under natural conditions or it may be induced by groundwater production wells (PWs). Wells for extracting bank filtrate may be either vertical or horizontal [1].

The aquifer serves as a natural filter and also biochemically attenuates potential contaminants present in the surface water. Compared with direct surface water abstraction, bank filtration with its effective natural attenuation processes eliminate bacteria, biodegradable compounds, parasites, particles, suspended solids, viruses, etc.; partly eliminates adsorbable compounds; and equilibrates temperature and concentrations of dissolved constituents in the bank filtrate [2]. The success of such scheme is dependent on the microbial activity and chemical transformations that are commonly enhanced in the clogging layer within the riverbed compared to those that take place in surface or groundwaters [3].

Bank filtration has been shown to be effective in removing many of the contaminants present in surface water. Studies have shown that bank filtration is a highly efficient method for significant removal of turbidity [4–8], natural organic matter, pesticides, and pharmaceuticals [9–15], salinity [5], as well as taste- and odor-causing compounds, which may not be removed from the surface water by conventional treatment methods [16,17]. The potential of RBF systems to provide a significant barrier to micro-organisms has also been observed [7,8,14,18–23]. Giardia and cryptosporidium have been shown to be removed significantly in drinking water applications when flow path length and filtration times are sufficient [18,22].

In many countries of the world, alluvial aquifers hydraulically connected to a water course are preferred sites for drinking water production, given the relative ease of shallow groundwater exploitation, the generally high production capacity, and the proximity to demand areas [10]. Groundwater derived from infiltrating river water provides 45–50% of potable supplies in the Slovak Republic & Hungary, 16% in Germany, and 5% in the Netherlands. RBF has also been used in many communities in the US for about five decades [12]. A number of Indian cities, with source waters of significantly varying quality, are using RBF. In most of these cities, no significant additional treatment is provided to the filtrate for their water supply [1].

The RBF scheme in Haridwar, India, (Fig. 1) provides more than 35% of the drinking water of the town. Bank filtrate is abstracted through 25 large-diameter PWs (open bottom) located between the River Ganga and the Upper Ganga Canal (UGC) and is supplied to 0.2 million people.

Previously, only PW no. 18 (PW 18) was investigated for water quality at Haridwar during monsoon and non-monsoon periods [8]. PW 18 is located between the river and UGC. The sub-surface flow from the river, UGC, and New Supply Channel (NSC) feed the well. Most of the organics, bacteria, and turbidity were removed during RBF.

The efficiency of RBF depends on the travel time which is decided by location of the well. The productions wells in Haridwar, drawing river bank filtrate are located at distance varying from 4 to 250 m from the river. It therefore became necessary to assess the quality of river bank filtrate obtained from the other 15 PWs along with PW 18. With this objective in mind, a study was undertaken. To assess the quality of water from 16 PWs, water samples were collected in non-monsoon and monsoon months during 2005–2006.

2. Study site and its hydrogeology

The River Ganga originates from Gaumukh (Gangotri glacier) and travels a total length of 2,510 km. At Haridwar, a significant portion of the main stream is diverted into the UGC which is an irrigation channel that feeds the alluvial tract lying between the rivers Ganga and Yamuna. At Bhimgoda, a barrage or head work on the River Ganga was constructed near Pant Dweep Island, Haridwar. It provides an additional supply of water to UGC through the NSC.

Haridwar (latitude 29°58′N and longitude 78°13′E) town is the district headquarters in the State of Uttarakhand, India. It is situated in the foothills of Shivalik Range Mountains and lies on the right bank of River Ganga. It is about 60 km in length from east to west and about 80 km in width from north to south. The town is among the most important pilgrimage centers of Northern India, where people from all parts of the country congregate every year to have a holy dip in the River Ganga.

Piped water supply in the town was first introduced in 1927 and has since been reorganized/augmented several times. For the supply, water is stored at several points in clear water underground and overhead reservoirs in the town through the force mains from tube and PWs, constructed in several

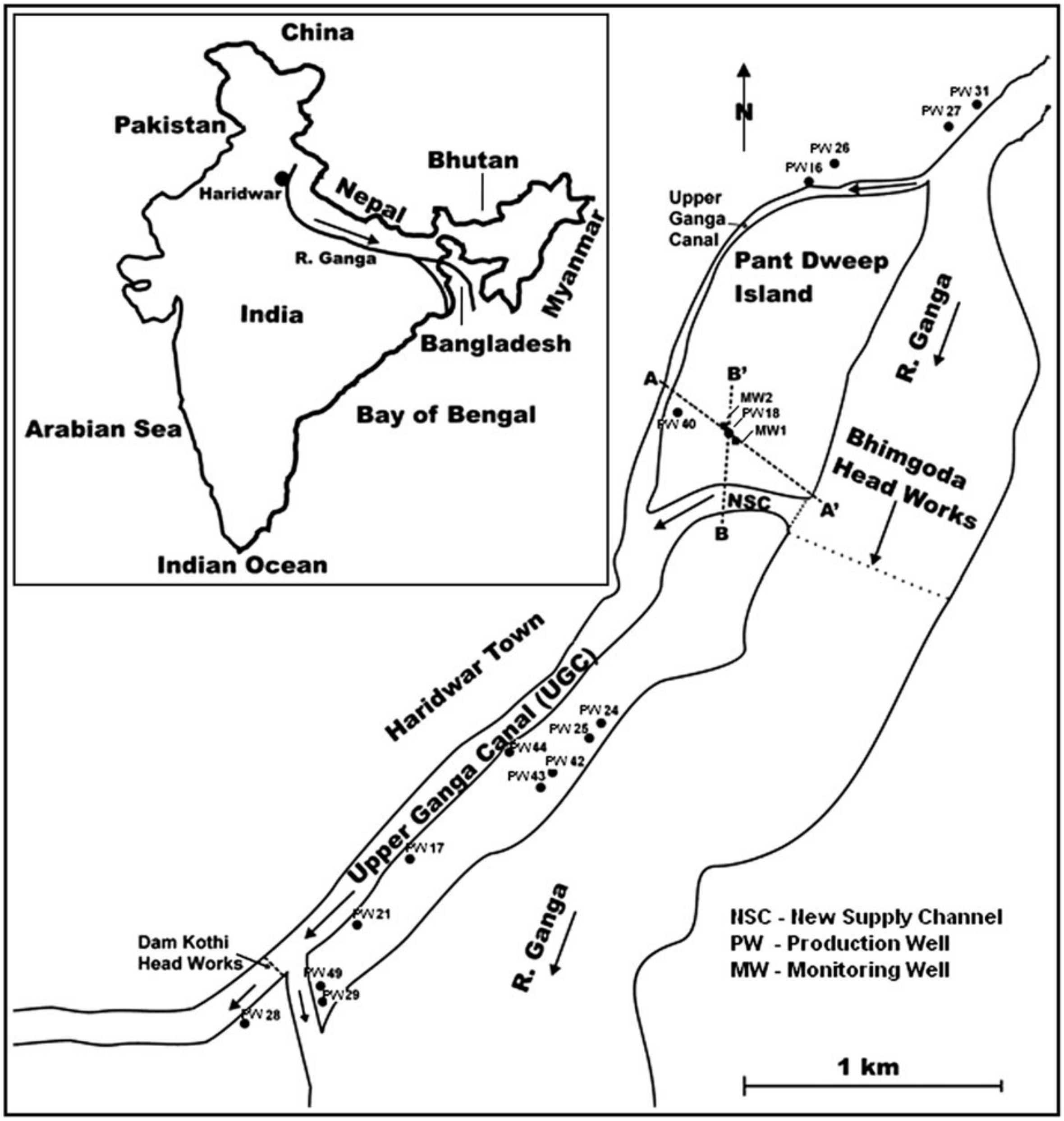

Fig. 1. Location of production and monitoring wells and watercourses at Haridwar [8].

areas of the town. Water is distributed through pipe lines having individual house water connections. At the time of crisis, when water demand is more and the present network is inadequate to cope up with the requirement, direct pumping in distribution mains is also resorted to from tube/PWs. The entire town is divided in six zones and the water supply of each zone is practically separate. In the present system of water supply, there are 25 PWs, and 27 tube wells having a total discharge of about 64 ML/d. With unexpected increase in permanent, camping, and floating populations of the town, the available water falls short of the demand. All the PWs together pump 22 million liters of water everyday. These wells are 10 m in diameter and depths below ground level range from 6.5 to 10.7 m. The walls of the caissons are made up of 65-cm thick-reinforced brick work. Weep holes, filled using graded filter media sized 15 cm × 15 cm (outer face) and 30 cm × 30 cm (inner face), are provided in two rows in the walls. The bottoms of the wells are open and packed with gravel and coarse sand to allow the water to enter. The region where

Table 1
Dimension and discharge capacities of PWs

Sl. no.	Name of well	Dia (m)	Depth (mbgl)	Distance from river (m)	Distance from canal (m)	Installed capacity of pumps (LPM)	Running hours per day	Average water abstraction (KL/d)
1	PW 43	10.50	10.6	*4*	235	1,800	16	1,512
2	PW 28	10.75	10.4	–	*8*	1,600	24	1920
3	PW 40	10.35	7.50	650	*10*	1,500	20	1,440
4	PW 16	10.10	7.35	450	*10*	600	13.5	648
5	PW 24	10.20	10.7	*12*	230	1,700	24	1836
6	PW 25	10.40	7.90	*15*	230	1,700	24	2,448
7	PW 29	10.75	10.3	65	*15*	1,500	24	1980
8	PW 42	10.50	10.5	*15*	235	1,800	16	1,512
9	PW 21	10.80	6.85	95	*26*	1,400	24	1,764
10	PIW 49	10.60	9.20	35	*28*	1,800	24	1,728
11	PW 44	10.30	8.80	210	*30*	1,600	24	1,536
12	PW 17	10.00	8.80	210	*30*	2,800	24	4,032
13	PW 31	10.20	7.90	*50*	–	1,400	24	2016
14	PW 26	10.00	8.95	300	*50*	1,400	24	1,680
15	PW 18	10.00	9.05	320	*115*	1,140	8	547
16	PW 27	10.30	6.50	*250*	–	1,650	24	1980

Note: mbgl—meter below ground level.

wells are located is predominately urban [8]. A few details of PWs are given in Table 1 (data compiled from the information provided by Uttarakhand Jal Sansthan, Dehradun).

3. Methodology

Three sets of subsurface water samples from the 16 PWs and surface water samples from the River Ganga (three locations) and UGC (three locations) were collected by carrying out three separate sampling campaigns during monsoon season in 2005 (July–August). The exercise was repeated by collecting three sets of water samples from the PWs and from the River Ganga and UGC (three locations each) on three different dates during non-monsoon season in 2006 (January–February). Water from the PWs was obtained using the installed submersible pumps. Surface water samples from the River Ganga and canals were collected from a depth of 0.5 m below the top-water level using a sampler. Samples for physico-chemical analysis were collected in polyethylene bottles. Water samples for bacteriological examination were collected separately in sterilized glass bottles. The collection, preservation, transportation, and analysis of the samples were done in accordance with the procedures in the Standard Methods [24].

Temperature, pH, electrical conductivity, and dissolved oxygen (DO) were measured on-site. Other parameters such as turbidity, total dissolved solids (TDS), and major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}), UV absorbance, total organic carbon (TOC), and total and fecal coliforms were determined in the Environmental Engineering Laboratory of the Department of Civil Engineering, Indian Institute of Technology, Roorkee. Turbidity was measured using a nephelometer (AN 2100, Hach, USA). Electrical conductivity and pH were measured using conductivity and pH meters (WTW pH and conductivity 720, Germany). TOC was determined using VCSN 5000, Shimadzu, Japan, TOC analyzer. DR-4000 UV–vis spectrophotometer (Hach, USA) was used for all spectrophotometric measurements. DO was measured by Senso Direct OX-24 DO meter (Aqualytic, Germany). Sodium and potassium were analyzed in a microprocessor-based flame photometer (Toshniwal, India).

4. Results and discussion

4.1. *Water quality: 16 PWs & source*

The water collected from PWs is groundwater under the direct influence of surface water. The pumping action creates a pressure “head” difference between the river/canals and aquifer, which induces the water from the surface bodies to flow downward through the porous media. During percolation, water passes through aquifer material until it enters finally into the pumping wells/PWs mainly from the bottom.

Observations pertaining to the quality of water samples collected from the PWs and the river, UGC and NSC during monsoon and non-monsoon periods are summarized in Table 2. The percentage error in

Table 2
Water quality: comparison of source water and river bank filtrate

	Monsoon		Non-monsoon	
Parameter	River and UGC	PWs (1–16)	River and UGC	PWs (1–16)
pH	7.9–8.4 (8.2)	7.6–8.3 (8.1)	8.4–8.7 (8.5)	7.8–8.7 (8.4)
DO (mg/L)	8.3–8.7 (8.6)	0.8–6.0 (3.9)	3.0–4.9 (4.1)	1.7–3.8 (2.9)
Turbidity (NTU)	167–256 (208)	0.2–0.5 (0.3)	1.2–3.4 (1.9)	0.4–1.4 (0.7)
Electrical conductivity (μS/cm)	144–179 (160)	239–664 (399)	173–277 (199)	188–668 (339)
TDS (mg/L)	90–120 (104)	156–463 (270)	108–173 (125)	118–418 (213)
Total hardness (mg/L as $CaCO_3$)	68–88 (76)	112–280 (177)	80–144 (99)	91–274 (148)
Ca^{2+} (mg/L)	20–22.4 (20.8)	17.6–80.8 (51.6)	26–36 (28)	27–69 (43)
Mg^{2+} (mg/L)	3.8–8.6 (5.8)	4.8–20.2 (11.4)	3.6–10.6 (6.5)	2.6–29.3 (10.1)
Na^{+} (mg/L)	2.5–3.4 (2.8)	4.0–25.6 (11.1)	1.6–6.9 (3.0)	1.8–17.3 (6.2)
K^{+} (mg/L)	2.7–3.0 (2.8)	3.0–7.3 (4.8)	1.9–3.7 (2.3)	2.6–6.1 (3.5)
HCO_3^- (mg/L)	59–88 (71)	100–339 (187)	105–159 (123)	112–424 (205)
SO_4^{2-} (mg/L)	17.4–25.7 (21.7)	13.6–38.3 (23.3)	13.1–18.4 (15.6)	7.8–17.8 (14.1)
Cl^- (mg/L)	1–3 (1.6)	3–27 (8.1)	1.5–6.0 (3.6)	2.5–44.0 (14.1)
UV absorbance at 254 nm (cm^{-1})	NA	NA	0.151–0.256 (0.197) 2.01)	0.029–0.160 (0.076)
Total coliform (MPN/100 mL)	5,000–16,000 (10,200)	<2–110 (26)	4,300–930,000 (151,230)	<2–80 (10)
Fecal coliform (MPN/100 mL)	1,400–16,000 (6,760)	<2–9	2,400–24,000 (8,000)	<2–4

Notes: NA, not available; ND, not detectable; values in parenthesis are average values.

ionic balance varied from 0 to 7%. Water quality analysis demonstrates the dominance of calcium, magnesium, and bicarbonate.

A comparison between PW waters and river/canal waters is presented in Table 2, Figs. 2 and 3. Following are the main points of difference:

- TDS, conductivity, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-} and Cl^-: filtrate from PWs > river water.
- Organic matter (in terms of UV–absorbance): river water > filtrate from PWs.
- Total and fecal coliform: river water > filtrate from PWs.

5. Water quality: monsoon and non-monsoon seasons

The turbidity of water from the river and UGC in monsoon was found to be 100–150 times the turbidity during non-monsoon period. Contrary to this the bacterial counts and conductivity of the river/canal water

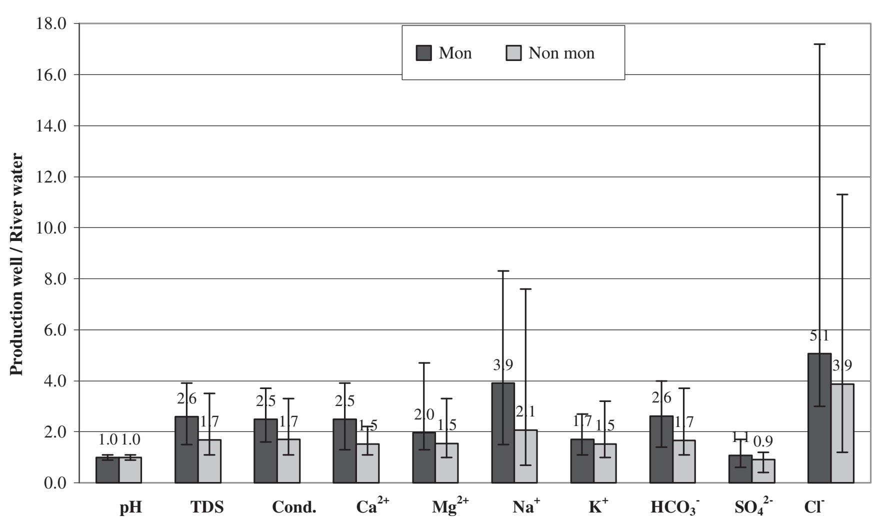

Fig. 2. Characteristics of PW water samples relative to river water samples.

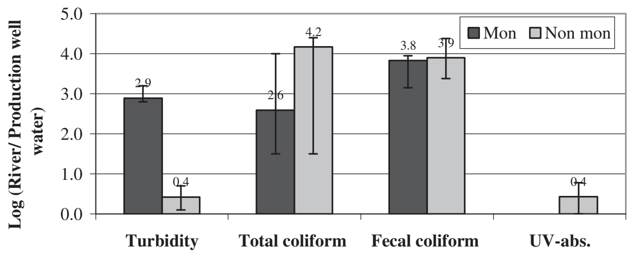

Fig. 3. Turbidity, UV–absorbance, coliform counts in PW waters relative to river water.

samples collected during non-monsoon season were found to be about 10 and 1.2 times more than the river/canal water samples collected during monsoon season, respectively. Irrespective of this large variation in turbidity and coliform MPN, the bacteriological quality of water from the PWs was not found to vary significantly in monsoon and non-monsoon periods (Table 2).

5.1. TDS and EC

The filtrate collected from the PWs contained nearly 1.1–1.6 to 3.6–3.9 times the dissolved solids in the river water in monsoon and non-monsoon periods (Table 2). The concentration of all the major ions was also more in the PW waters than the river water for both the sampling periods. This may be due to the mixing of groundwater and infiltrated surface water from the river. Another reason may be due to weathering and/or leaching of materials from the deposits into the percolated water. Water coming into the PW has higher percentage of surface water as it was observed during the closure of UGC for annual maintenance. During closure of the UGC, the water level reduced drastically in the PWs and after third day of closure of UGC, the discharge to the PWs, close to UGC, reduced significantly.

Perusal of observations recorded in Fig. 2 reveals that the ratio of TDS, EC, and all the anions and cations in the PW water to river water for monsoon period was higher than that of non-monsoon period.

Average EC of river water increased from 160 μS/cm in monsoon period to 199 μS/cm in non-monsoon period, whereas the average EC of PW water decreased from 399 μS/cm in monsoon period to 339 μS/cm in non-monsoon period. From Figs. 2 and 4, it was observed that for all the PWs located to the north of NSC, i.e. PW-18, 40, 16, 26, 27, and 31, the average increase in EC in comparison to source water is 3.5 times (2.6–3.9 times) in monsoon and 2.6 times (1.8–3.6) times in non-monsoon season, whereas for the PWs located to the south of NSC, i.e. PW 25, 24, 43, 42, 44, 17, 21, 29, 49, and 28, the average increase in conductivity in comparison to source water is 2.1 times (1.6–2.5 times) in monsoon and 1.3 times (1.1–1.6) times in non-monsoon season. This indicated that the pumped water in PWs located to the north of NSC have a higher percentage of groundwater in comparison to the PWs located to the south of NSC. Same pattern was also observed for TDS (Fig. 5).

5.2. DO, turbidity, coliforms, and organics

DO concentration decreased from 8.6 to 4.1 mg/L in river water to 3.9–2.1 mg/L in the bank filtrate in monsoon and in non-monsoon periods, respectively. The decrease in DO concentration may be due to bacterial respiration. The trend in DO decrease is contrary to the trend in conductivity increase.

As the river water passes through the aquifer, the water gets filtered and most of the turbidity and organics are removed [12]. This was quite clear for PWs at Haridwar from the results compiled in Table 2. Reduction in turbidity, total coliform, fecal coliform, and organics in the water samples collected from the PWs were quite noticeable (Fig. 3). The water from PWs when compared with the source water showed 2.6 log removal of total coliform (1.8–4.0), 3.8 log removal of fecal coliform, 2.9 log removal of turbidity in monsoon period and 4.2 (1.5–4.4) log removal of total coliform, 3.9 log removal of fecal coliform and 0.4 log removal of turbidity in non-monsoon period (Figs. 3, 6 and 7). A removal of 0.4 (0.02–0.8) log was also observed for organics (in terms of UV–abs.) during the non-monsoon period (Figs. 3 and 8). Less turbidity removal during the non-monsoon period was because of the presence of less turbidity in river/UGC water during this period. The fate and transport of micro-organisms in the subsurface are controlled by several processes, including advection, dispersion, physicochemical filtration, straining, inactivation, dilution, and possibly grazing by higher trophic levels. Of these, physicochemical filtration and inactivation play a significant role in the removal of organics, turbidity, and coliform from the river water during the passage to the PWs.

5.3. Presence of coliforms in different PWs

Tests for the total coliforms for four PWs (PW 26, PW 25, PW 43, and PW 42) in monsoon and eight PWs (PW 26, PW 27, PW 28, PW 31, PW 25 PW 24,

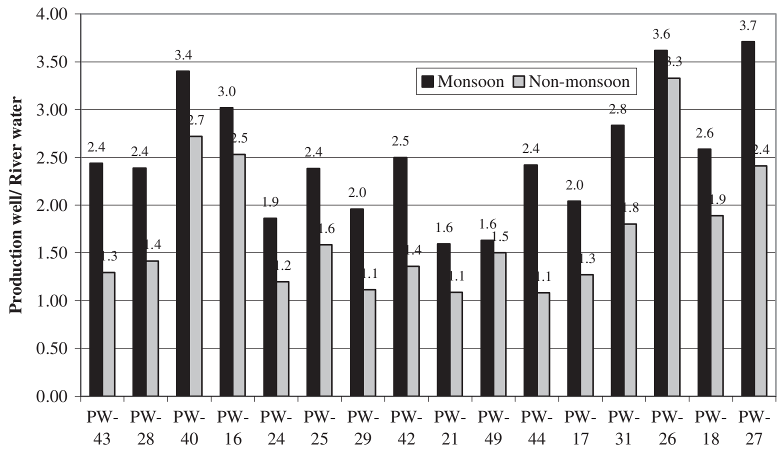

Fig. 4. Electrical conductivity: PW water relative to source water.

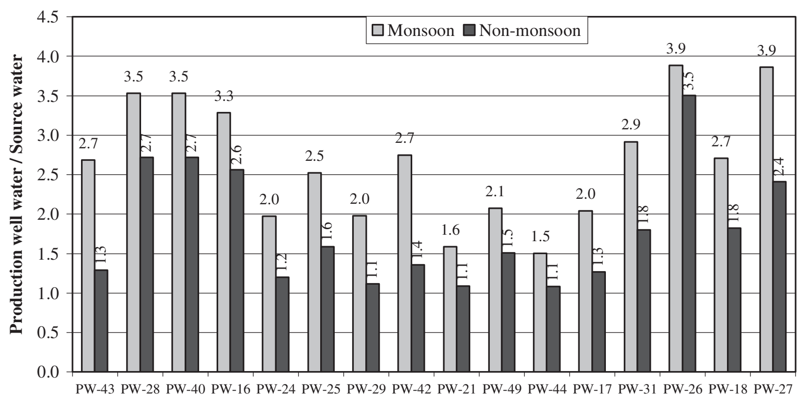

Fig. 5. TDSs: PW water relative to source water.

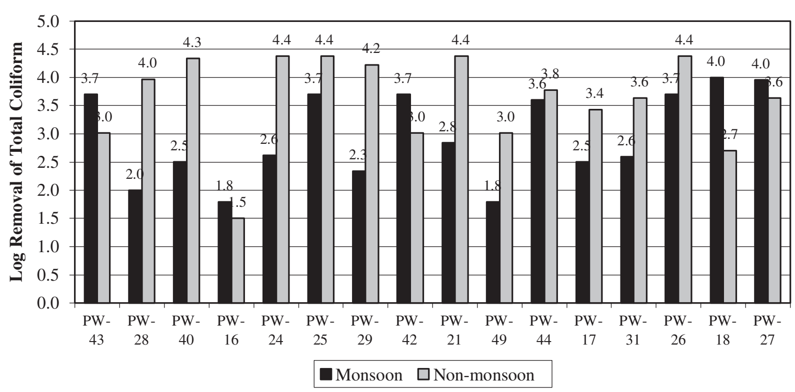

Fig. 6. Log removal of total coliform in different PW waters relative to river water.

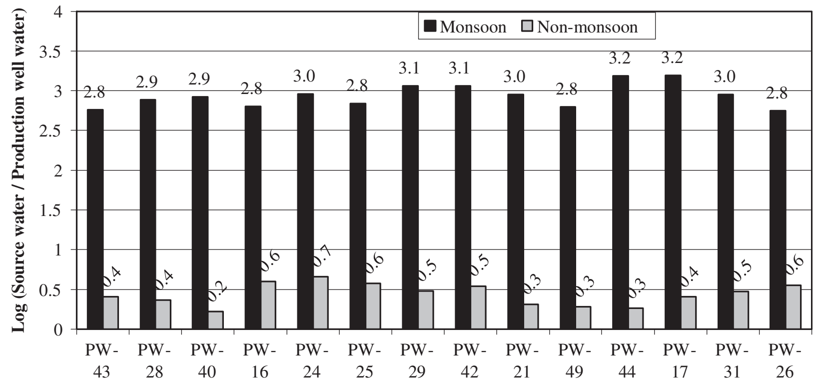

Fig. 7. Log removal of turbidity in different PW waters relative to source water.

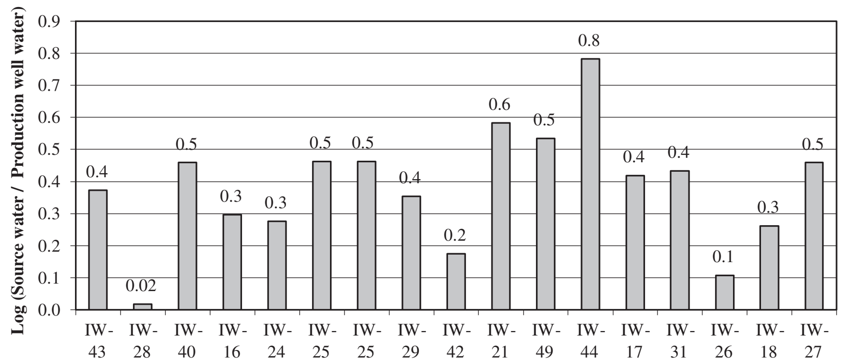

Fig. 8. Log removal of organics (UV–abs.) in different PW waters relative to source water in non-monsoon period.

PW 21, and PW 29) in non-monsoon yielded negative results, indicating that water was free from any fecal contamination and disease-causing micro-organisms and for rest of the 12 PWs during monsoon period and eight PWs during non-monsoon period, total coliforms were detected with the maximum value of 110 MPN/100 mL. Except two PWs (PW 24, PW 17) in monsoon and one PW (PW 40) in non-monsoon, rest of the wells were free from fecal coliforms (Table 3).

5.4. Distance and travel time

The travel time between the PW and the source is an important parameter for the removal of bacteria and turbidity. The minimum travel times calculated (using Darcy's law) on the basis of water level measurements in the River/UGC/NSC and in the PWs, assuming that the river/canal water infiltrates at the bank are presented in Table 3. It reflects the minimum travel because the water levels measured in the wells were used to calculate the gradients, but some wells are affected by clogging (bottom entry area), thus the gradient could be overestimated. Hydraulic conductivity and porosity of the aquifer material were taken as 22–40 m/d and 0.3 [8], respectively for the calculation of travel time. The shortest travel time of 0.6–1.1 d was noticed at PW 43. From Table 3, it can be observed that filtrate from PW 25, which was at a distance of 15 m (travel time of 1.9–3.4 d) from the river was free from both total and fecal coliform during monsoon and non-monsoon period. Filtrate from PW 42 (travel time of 1.5–2.8 d) and PW 43 (travel time of 0.6–1.1 d), which was at a distance of 15 and 4 m from the river, was also free from both total and fecal coliform during monsoon period.

Water collected in PW 24 and PW 28, which was at a distance of 12 m (travel time of 1.6–2.8 d) and 8 m (travel time of 0.7–1.3 d), respectively from the UGC was free from both total and fecal coliform. The travel time thus calculated was shorter for the treatment achieved than reported by other researchers [19,25,26]. To reach 4–5 log removal of coliform during bank filtration, travel time between 10 and 20 d is needed [19]. In the present case, a clogging layer may have been produced, which is likely to be

Table 3
Coliform removal: distance and travel time from the source

Sl. no.	Name of well	Shortest distance from source (m) (River/ UGC/NSC)	Average hydraulic head difference between the water level in the source and PW (m)	Minimum travel time from source water[a] (d)	Log removal of total coliform		Monsoon		Non-monsoon	
					Mon	Non-mon	Total coliform (MPN/ 100 mL)	Fecal coliform (MPN/ 100 mL)	Total coliform (MPN/ 100 mL)	Fecal coliform (MPN/ 100 mL)
1	PW 43	4	0.2	0.6–1.1	3.7	3.0	(<2)	Nil	8–30(23)	(<2)
2	PW 28	8	0.7	0.7–1.3	2.0	4.0	50–60 (53)	(<2)	(<2)	Nil
3	PW 40	10	0.7	1.1–2.0	2.5	4.3	30–90 (50)	(<2)	22–80 (40)	<2–4 (2)
4	PW 16	10	0.6	1.3–2.3	3.7	4.4	40–110 (80)	(<2)	30–80 (50)	(<2)
5	PW 24	12	0.7	1.6–2.8	2.6	4.4	<2–30 (12)	<2–6 (2)	(<2)	Nil
6	PW 25	15	0.9	1.9–3.4	3.7	4.4	(<2)	Nil	(<2)	Nil
7	PW 29	15	0.8	2.1–3.9	2.3	4.2	2–50 (26)	(<2)	(<2)	Nil
8	PW 42	15	1.1	1.5–2.8	3.7	3.0	(<2)	Nil	23–30 (26)	(<2)
9	PW 21	26	1.6	3.2–5.8	2.8	4.4	21–33 (24)	(<2)	(<2)	Nil
10	PW 49	28	1.8	3.3–6.0	1.8	3.0	40–110 (75)	(<2)	<2–23 (10)	(<2)
11	PW 44	30	1.9	3.6–6.5	3.6	3.8	<2–9 (4)	(<2)	<2–11 (4)	(<2)
12	PW 17	30	2.1	3.2–5.9	2.5	3.4	40–90 (48)	2–9 (4)	2–14 (9)	(<2)
13	PW 31	50	2.3	8–15	2.6	3.6	17–40 (23)	(<2)	(<2)	Nil
14	PW 26	50	1.9	10–18	1.8	1.5	(<2)	Nil	(<2)	Nil
15	PW 18	115	1.4	71–129	4.0	2.7	13–40 (23)	(<2)	17–80 (43)	(<2)
16	PW 27	250	3.1	151–275	4.0	3.6	<2–50 (25)	(<2)	(<2)	Nil

Notes: Values in parenthesis are average values.
[a]Travel time $(d) = t_t = L/V_n$.
V_n = seepage velocity (m/d) = $[K(H-h)]/Ln$, K = hydraulic conductivity (22–40 m/d), $(H-h)$ = average hydraulic head difference between the water level in the source and IW, L = shortest distance between source and IW, n = porosity (0.3).

sustained during well operation and its extension is balanced out by the self-cleaning mechanisms by benthos. Therefore, the effective travel time can be speculated to be more than the calculated travel time from Darcy's law. However, bacterial transport in soil and other unconsolidated or consolidated material also depends strongly on material properties in fine sand, the migration of bacteria is limited and most of the bacteria are removed at the beginning of the production, many even within the first 0.5 m [27–29]. So, the formation of a clogging layer at the riverbed and at the beginning of production may be the vital factor, other than travel time, for removal of bacteria.

The presence of coliform in rest of the PWs during monsoon and non-monsoon may be attributed to the fact that the PWs were not protected from the human activities and open land defecation. Due to the presence of human activities near the PWs, waste deposited near the PWs leached and passed through the aquifer during rainwater percolation. This may cause the presence of coliform in some of the PWs.

6. Conclusions

This example clearly illustrates the benefits of drawing surface water after its natural purification through layers of filtering material and not directly as such. The RBF facility in Haridwar was found to be efficient through the study done on water quality. It yields water of potable quality without any expenditure on treatment or with little treatment. It was observed that water in most of the PWs were free from coliform irrespective of the distance from the source during monsoon and non-monsoon period. Based on the results from the present investigation, six new PWs were installed in 2010 at shorter distances (5–30 m) from the river/canal.

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