Performance evaluation of riverbank filtration scheme

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This article presents an analytical method to determine the distance of a bank filtration well from a river in commensuration with the desired percentage of bank filtrate and removal of pathogenic compounds. Applying least squares optimization technique using Marquardt algorithm, the unknown parameter, distance of the well from the river has been estimated. The travel time in commensuration with the desired percentage removal of pathogenic compounds has been ascertained using the first-order decay equation.

For evaluating effectiveness of the technique, the physico-chemical and biological parameters of extracted bank filtrate from 22 wells located in the vicinity of the River Ganga and the Upper Ganga Canal network at Haridwar have been analysed for the non-monsoon and the monsoon periods. The physico-chemical parameters of the extracted water showed concentration much below the acceptable limits, except turbidity. The percentage removal of turbidity in the extracted water was found about 98 and 76 during the monsoon and non-monsoon periods respectively, in comparison to water from the river/canal. The count of biological parameters, viz. total coliform and faecal coliform in the extracted water is removed considerably (65% to 85%), but is found above the acceptable limit. The reason could be mixing of bank filtrate with the rich constituents in the groundwater. It is suggested that bank filtration dilutes groundwater quality and can be regarded as a technique to conjunctive management of surface and groundwater quality.

Keywords: Analytical method, bank filtration, case study, distance, hydrochemistry, performance evaluation.

BANK filtration (BF), as a natural pre-treatment technique, is being widely used in many European countries and USA since more than a century[1]. In Europe, potable water of about 50% in the Slovak Republic, 45% in Hungary, 16% in Germany, 7% in the Netherlands, 48% in Finland, 50% in France and 80% in Switzerland is supplied through BF[1,2]. This technique is used for the supply of drinking water in urban and peri-urban areas owing to its prospect of removing suspended particles, pathogenic compounds, trace organics and microorganisms present in the source water to a reasonable extent[3,4]. It is also gaining popularity in India[5,6]. The case studies reported by different investigators[7,8] are examples of its recognition in India. However, its large-scale implementation in India is confronted by a number of issues. This is because (i) a haphazard and intensive growth of BF wells can upset stream flow causing adverse effects on the habitat and ecology downstream of a river, (ii) it can affect water budget and (iii) it may have an impact on catchment water balance and administration rights. India's domestic water demands that amounted to only 5.13% (30 BCM/yr) and 6.75% (42 BCM/yr) of the total use in 1999 and 2010 respectively, may increase to 8% (59 BCM/yr) and 10% (100 BCM/yr) of the total use in 2025 and 2050 respectively[9,10]. The risk due to deterioration of water quality on the available quantity can be one of the main hurdles, in addition to the quantity available as utilizable water resources to secure the future demands of domestic water supply. Attainment of India's domestic water supply security with the approach of business usual may be a difficult task and would require a coordinated management of available resources. BF is one of the approaches that considers conjunctive management of surface and groundwater by way of inducing surface water when groundwater is pumped in the vicinity of a surface and the groundwater system can bring source sustainability in domestic water supply security. India has the potential for employing the BF technique, particularly in the Indo-Gangetic–Brahmaputra alluvium areas, coastal alluvium tracks and scattered inland pockets in different states where surface water bodies are hydraulically connected to the adjoining porous aquifers. Distance of a bank filtration well from its surface source water is an important parameter that characterizes travel time of contaminants and quantity of bank filtrate, required to be known prior to implementation of a scheme. As such, no straightforward approach is available in the literature to determine the distance of a well from the river hydraulically connected to its underneath aquifer.

This article is aimed to develop an analytical method for estimating distance of a bank filtration well from a river to satisfy certain percentage of bank filtrate with a

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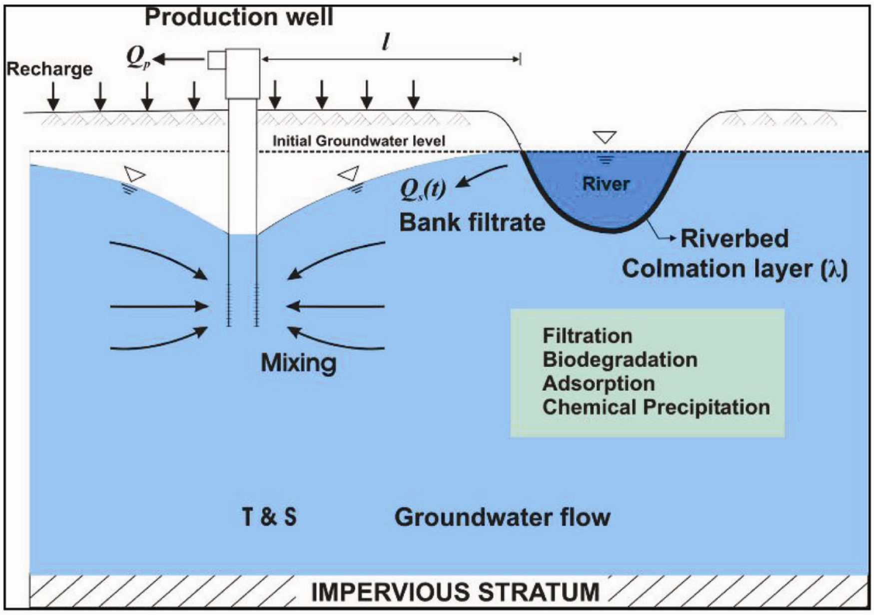


Figure 1. Schematic diagram of a bank filtration process affecting the quality of groundwater and extracted water.

desired removal efficiency of pathogenic compounds. To evaluate the effectiveness of bank filtration technique, as a pilot study, the performance of physico-chemical and biological parameters of the riverbank filtration scheme located in the vicinity of the River Ganaga and the Upper Ganga Canal (UGC) in Haridwar, India has been assessed and is presented here.

Bank filtration processes

Riverbank filtration (RBF) or simply bank filtration is a unified term for river and lake bank/bed filtration. This is a process by which surface water from a river, channel or lake is induced to flow through the natural porous medium (aquifer) by pumping from nearby production wells[11]. The induced water finally mixes with local groundwater in the land side before being abstracted for direct use or further treatment (Figure 1). The porous medium serves as a natural filter and reduces the amount of suspended solids and pathogens.

The process of BF is initiated by lowering of the groundwater table near a river or lake, which causes surface water to seep through the permeable river or lake bed and bank into the aquifer due to the difference in water levels, provided that no artificial or natural barriers exist (e.g. brick or concrete-lined bed, or a low hydraulic conductivity layer like clay)[1]. River/lake water contaminants are attenuated due to a combination of processes such as filtration, microbial degradation, sorption to sediments and aquifer sand, and dilution with background groundwater. The process is similar to the slow sand filtration process.

Analytical models

Theis[12] first derived an analytical expression for predicting river contribution to pumping from a fully penetrating well near the river in an unconfined aquifer hydraulically connected to the river. Later, Glover and Balmer[13] gave an exclusive closed form solution to Theis' equation. The step response function derived by Glover and Balmer[13] for dimensionless stream depletion, in other words, the induced recharge consequent to pumping, is:

$$\frac{Q_s(t)}{Q_p} = \text{erfc}\left(\sqrt{\frac{Sl^2}{4Tt}}\right), \quad (1)$$

where $Q_s(t)$ is the stream/river depletion rate $[L^3T^{-1}]$; Q_p the pumping rate $[L^3T^{-1}]$; S the storage coefficient (dimensionless); l the distance between the well and stream [L]; T the transmissivity of the aquifer $[L^2T^{-1}]$; t the time since pumping commences [T]; erfc(x) the complementary error function = 1 – erf(x) and

$$\text{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^X e^{-u^2} du.$$

Hantush[14], first developed an analytical model for a partially penetrating stream to determine the rate of stream depletion as a function of stream depletion factor (SDF) and time considering the streambed lined with semi-pervious material. The solution given by Hantush[14] and later modified by Hunt[15] for partially penetrating stream with streambed conductance is

$$\frac{Q_s(t)}{Q_p} = \left[\operatorname{erfc}\left(\sqrt{\frac{Sl^2}{4Tt}}\right) - \exp\left(\frac{\lambda^2 t}{4ST} + \frac{\lambda l}{2T}\right) \times \operatorname{erfc}\left(\sqrt{\frac{\lambda^2 t}{4ST}} + \sqrt{\frac{Sl^2}{4Tt}}\right)\right], \quad (2)$$

where λ is the riverbed conductance parameter [LT^{-1}] that ranges between 10^{-6} and 10^{-4} m s^{-1} (ref. 16).

Comparison of time-varying responses [$Q_s(t)/Q_p$] given by eqs (1) and (2) shows (Figure 2) that the well in a fully penetrating stream (eq. (1)) abstracts more water from the stream than a partially penetrating one (eq. (2)) at a given time and hydraulic properties having the same distance (Figure 2). In other words, streambed conductance reduces the stream depletion rate than a stream with no bed conductance.

The decay model for population of assembly of microbes describing first-order kinetics is given as[17]

$$\frac{C(t)}{C_0} = \exp(-kt), \quad (3)$$

where $C(t)$ is the concentration of microbes at time t; C_0 the concentration of microbes at initial time $t = 0$ and k is the first-order reaction kinetics (t^{-1}), normally ranging between 0.011 and 0.033 d^{-1} (ref. 18).

Methodology

The problem under consideration is to determine the distance of a well from a straight river reach for a certain amount of pumped water as bank filtrate with desired removal efficiency of pathogenic concentration. The idealized flow domain is shown in Figure 1. Prior to pumping, the groundwater table is considered to be in dynamic equilibrium with the river water level. The time parameter is reckoned since pumping starts. The aquifer is assumed to be homogeneous, isotropic and unconfined.

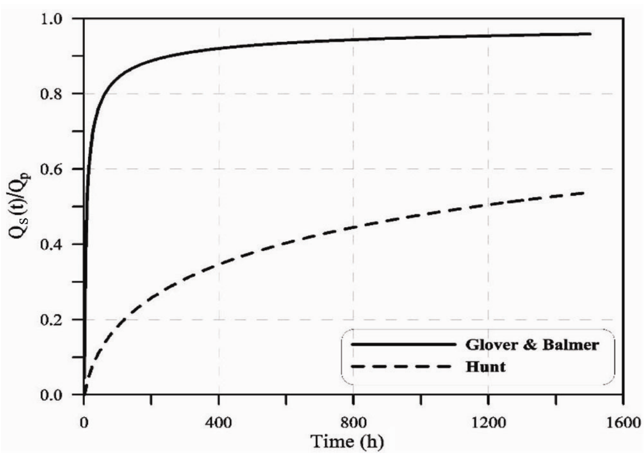


Figure 2. Comparison of time-varying responses of $Q_s(t)/Q_p$ computed using Glover and Balmer[13] and Hunt[15] for $S = 0.01$, $T = 50$ m^2 h^{-1}, $l = 200$ m, and $\lambda = 0.036$ m h^{-1}.

The changes in the groundwater level due to pumping from production wells are assumed to be small in comparison to the aquifer thickness to allow linearization of the unconfined aquifer. The river is assumed to be partially penetrating with bed conductance of λ, i.e. eq. (2) is applicable and its water has the steady input concentration C_0 of the pathogenic compounds. The well is pumped continuously at a steady rate of Q_p.

The aim here is to: (i) determine the distance l of the well from the river bank to ensure a certain amount of pumped water as bank filtrate with the desired removal efficiency of pathogenic compounds, for the given hydraulic properties (T, S and λ) of the aquifer.

The problem under consideration is basically an inverse problem. The solution of an inverse problem to determine an unknown parameter, when input and output are given, involves an optimization procedure. In the present case, the desired quantity ($Q_s(t)/Q_p$) and quality ($C(t)/C_0$) of bank filtrate water are given, together with the aquifer parameters S, T and λ; the only unknown is l for a particular time t in eq. (2). The travel time T_t of bank filtrate water to achieve a certain percentage of removal of contaminants can be determined using eq. (4) as follows

$$T_t = -\frac{\ln\left(\frac{C(t)}{C_0}\right)}{2.303 * k}, \quad (4)$$

where T_t is the travel time of the contaminant to reach the production well from the river and k is the first-order decay coefficient normally ranging between 0.011 and 0.033 d^{-1} (ref. 18).

Using the estimated T_t from eq. (4) in eq. (2), the distance l can be determined by least squares optimization technique using Marquardt algorithm[19] on Hunt's[15] stream depletion model. The method of least squares by Marquardt algorithm involves estimating the parameters by minimizing the sum of squares of deviation between the desired and computed values. Let the sum of squares of the error between the desired value and response of $Q_s(t)/Q_p$, computed based on a guess value of l, be E. The error associated with the guess value of l can mathematically be written as

$$E = \left[Q_f - \left\{Q_f|_{l*} + \left.\frac{dQ_f}{dl}\right|_{l*} \Delta l\right\}\right]^2, \quad (5)$$

where O_f is the desired value of $Q_s(T_t)/Q_p$; $Q_f|_{l*}$ is the computed value of $Q_s(T_t)/Q_p$ (eq. (2)) for the given value of T_t at the guess value of l, regarded as $l*$, $dQ_f/dl|_{l*}$ is the derivative of $Q_s(T_t)/Q_p$ (eq. (2)) computed at l^* and Δl is the increment of l^*.

If l is the true value of the distance between the well and the river, the square of the error will be zero and minimum. This means that (dE/dl) should be equal to zero. Performing the differentiation and simplifying

$$\Delta l = \frac{Q_f - Q_f|_{l^*}}{\frac{dQ_f}{dl}|_{l^*}}. \quad (6)$$

Thus, the estimated value of distance between the well and the river, $l = l^* + \Delta l$.

An illustrative example

A partially penetrating straight river reach is hydraulically connected to its underneath aquifer (Figure 1) that has hydraulic properties of $T = 1200\ \text{m}^2\ \text{d}^{-1}$ and $S = 0.01$. The river has its bed conductance $\lambda = 0.864\ \text{m d}^{-1}$. It is required to determine the distance (location) of the pumping well from the bank of the river to ensure 50% of abstracted water as bank filtrate with reduction of 2-log removal (i.e. 99% removal) of pathogenic contaminants having decay rate coefficient $k = 0.025\ \text{d}^{-1}$. Assume that the river and aquifer are under dynamic equilibrium prior to pumping, and that the river and aquifer water levels are horizontal.

The removal efficiency of 99% means $C(t)/C_0 = 0.01$. For $k = 0.025\ \text{d}^{-1}$, from eq. (4) the travel time $T_t = 80$ d. Bank filtrate of 50% means $Q_s(t)/Q_p = 0.5$. That is we are required to determine the value of l from eq. (2) for $Q_s(t)/Q_p = 0.5$, $t = T_t = 80$ d; $T = 1200\ \text{m}^2\ \text{d}^{-1}$, $S = 0.01$ and $\lambda = 0.864\ \text{m d}^{-1}$. In accordance with eq. (6), observed $Q_f = Q_s(t)/Q_p = 0.5$, and Q_f is the expression given on the R.H.S. of eq. (2). Making use of the given data in eq. (2) and its derivative, Δl from eq. (6) with an initial guess of $l^* = 500$ m is estimated to be 237.57 m, that gives the distance $l = l^* + \Delta l = 737.57$ m. For any guess value of l^*, the value of l remains unaltered.

The time-varying profile of $Q_s(t)/Q_p$ corresponding to the estimated l (Figure 3) and the variation of bank filtrate quality w.r.t. the contaminant concentration of river water show that the river attains 50% depletion when the well is located at 737.57 m from it and pumped continuously for 80 days that would reduce the contaminant level by 2-log removal, i.e. 99%.

Case study of Haridwar

The bank filtration scheme at Haridwar is comprised of 22 large diameter (10 m) bottom-entry caisson of 7–10 m deep wells located along the right bank of the River Ganga at varying distances (10–295 m) from the river/canal within a stretch of about 6.5 km (Figure 4). These RBF wells, locally called 'infiltration wells (IWs)', are situated in the vicinity of the River Ganga and the UGC network. The UGC receives diverted flow from the river and meets the agricultural and drinking water requirements downstream.

Haridwar is one of the important Hindu pilgrimage sites of the world. The city, situated along the right bank of the River Ganga, has population of approximately 225,235 (ref. 20). More than 50% (>64,000 m^3/day) of drinking water requirement of the city is supplied by 22 RBF wells. Each RBF well is equipped with a pump set above the ground surface and extracts water by a suction pipe of 15 cm diameter. Some have been constructed as a tube well in the caisson well. The tube wells have an aquifer penetration depth of about 5–6 m below the bottom of the caisson well. The discharge of the pumps ranges from 72 to 170 m^3/h and the operating hours of these wells vary from one season to another between 10 and 24 h continuously in a day. A schematic diagram of a RBF well in Haridwar is shown in Figure 5. The wells tap the unconfined aquifer of average thickness about 21 m hydraulically connected with the river/canal. Being located in the vicinity of the canal and river network, the wells when pumped induce water from both the river and the canal at varying rates depending upon the distance of the wells from them. The analysis of interactions of river–canal–aquifer and well fields has been elaborated elsewhere[21].

This study deals with the analysis of quality of source water (i.e. Ganga and canal water) and its variation when extracted through wells by natural filtration processes, including analysis of groundwater quality.

Hydrochemistry

Water samples from the River Ganga, UGC, groundwater and 22 RBF wells were collected monthly from May

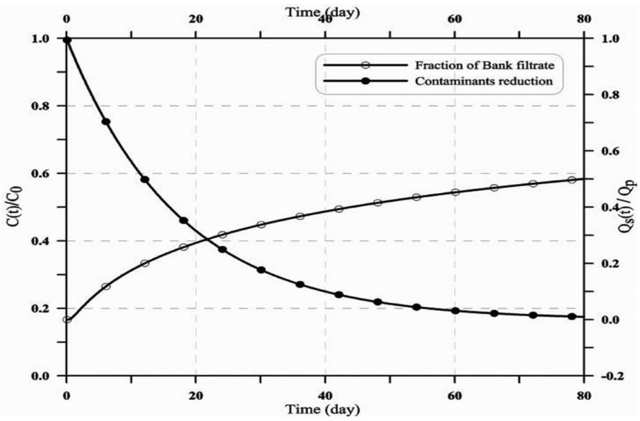
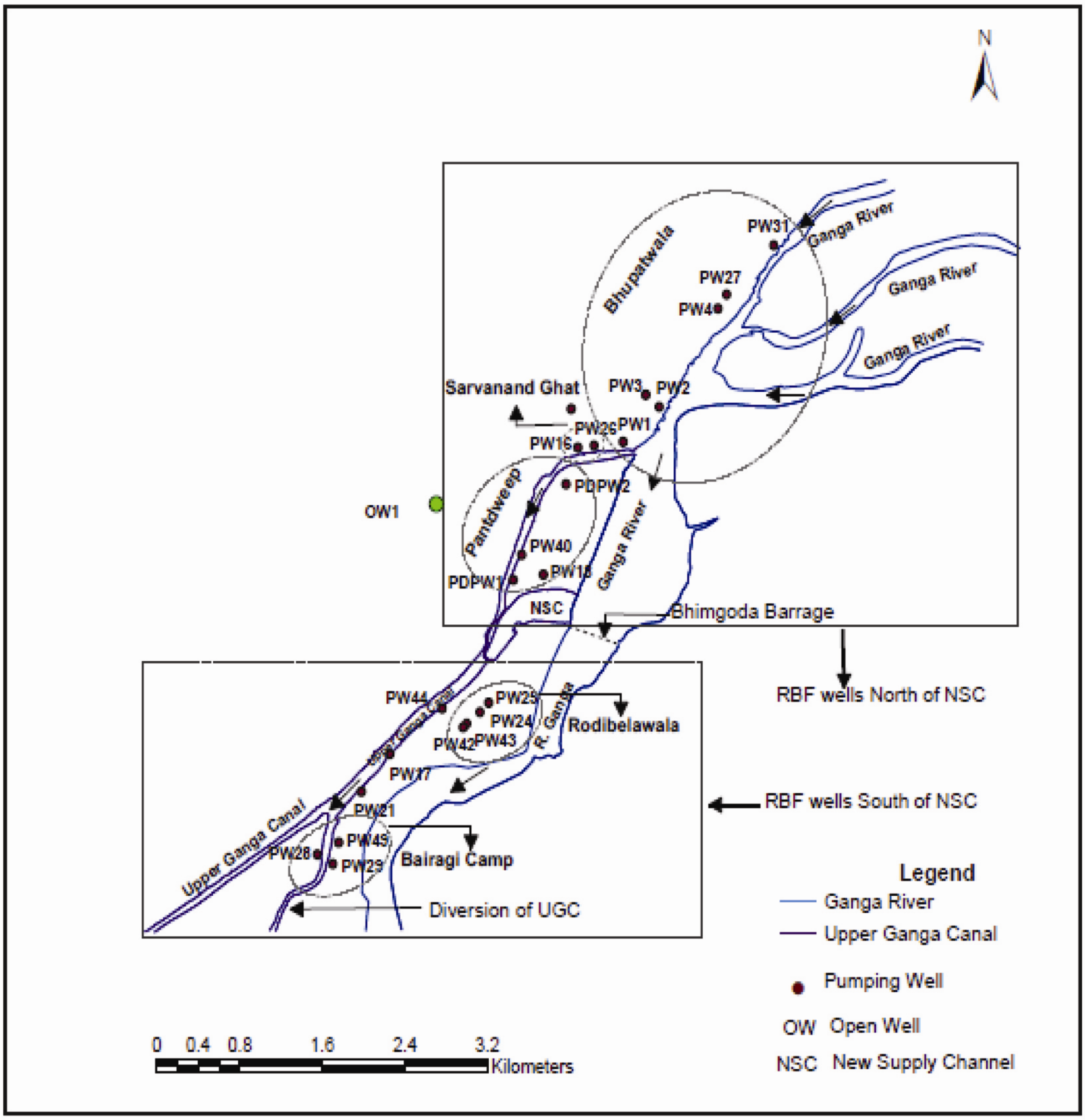


Figure 3. Time-varying profile of $C(t)/C_0$ and $Q_s(t)/Q_p$ for two-log removal (99%) with 50% bank filtrate computed using estimated travel time, $T_t = 80$ d, distance $l = 737.57$ m and hydraulic properties $T = 1200\ \text{m}^2\ \text{d}^{-1}$, $S = 0.01$ and $\lambda = 0.864\ \text{m d}^{-1}$.



Well ID#	Distance from nearby surface water source (m)	Well ID #	Distance from nearby surface water source (m)
P1 (IW 31)	44	P12 (PDIW 1)	12
P2 (IW 27)	166	P13 (IW 25)	26
P3 (IW 4)	217	P14 (IW 24)	20
P4 (IW 2)	53	P15 (IW 42)	15
P5 (IW 3)	188	P16 (IW 43)	20
P6 (IW 1)	45	P17 (IW 44)	15
P7 (IW 26)	20	P18 (IW 17)	22
P8 (IW 16)	10	P19 (IW 21)	30
P9 (PDIW2)	170	P20 (IW 49)	135
P10 (IW 40)	10	P21 (IW 21)	10
P11 (IW 18)	295	P22 (IW 29)	18

IW, Infiltration well

Figure 4. Setting up of 22 riverbank filtration wells in the vicinity of the River Ganga and Upper Ganga Canal (UGC) at Haridwar and their distances from the nearby surface water source, river/canal.

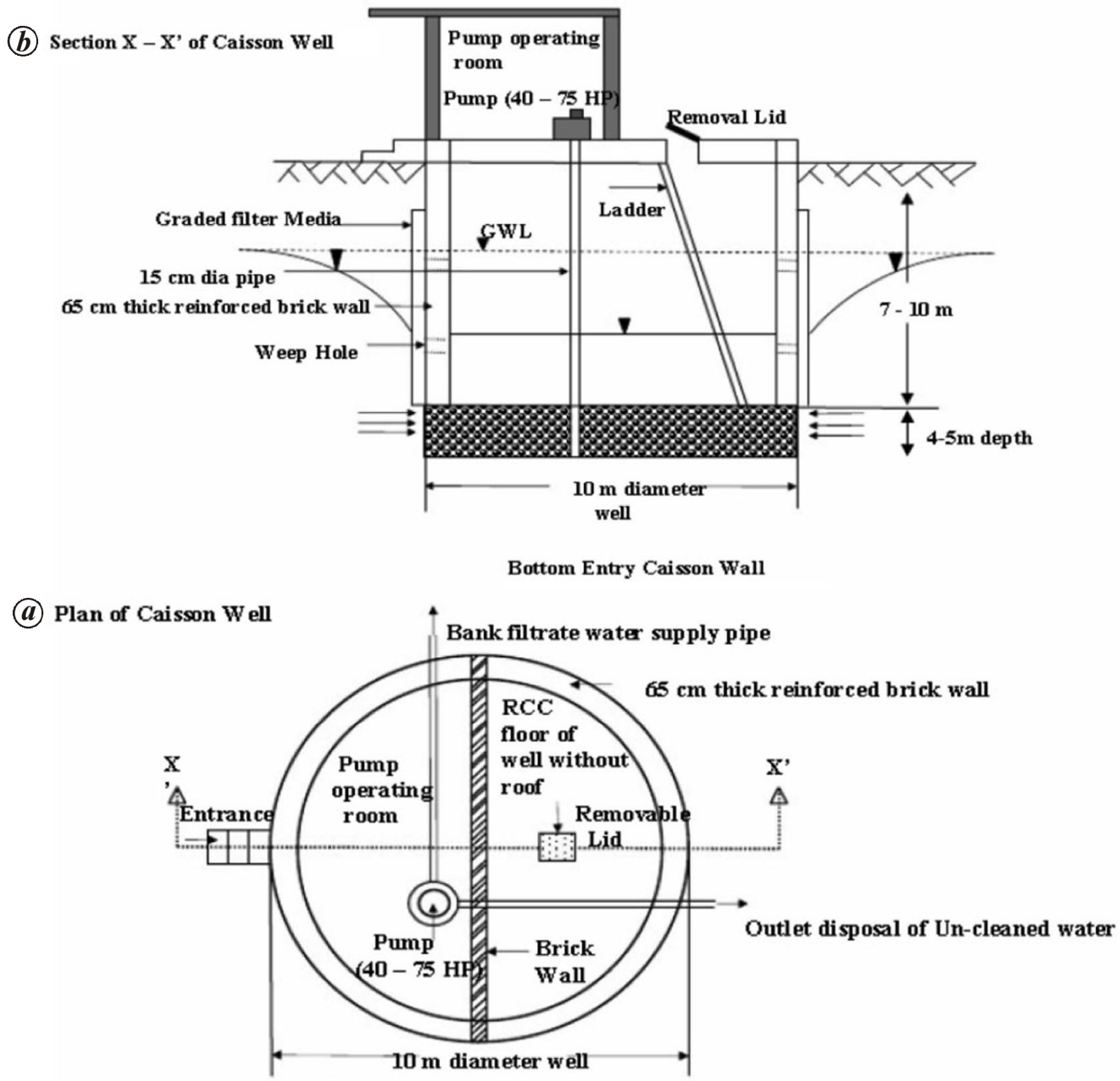


Figure 5. Schematic diagram of bank filtration well at Haridwar.

2012 to October 2013 during the non-monsoon and monsoon seasons. Each sampling campaign comprising 25 samples was analysed in the laboratory according to the guidelines prescribed by the American Public Health Association[22] to determine physico-chemical and biological parameters. The analysis of physico-chemical parameters include pH, temperature, turbidity, alkalinity, total hardness, Cl^-, NO_3^-, SO_4^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and the bacteriological parameters include total coliform and faecal coliform. Analysed results of physico-chemical and biological parameters (total sample size: 10 for non-monsoon and eight for monsoon) are summarized in Table 1. Spatial variation of concentration of few physico-chemical and biological parameters measured in the extracted water from 22 RBF wells is shown in Figure 6.

Results and discussion

The results in Table 1 show statistical values (mean and standard deviation) of 10 physico-chemical and two biological parameters for both non-monsoon and monsoon seasons, for three categorized sources – river/canal, groundwater and extracted (pumped) water. The values of extracted water represent statistical data of 22 RBF wells. These wells are located at varying distances (10–295 m) from the river/canal. Largely, all physico-chemical parameters, except turbidity of the extracted water, which constitutes mixing water of riverbank filtrate and groundwater, show concentration much below the acceptable limits prescribed in IS:10500 (Table 1)[23] for both non-monsoon and monsoon periods. The turbidity in the extracted water although reduced about 98% during the

Table 1. Statistical summary of physico-chemical and biological parameters of Haridwar river bank filtration (RBF) site (sample size: 10 for non-monsoon and 8 for monsoon)

	River and canal water				Extracted water (RBF wells)				Groundwater (open well)				
	Non-monsoon		Monsoon		Non-monsoon		Monsoon		Non-monsoon		Monsoon		
	(Minimum–Maximum)	Mean ± SD	(Minimum–Maximum)	Mean ± SD	(Minimum–Maximum)	Mean ± SD	(Minimum–Maximum)	Mean ± SD	(Minimum–Maximum)	Mean ± SD	(Minimum–Maximum)	Mean ± SD	Acceptable limit (IS:10500)
Turbidity (NTU)	2.25–19.10	8.49 ± 6.33	3.20–346	104.66 ± 109.74	1.09–5.67	2.08 ± 1.05	1.24–7.62	2.2 ± 1.48	0.73–5.02	1.99 ± 1.41	0.70–48.10	6.54 ± 14.65	1
TDS (mg/l)	141.44–329.60	233.92 ± 74.03	93.44–286.08	160.45 ± 160.45	136.88–459.52	256.6 ± 104.36	161.88–442	272.94 ± 88.62	660.48–760.96	712.05 ± 35.77	684.16–884.48	769.22 ± 63.77	500
Ca^{2+} (mg/l)	23.30–71	44.08 ± 17.30	17.60–58.47	31.63 ± 13.27	29.36–71.35	45.39 ± 13.35	28.29–72.45	47.25 ± 14.35	94.64–133.13	120.21 ± 12.72	68.97–159	113.2 ± 26.25	75
Mg^{2+} (mg/l)	7.78–25	15.61 ± 7.05	4–20.41	10.17 ± 5.11	7.16–30	17 ± 8.42	8.52–28	16.72 ± 6.44	9.23–60.75	34.24 ± 17.64	31.98–64	48.47 ± 11.71	30
Na^{+} (mg/l)	3.63–11.60	7.25 ± 2.68	0.82–10	4.46 ± 2.60	4.62–24.18	11.85 ± 6.93	7.62–34.92	14.7 ± 6.93	40–78	51.48 ± 12.15	24.29–95	49.03 ± 26.75	–
K^{+} (mg/l)	1.61–2.90	2.16 ± 0.43	0.31–16.31	5.24 ± 5.36	2.70–7.07	4.27 ± 1.29	3.88–6.73	4.61 ± 0.70	6.94–8.60	8.08 ± 0.58	1.14–9.80	6.4 ± 2.30	–
HCO_3^- (mg/l)	97.60–280.60	180.87 ± 67.72	75.64–225.70	116.17 ± 49.95	113.16–367.74	216.83± 89.24	117.96–324	212.23 ± 74.35	434.32–566.08	531.92 ± 45.21	499.96–688.08	558.39 ± 62.76	–
Cl^- (mg/l)	0–14	10.5 ± 4.68	1–16	8.4 ± 5.52	8.50–28.57	15.35 ± 5.85	8.04–22.41	12.26 ± 3.84	46–60	53.71 ± 5.09	42.40–61	50.88 ± 5.53	250
SO_4^- (mg/l)	20–46	31.69 ± 10.55	18.14–41.80	28.55 ± 7.92	15.79–30.63	22.49 ± 3.50	13.85–28.96	21.09 ± 3.40	26–52.50	42.2 ± 8.64	29.30–58.80	46.89 ± 8.97	200
NO_3^- (mg/l)	1.32–11	4.89 ± 3.22	3.90–32.12	11.92 ± 9.10	4.36–18.68	8.22 ± 3.82	5.08–14.28	9.32 ± 2.65	0.40–63	27.68 ± 23.84	8.80–137	38.29 ± 44.31	45
TC (MPN/100 ml)	28–2400	897.625 ± 1045.27	1000–2400	1614.29 ± 735.82	64–1305	374.27± 284.84	9.20–2400	416.7 ± 524.66	1100–2400	2140 ± 581.38	1100–2400	1966.67 ± 750.56	Must not be detectable
FC (MPN/100 ml)	43–2400	686 ± 1004.17	93–2400	1006.63 ± 1160.3	3–498	164.45± 162.76	6.75–2400	570.21 ± 698.35	150–2400	1120 ± 1047.07	75–2400	1625 ± 1342.34	Must not be detectable

TC, Total coliform; FC, Faecal coliform.

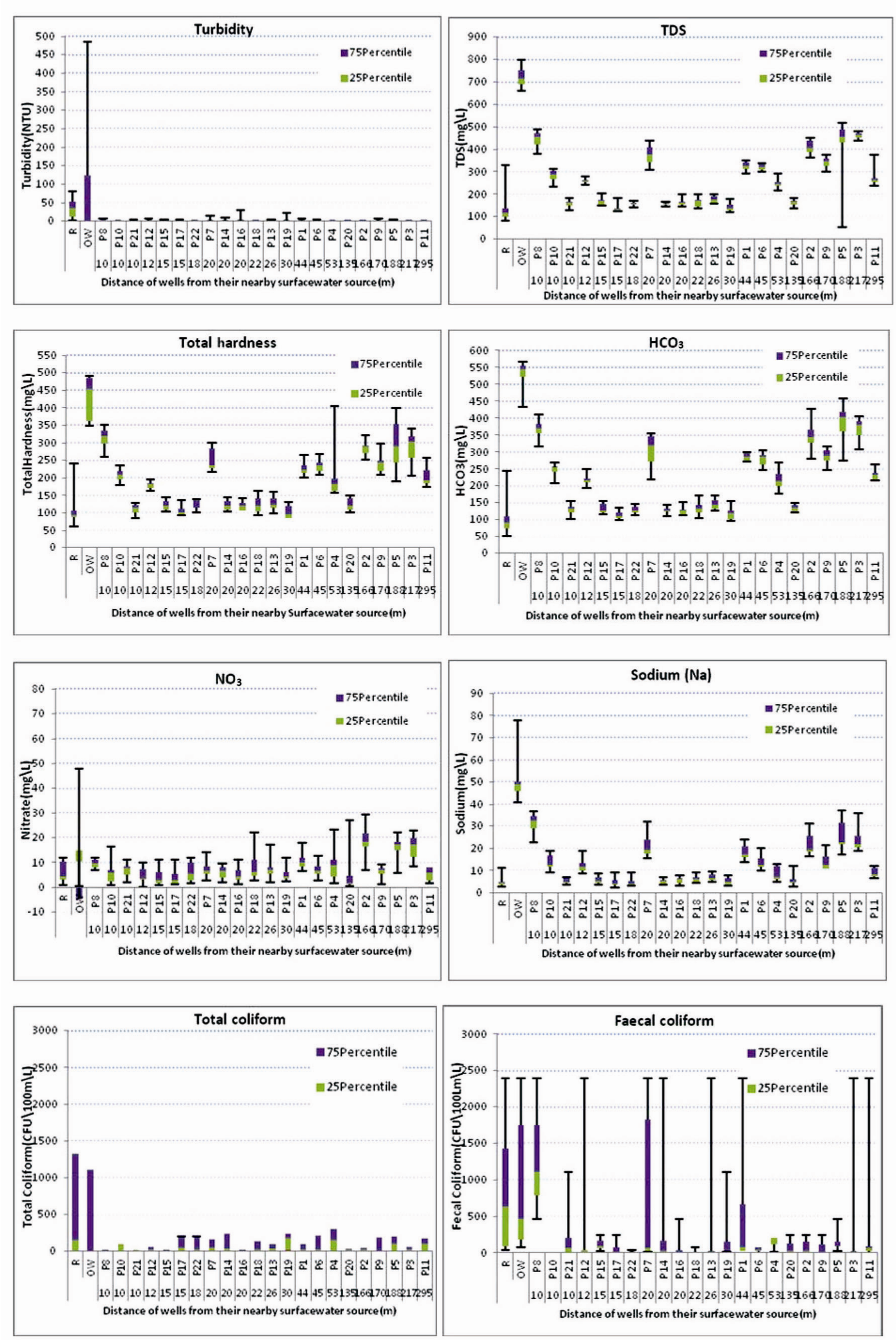


Figure 6. Box-and-Whisker plots of physico-chemical and biological parameters of the 22 RBF wells, surface water and groundwater at Haridwar during the non-monsoon period, arranged in ascending order of distances of wells from the surface water source (Box-and-Whisker diagram represents plot of min, max, median, 25% percentile and 75% percentile).

monsoon and 76% during the non-monsoon period in comparison to the river/canal water, its concentration in some of the production wells was higher than the acceptable limit of 1 NTU. The count of biological parameters, viz. total coliform and faecal coliform, although found to be removed considerably in the extracted water, the count still remains above the acceptable limit, during both non-monsoon and monsoon periods. The percentage removal of coliform varies between 78 and 83 for total coliform and between 65 and 85 for faecal coliform in comparison to the quality of groundwater for both non-monsoon and monsoon periods. The variability of concentration of physico-chemical parameters in the extracted water between the non-monsoon and the monsoon periods, by and large, was found to be small, whereas the variability of biological parameters was found to be high with the monsoon period showing higher value than the non-monsoon period. As evident from Table 1, all physico-chemical and biological parameters (except turbidity) of groundwater show higher concentration than the river/canal water for both periods. However, in the case of turbidity, it is the reverse. A comparison between the results of the extracted and river/canal water shows that there is considerable reduction in all physico-chemical and biological parameters in the extracted water. One of the reasons for high pathogenic contents, viz. NO_3^-, total coliform and coliform in groundwater in Haridwar area may be because it is a pilgrimage site and pathogenic refusals leach to the aquifer during monsoon season by the process of groundwater recharge. The reason of high content of physico-chemical parameters in groundwater could be due to the presence of weathered and eroded source rocks. According to the physical process of bank filtration, during pumping, the induced bank filtrate from river water after mixing with the groundwater gets withdrawn, which leads to change in the quality of bank filtrate water by groundwater. Thus, the quality of extracted water depends on mixing proportion of groundwater with the bank filtrate water.

For examining the spatial variation of quality of bank filtrate water, Box-and-Whisker plots between various parameters of the extracted water from the 22 RBF wells for non-monsoon period and the distances of the wells from the river/canal are shown in Figure 6. In these plots, parameters of the river/canal water and groundwater quality are also shown. The Box-and-Whisker plots showing the min, max, median, 25 percentile and 75 percentile of the distribution represent an exploratory statistics of the databases[24]. It is evident from Figure 6 that a persistence trend of reduction of physico-chemical and biological parameters with distance is not visible. This may be because of the mixing of bank filtrate water with the groundwater having high contents of the respective parameters. For example, the concentration of chemical and biological constituents in the groundwater, namely total dissolved solid, total hardness, HCO_3^-, NO_3^-, Na^+, total coliform and faecal coliform is higher than the surface water source. The reason for higher concentration of cations in groundwater could be due to geogenic source, and that of anions and biological parameters could be due to refusals from the anthropogenic sources, such as septic tanks or leaching from land surface. The bank filtrates, under such circumstances, facilitate dilution of contaminants present in the groundwater by the process of mixing surface water, and thus improve the quality of extracted groundwater. The biological parameters exceed the acceptable and permissible limits in the present analysis. Therefore, post-treatment of the extracted water, particularly disinfection of the biological parameters, would be necessary before supplying it to users for drinking purposes. As post-treatment, Uttarakhand Jal Sansthan (UJS), which is responsible for domestic water supply, has been using appropriate doses of sodium hypochlorite (NaClO) solution as disinfectant to remove biological contents in the extracted water.

Conclusion

The bank filtration as a standalone technique or as a supplementary pre-treatment technique to conventional water treatment system for removal of turbidity and pathogenic contents can be used for domestic water supply in different potential sites in India. The distance of the bank filtration well from the river/stream characterizes the travel time of contaminants and quantity of water to be induced from the river to the aquifer. An analytical method, employing least squares optimization using Marquardt algorithm was utilized to determine the distance of bank filtration well from the river in commensuration with the desired amount of bank filtrate and removal of pathogenic contents for the given hydraulic properties of the aquifer. The method uses percentage requirement of bank filtrate and removal of pathogenic contents as inputs, in addition to aquifer hydraulic properties.

For evaluating effectiveness of the technique, the physico-chemical and biological parameters of bank filtrate water from 22 wells located in the vicinity of the River Ganga and the UGC network at Haridwar were analysed. The physico-chemical parameters of the extracted water showed concentration much below the acceptable limit, except turbidity. The percentage removal of turbidity in the extracted water varied between 76 and 98 in comparison to the water from river/canal. The count of biological parameters, viz. total coliform and faecal coliform in the extracted water was removed between 65 and 85. The reason could be mixing of bank filtrate water with constituents in the groundwater. It was also noted that the bank filtration dilutes groundwater quality and can be regarded as a technique to conjunctive management of surface water and groundwater quality.

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