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Use of bank filtration systems in the sub-tropical region of the lower Brahmaputra valley

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Abstract

River bank filtration (RBF) is a natural method of obtaining surface water from a river or lake via the sub-surface for domestic use. It has been intensively used worldwide to augment water supply systems for sustainability and can be operated under various conditions. Its energy requirements are comparatively lower than those of conventional water treatment systems.

Field investigations were carried out at various locations in Kokrajhar district of Assam, India to assess groundwater quality and aquifer characteristics. The results suggest that major water quality parameters were within the Indian drinking water standards. The iron concentration exceeded the permissible maximum in more than 50% of samples from hand pumps, its concentration ranging between 0.33 and 3.50 mg/L. The pH was mostly in the range 5.4 to 7.4, suggesting that the water is slightly acidic. Aquifer and riverbed material collected along the banks of the Gaurang River were sieved, and classified as coarse silt to fine gravel, with gravel and sand predominant. The hydraulic conductivity, determined from the grain size distributions, were between 5×10^{-3} and 1.4×10^{-2} m/s, suggesting good aquifer permeability. The maximum safe well yield was estimated at 2,000 to 7,500 L/min, and the mean travel time at less than a week during the monsoon and more than 3 years under non-monsoon conditions.

The aim of this paper is to demonstrate the RBF method for treating river water naturally under wet climatic conditions. The lower Brahmaputra basin is a unique physiographic setting with a powerful monsoon regime and a fragile geological base. The approach was to prepare a comparative study of water quality and aquifer characteristics with the present site and few active RBF sites.

Key words: drinking water, river bank filtration, water quality

INTRODUCTION

River bank filtration (RBF) is an excellent treatment technology for drinking water production and is used worldwide (Grischek *et al.* 2003; Ray 2008; Sandhu *et al.* 2011; Ronghang 2015). As the world's growing population puts greater demands on the supply of high quality drinking water, RBF is being increasingly used to treat waters of degraded quality (Tufenkji *et al.* 2002).

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The effectiveness of RBF has been recognized in Europe since the later nineteenth century, supplying potable water to people along the Rhine, Elbe, Danube, and Seine Rivers (Hiemstra *et al.* 2003; Eckert & Irmscher 2006). RBF supplies 70% of the drinking water to Berlin, a densely populated city (Massmann *et al.* 2008). Düsseldorf waterworks in Germany has used RBF since 1870 (Schubert 2002), as has Saloppe waterworks in Dresden since 1875 (Grischek *et al.* 1994). Riverbank filtrate was probably pumped for public drinking water supply in 1879 along the Rhine River in the Netherlands at Nijmegen pumping station (Stuyfzand *et al.* 2006). After World War II, when municipal and industrial pollution in rivers was severe, RBF and filtration through sand dunes provided drinking water to many communities in the Netherlands (Ray 2008).

RBF is widely recognized in the United States (Kühn & Müller 2000). In the early 1940s, a direct connection between the alluvial aquifer and the Ohio River was well documented. The Louisville Water Company also induced RBF as a potentially effective treatment process for removing selected water-borne contaminants and started to investigate its effectiveness for removing disinfection byproducts in the late 1970s (Hubbs 2006). Efforts are being made in Korea to use RBF to improve stream water quality on short, steep slopes in urban environments (Ray 2008).

India has many perennial rivers and the many large cities along them could easily use RBF to help treat surface water for their supply systems. The potential of RBF has been recognized in many cities on the Ganga plains (Sandhu *et al.* 2011). Since 2005, investigations have been conducted into hydrogeological conditions, water quality, and the sustainability of RBF in Haridwar, Patna, and Varanasi along the Ganga River (Thakur & Ojha 2010; Dash *et al.* 2010). Other places where RBF is used for water supply in India include Muzaffarnagar along the Kali River in Uttar Pradesh, Nainital by Lake Nainital on the Yamuna River in the Palla region of Delhi, and the Yamuna River at Mathura and in Srinagar (Uttarakhand) along the Alaknanda River (Sandhu 2013; Ronghang 2015). RBF schemes have been implemented successfully in India at Ahmadabad, Patna, Kharagpur, Dandeli, Haridwar, and Delhi, etc. (Singh 2008; Sprenger *et al.* 2008; Dash *et al.* 2010; Lorenzen *et al.* 2010; Singh *et al.* 2010; Sandhu *et al.* 2011; Kumar *et al.* 2012).

Many cities are experimenting with RBF to produce higher quality water from the polluted rivers as a cost effective process (Sandhu *et al.* 2011). In view of the worldwide success of RBF, its potential and limitations are now being investigated at Kokrajhar in Assam.

STUDY AREA

The study area is in the Kokrajhar district (58°52’30’ E to 90°33’10"E latitude and 26°13’30’ to 26° 53’20"N longitude) of Bodoland Territorial Area District (BTAD), along the River Gaurang in the lower Brahmaputra valley (Figure 1).

The district geomorphology comprises (1) a northern alluvial region (between 120 and 140 m msl) and (2) the southern swamps or flood plain of the Brahmaputra River (<100 to 300 m msl). Much of the district consists of a vast alluvium fan formed by the river system of the Himalayan range in Bhutan (CGWB 2012). This has thick alluvial deposits, comprising alluvium and thick beds of clay in some parts, with a southerly slope. Its elevation varies from 40 to 300 m msl but the topography is flat elsewhere (CGWB 2012). The district's pedology consists largely of older alluvium in the north, and younger, flood plain and alluvial deposits towards the Brahmaputra River in the south (CGWB 2012).

The climate is subtropical and humid, and is characteristically dry outside the monsoon, but hot and wet (heavy rainfall) in the monsoon. The rivers and rivulets become narrower and groundwater levels start to fall in the dry season (winter). The monsoon (summer), however, brings heavy rainfall with highly turbulent river flows and the river banks collapse (Das 2014). Because of this, the river water becomes muddy and carries suspended materials along, with a high debris loading and surface runoff from the agricultural land. Because of this, it has become necessary to investigate the possibility of natural filtration based on RBF in Kokrajhar. The relevant statistics are given in Table 1.

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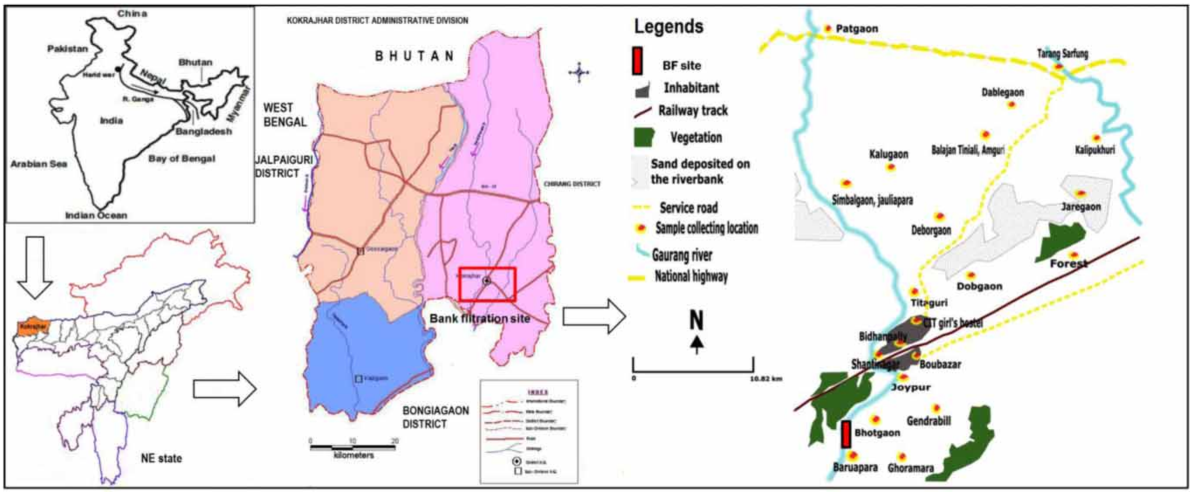

Figure 1 | Location of bank filtration site at Kokrajhar (BTAD).

Table 1 | The study area

Parameter	Details
Location	Patharghat Kokrajhar town
Latitude and Longitude	90°15'40.89"E 26°24'37.69"N
Mean altitude	75 m msl
Average annual rainfall between 2010–11[a]	3,100 mm
No of water supply units	Not available
Water demand per capita per day[b]	135 L
Total town population (Census 2011)	32,000
Available piped water supply	Nil
Average domestic water supply deficit	4.2 MLD
Distance from available water sources (hand pumps)	Less than 50 m
Per capita availability (L/P/day)	Nil
Project water demand for domestic and industrial use up to 2025[a]	31,430 MLD
Major groundwater problems and issues[a]	High concentrations of iron in some groundwater pockets

[a]CGWB 2012.
[b]Adopted from Raghunath 2006.

MATERIALS AND METHODS

Sampling campaign for groundwater and aquifer characterization

Water samples were collected from different locations around Kokrajhar sub-division-I (Figure 1). The sampling site latitudes and longitudes were obtained using GPS (Garmin) with a precision of ± 5 m, and the campaign took place during 2016. The samples other than bacteriological were collected in 500 to 1,000 mL bottles (Figure 2(a)), those for bacteriological analysis were taken in sterilized 100 mL glass bottles. The hand pump orifice was flame sterilized and water pumped for about 2 or 3 minutes, before the samples were taken (Figure 2(b)). Samples were transported to the laboratory of the Public Health Engineering Department (PHED) at Kokrajhar for testing and analysis (Figure 2(c)). Sampling, storage and analyses were carried out according to the procedures in APHA Standard Methods (American Water Works Association 2005). Electrical conductivity (EC), total dissolved

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Figure 2 | Sampling campaigns (a) Collecting water samples, (b) Sterilization of hand pump before collecting water sample for bacteriological testing (c) Preparation of groundwater sample (d) Measurement of onsite parameters.

solids (TDS), and temperature were measured on-site using portable instruments, and pH was measured using pH kits (Figure 2(d)). Various parameters like hardness, chloride, iron, fluoride, arsenic, alkalinity, nitrate, manganese, turbidity and the bacteriological tests were carried out in the laboratory.

Aquifer materials were collected at different locations and depths (down to 1.5 m bgl) from the bank and bed of the Gaurang River (Figure 3).

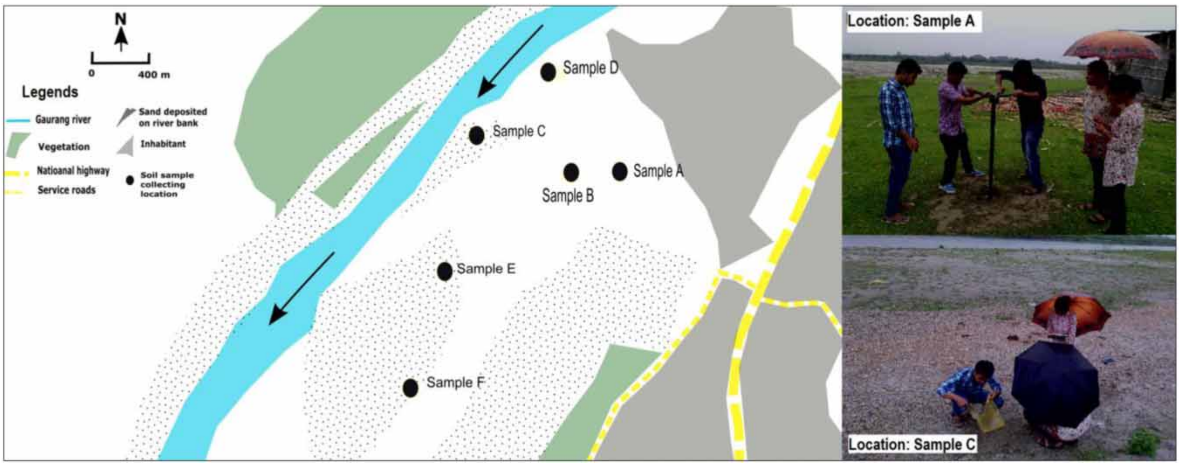

Figure 3 | Soil sampling locations.

DRILLING AND CONSTRUCTION OF OBSERVATION WELLS

Based on the field campaign and site selection, three observation (monitoring) wells were drilled using the traditional wash boring technique called 'Dheki' locally. The drilling locations are shown Figures 4(a) and 4(b). Details of well construction are given in Table 2.

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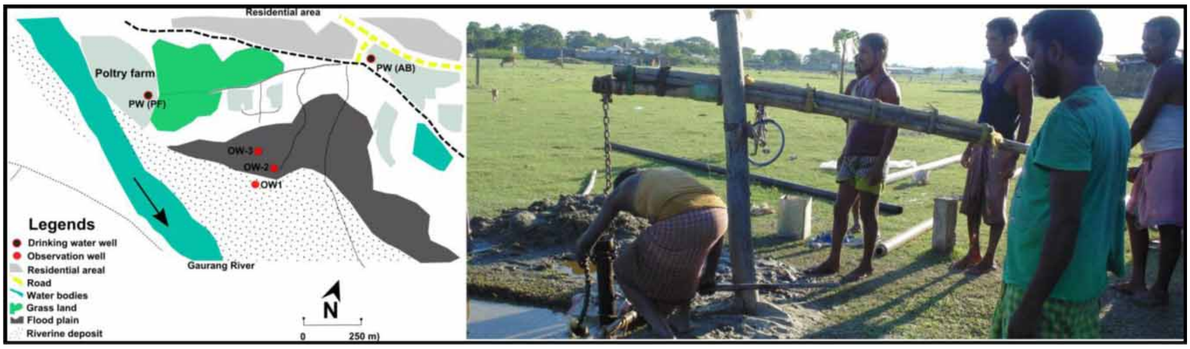

Figure 4 | Well drilling locations.

Table 2 | Well construction details

Well ID	Well diameter (m)	Screened section (m)	Bore depth (m)	Distance from the river (m)	Type of the aquifer	GPS coordinates
OW-1		4.80–5.80	6.10	243.5	Course Sand	E090°15’39.1’ N026°24’39.2"
OW-2	0.10	9.37–10.37	10.67	297.4	Course Sand and Gravel	E090°15’41.0’ N026°24’38.1"
OW-3		13.99–14.99	15.29	334.2	Sand and Course Gravel	E090°15’42.5’ N026°24’39.3"

Monitoring well (OW-1) is 243.5 m from the river shore and drilled to a depth of 6.1 m (Table 2). OW-2 is 53.9 m away from OW-1 and 10.7 m deep. OW-3 is 90.7 m away from OW-1 and 15.3 m deep – drilling stopped there when hard rock was struck.

After drilling, aquifer material samples were collected from 1.52, 3.05, 4.57, 6.10, 7.62, 9.14, 10.57, 12.19, 13.72, 15.29 m bgl, as limited by the depths of the individual boreholes, and transferred to the Geotechnical Laboratory of the Central Institute of Technology, Kokrajhar, for sieve analysis.

All samples from the flood plain, riverbed and aquifer were washed through 75 micron sieves to remove fines, dirt and dust, before being oven dried at 105 °C for 48 hours. They were then weighed and transferred to the sieve shaker (Tohniwal, India) to determine the grain size distribution. The hydraulic conductivities (K) of the aquifer materials were calculated using established empirical formulae adopted from Odong (2007).

RESULTS AND DISCUSSION

Water quality

Water sample temperatures were all within the range 24.3 to 27.0 °C. The pH range was narrow – between 5.4 and 7.4 – and the water is generally slightly acidic (Figure 5(a)). The EC and TDS ranges were 41 to 334 μS/m and 22 to 189 mg/L, respectively, suggesting that the water has low mineralization, perhaps because the groundwater is directly recharged by rainfall (Figure 5b). Turbidity was very low – less than 2 NTU – in most samples, although two samples, from E090°21’30″, N26° 30’41″ and E090°17’8″, N26°25’55″ reported 6 and 5 NTU, respectively.

Water alkalinity and hardness ranged between 28 and 162 mg/L, and 4 and 204 mg/L (both as calcium carbonate), respectively, which is within the permissible limit of the Indian drinking water standards. The highest alkalinity was observed in dug well-IV at Kalipukhuri whereas the maximum hardness was found at Shantinagar, HP-I (Figure 6(a) and 6(b). In some places such as Joypur (Bhatipara) and Dimalgaon (Titaguri), the hardness was less than 10 mg-$CaCO_3$/L (Figure 6(b)). The chloride concentration ranged from 6 to 82 mg/L, well below the permissible limit of 1,000 mg/L (BIS, 2012).

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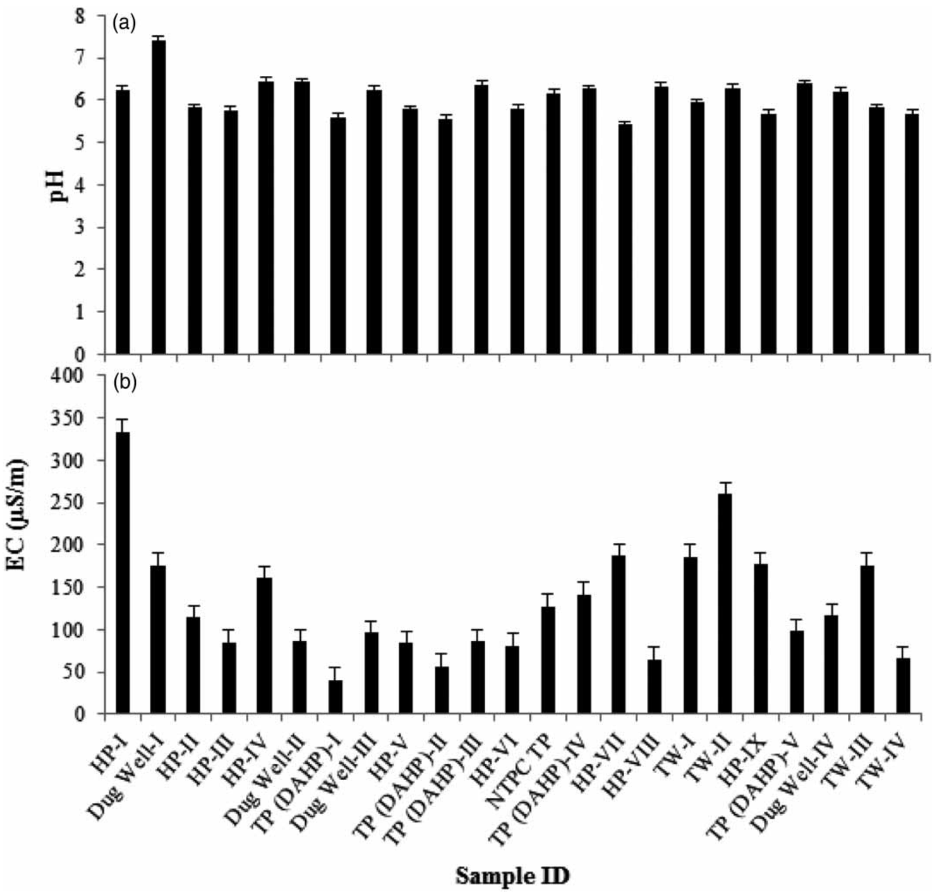

Figure 5 | Variations of pH and EC of water samples.

In most places, the chloride concentration is less than 30 mg/L, with only four locations – Shantingar (HP-I), Bhatipara (HP-IV), Forest colony (NTPC-DAHP) and CIT girl's hostel (TW-I) – reporting concentrations of 80 mg-Cl/L. It can be inferred from these data that contamination levels are low.

The concentrations of other ionized solutes, like fluoride, arsenic and nitrate are within the limits set by BIS (2012). The iron concentration exceeded the 0.3 mg/L maximum permissible in samples HP-I, HP-VI, NTPC-DAHP and Dug Well-IV. This may have been caused by leaching from corroded pipes by relatively low pH water. The manganese concentration is below the limit of detection in waters from most places, the eight exceptions being Shantinagar, Bhatipara, Simbargaon, Patgaon, Forest colony, Bidhanpally, Dobgaon and Habrubari; although even at these places the values are very low, if slightly higher than elsewhere. The arsenic determinations showed that arsenic is generally absent, except at Titaguri, CIT girl's hostel and Kokrajhar rail gate, where the concentrations were 7 μg/L, below the desirable limit of 10 μg/L.

Aquifer characteristics

The particle size distributions were determined by plotting grain size (mm) against proportion of fines retained (p%). The plots were compared and the graph (not shown) suggests that the aquifer material is mostly sandy, consisting mainly of coarse to medium sand. It is generally homogeneous with a small percentage of coarse silt, and the curves enable estimation and tabulation of characteristics like effective size (d_{10}), mean particle size (d_{50}), uniformity co-efficient (C_u), co-efficient of gradation (C_c) and porosity (η). From these sample hydraulic conductivity (K) was calculated using equations adopted from Odong (2007). Thus, for sample A – see Table 3 – the Hazen formula gave a hydraulic

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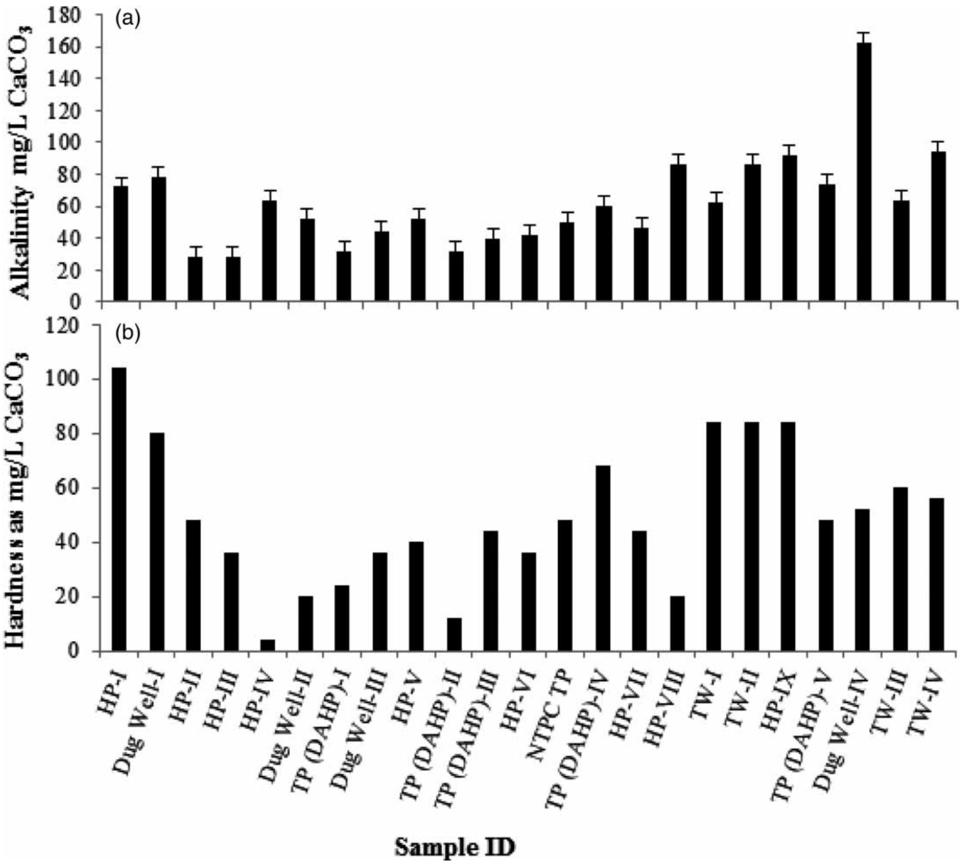

Figure 6 | Alkalinity and hardness in water samples.

conductivity of 4×10^{-2} m/s, whereas the Cozeny-Carman, Slitcher and Breyer equations gave 2×10^{-2}, 2×10^{-2} and 4×10^{-2} m/s respectively.

The hydraulic conductivity at the proposed RBF site is estimated at between 5×10^{-3} and 1.4×10^{-2} m/s. This is typical of the range found at most such sites around the world (Goldschneider *et al.* 2007; Ray 2008; Hiemstra *et al.* 2003; Dash *et al.* 2010; Sandhu *et al.* 2011; Ronghang *et al.* 2012; Gupta *et al.* 2015).

Table 3 | Aquifer and riverbed material characteristics.

				Hydraulic conductivity (m/s) $\times 10^{-4}$			
Sample ID	**C_u**	**Porosity (n)**	**d_{10}^2 (mm^2)**	**Huzen**	**Kozeny-Carman**	**Slitcher**	**Breyer**
Sample A	2.6	0.41	0.25	433	198.58	154	395.63
Sample B	3.3	0.39	0.16	255	107.33	83.6	242.08
Sample C	2.3	0.42	0.12	221	105.67	81.6	198.11
Sample D	1.9	0.43	0.03	48	24.	17	42.91
Sample E	2.3	0.42	0.04	72	34.52	26.7	64.66
Sample F	1.6	0.44	0.06	121	63.24	48.5	108.27
Sample G	2.9	0.4	0.01	20	8.87	6.8	18.68
Sample H	3.5	0.39	0.01	19	8.16	6.3	18.2
OW-1	2.7	0.41	0.02	3	3.31		2.72
OW-2	16.3	0.27	0.08	5	2.25	–	6.74
OW-3	13.9	0.27	0.43	30	13.95	–	40.19
River Bed	2.0	0.43	0.09	15	18.44	–	13

Note: Kinematic viscosity at 20 ° (υ) = 1.0 × 10 − 6 m^2/s, g/υ (–) = 9770916.

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It is clear from the results reported in Table 3 that sample A has the highest hydraulic conductivity. Other samples – e.g., E – have lower permeability, indicating that the material represented by sample E can be expected to retain the finer particle, whereas the material represented by sample A, which has the highest K values, is likely to allow finer particles to break through. Samples B and C have similar K values to one another and are well suited to use as filtration media (Ronghang 2015). Comparison with other RBF well fields suggests that the study site for this work is suitable (Table 4).

The maximum safe well yield was estimated at between 2,000 and 7,500 L/min, similar to the RBF wells at Srinagar, India, and Düsseldorf, Germany (Schubert 2002; Ronghang 2015). The estimated mean travel time at the study site was similar to that of the RBF at Satpuli, India (Ronghang *et al.* 2012; Kimothi *et al.* 2012).

Table 4 | Comparison of RBF well fields

Location	River	Distance from the river (m)	Depth drilled (m BGL)	Aquifer material	Hydraulic Conductivity (m/s)
Srinagar	Alakananda	169	19.7	medium-coarse, aquifer material sand	$7.7–9.9 \times 10^{-5}$
Kamaprayag		49	16.0	fine-medium sand, medium gravel	$1.1–6.2 \times 10^{-4}$
Satpuli	Eastern Nayar	26	45	medium to coarse sand and	$4.51–6.5 \times 10^{-4}$
Agastyamuni	Mandakini	33	30	gravel, with some large fluvial boulders	$2.02–2.2 \times 10^{-4}$
Palla, Delhi	Yamuna	35–250	5–54	medium to fine alluvium	$1–8 \times 10^{-4}$
Haridwar	Ganga	110	10	coarse sand & gravel	$1.2–4.7 \times 10^{-4}$
Patharghat,	Gourang	334.9	15.3	fine-medium	
Kokrajhar				sand coarse sand & gravel	$27.0–4.5 \times 10^{-4}$

CONCLUSIONS

The research was conducted to assess the potential for RBF at Kokrajhar, using a sampling campaign to investigate groundwater quality in the town. The groundwater is generally slightly acidic. Most water quality parameters determined were within the desired limits apart from iron. Soil samples from six different locations along the river bank to determine the aquifer characteristics indicate that the site is suitable for RBF. The hydraulic conductivity was in the same range as most RBF sites around the world.

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