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Research Article

Insight of Riverbank Filtration System at Haridwar for Enhancement of Drinking Water Quality

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Abstract

Water quality of 16 production wells at the bank of the river Ganga at Haridwar was evaluated in 2005-06. As a preparatory step for the Kumbh 2010, six more production wells were commissioned. A necessity was felt to assess the water quality from these new wells and a few existing production wells after a gap of 5 years. Twenty-three samples were collected monthly from four month during lean season (non-monsoon) where the water quality at the river is worsening in term of concentration except for turbidity. The analysed parameters for physical, chemical and bacteriological water quality parameters from the production wells were within the prescribe limits of BIS. The coliform count in the river water ranged from 160 to 16000 MPN/100 mL whereas 91% of samples drawn from the wells were devoid of coliform. Based on water quality analysis, production wells have been categorized in to north and south wells with reference to the new supply channel. Concentration of major ions in water from south wells is close to that of river water. However, water from wells in the north were found to have Ca, Mg, Na and alkalinity 3.2 to 5.5 times the concentration in the river water. Sulfate and chloride were respectively around 1.7 and 11.8 times more than the river water. An attempt has been made to explain the observed difference in water quality of wells on the basis of travel time and characteristics of river bed material.

Keywords: *Riverbank filtration; Water quality; Production wells; Drinking water supplies.*

1. Introduction

Riverbank filtration (RBF) has been used to provide drinking water to the cities located at the bank of Rhine, Elbe, Danube, and Seine rivers for more than a century in Europe and for nearly half a century in United States. A few water supply schemes along the river Ganga, Yamuna, Sabarmati etc. have recently been recognized as RBF sites. Based on this a few more RBF sites to provide drinking water are being developed in the cities located on the bank of rivers. Haridwar, the holy city with significant floating population has been using RBF for more than 30 years as one of the source for public water supply. River water after passing through the aquifer is collected in production wells (PWs), which have depth of 7 to 10 m below the surface and diameter of 10 m each. Water from these wells is pumped and supplied to Haridwar city. There were 16 PWs in Haridwar till 2009. As a preparatory step for the Kumbh 2010 six more production wells were commissioned in north of the new supply channel (NSC) (Fig.1). Water quality of surface water improves when it passes through the aquifer. At the time of bank filtration some physical, chemical, and biological processes (such as filtration, dilution, sorption, precipitation, redox reactions, leaching and biodegradation) occur (Kuehn and Mueller, 2000; Boulding and Ginn, 2004).

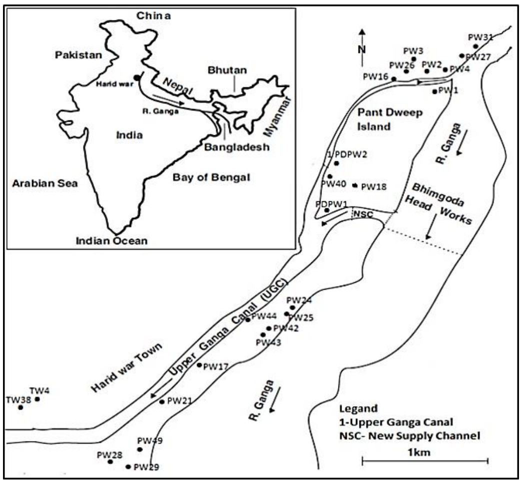

Fig.1. Watercourses, PWs and TWs at Haridwar (modified from Dash et al., 2010).

Through RBF, microbial pathogens, fecal indicator organisms and other surrogate are removed by contact

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with aquifer materials through attachment to the soil and bacterial inactivation. Microbial monitoring conducted by Weiss et al. (2005) over a period of more than 1 year at three full-scale RBF facilities, located in the United States along the Ohio, Missouri, and Wabash Rivers indicated that the Cryptosporidium and Giardia were detected occasionally in the river waters but never in any of the well waters. Average concentrations of aerobic and anaerobic spore-forming bacteria were reduced at the three facilities by 0.8 to >3.1 log and 0.4 to > 4.9 log respectively. Average concentrations of male-specific and somatic bacteriophage were reduced by >2.1 log and ≥ 3.2 log respectively. Total coliforms were rarely detected in the well waters, with 5.5 and 6.1 log reductions in average concentrations at the two wells at one of the site relative to the river water. Water quality of seven tube wells (TWs) (depth 22.6-36.7 m) located at a distance of < 100 m from the lake at Nanital was studied by Dash et al. (2008). Coliform count of ~15.6× 10^4 MPN/100 mL found in lake water was not detected in any of the tube-well water samples over the years Dash et al. (2010) studied the improvement in the quality of river water filtered through a 17-m thick sand-gravel unconfined aquifer at a PW surrounded by surface-water bodies in Haridwar (India). In non-monsoon months, RBF resulted in a reduction of coliforms by 3 log where as during monsoon, removal increased to more than 4 log. Column studies confirmed that a retention time of around 5 days was adequate to achieve more than 99.9% removal of coliforms. Singh et al. (2010) investigated a RBF site at Mathura and observed around 50% reduction of fecal coliforms. Drewes and Springs (2002) recorded the removal of natural organics through natural bank filtration. DOC removal during RBF at the Rhine River in Europe was constant and accounted for approximately 50-percent removal of organic matter in the river water (Kühn and Müller, 2000; Weiss et al., 2002). Wang (2002) recorded similar observations at RBF systems on the Ohio, Wabash, and Missouri Rivers in the United States. Singh et al. (2010) found that the chlorine doses as high as 60 mg/L ahead of the water treatment units reduced DOC and UV-absorbance by about 18%. In comparison to direct pumping of the river water, collection of water through RBF resulted in the reduction of DOC and UV-absorbance by around 50%. To reduce DOC to the desired level, the dose of ozone required for the riverbank filtrate was found to be considerably less than the ozone required for the river water. RBF as compared to direct pumping of Yamuna water appeared effective in improving the quality of the Yamuna water. Various researchers have demonstrated effective removal of turbidity and suspended solid during RBF at different sites (Wang et al., 1995; Schubert, 2001; Dillon et al., 2002; Dash et al., 2008; Dash et al., 2010)

2. Study site and its hydrogeology

Haridwar (29° 58' N and 78°10' E) is located in the western part of the Uttarakhand state of India with an average altitude of 294 m above the mean sea level. According to 2011 census, 2.5-lakh people live in Haridwar city and each year on an average 5.5-lakh people visit Haridwar city for the religious rituals of bathing and worshiping. Four month long festivals of Kumbha and Ardhakumbha are held every 12 and 6 years respectively. During these festivals, more than 5 million people take bath in River Ganga. A part of the River Ganga water at Haridwar is diverted into the Upper Ganga Canal (UGC) for the irrigation purpose. A barrage named as Bhimgoda Barrage has been constructed on the River Ganga near Pant Dweep Island to provide an additional supply of water through NSC to UGC (Fig.1). Six new PWs were commissioned at upstream of barrage during the Kumbh Mela 2010 at a distance of 10 to 60 m from the river/canal (Table.4). There are twenty-five TWs and twenty-two PWs located on the right bank of River Ganga at Haridwar. The Pant Dweep Island aquifer comprises of stream deposits to a depth of 20 m below ground level and sediments of aquifer were found to be ranging from fine sand and silt sand layer to medium sand and gravel.1.TWs pump the water from a confined multilayer deeper aquifer system (~25–110 m from ground level) and large diameter PWs pump out water from a shallower unconfined aquifer (thickness 3–21 m) which is in direct hydraulic contact with the river and the two canals (Dash et al., 2010).

3.Methodology

3.1.Water quality

Sampling campaign was designed covering the two months each of winter (January and February) and spring (March and April). Samples were collected every month from nineteen PWs, two TWs, Ganga river and UGC. Samples for the physico-chemical analysis were collected in 2-liter plastic bottles and for the bacteriological analysis in 250 mL sterilized glass bottles. Samples in a thermostatic box containing ice pack were transported to the Environmental Engineering Laboratory, Department of Civil Engineering, IIT Roorkee. Electrical conductivity (EC), pH and temperature were measured on site. Other parameters such as turbidity, total organic carbon (TOC), UV-absorbance at 254 nm, major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-), and total and fecal coliform were determined in the laboratory. Turbidity was determined by using a Nephelometer (AN 2100, Hach, USA). EC, and pH were measured using Hach instrument (HQ 40d Hach Company, USA). Samples for TOC were analyzed with a TOC analyzer (TOC-V CSN 5000, Shimadzu, Japan). UV-absorbance of all samples was determinedfrom DR-5000 UV-VIS spectrophotometer (Hach, USA). An ion exchange chromatograph (861 advanced compact IC Metrohm) was used to measure the major ions. Alkalinity was determined by titration method using bromocresol green indicator and N/50 H_2SO_4 as a titrant. Total and fecal coliform were determined by multiple tube fermentation method. All the parameters were analyzed in accordance with the procedures laid down in Standard Methods (APHA, 2005).

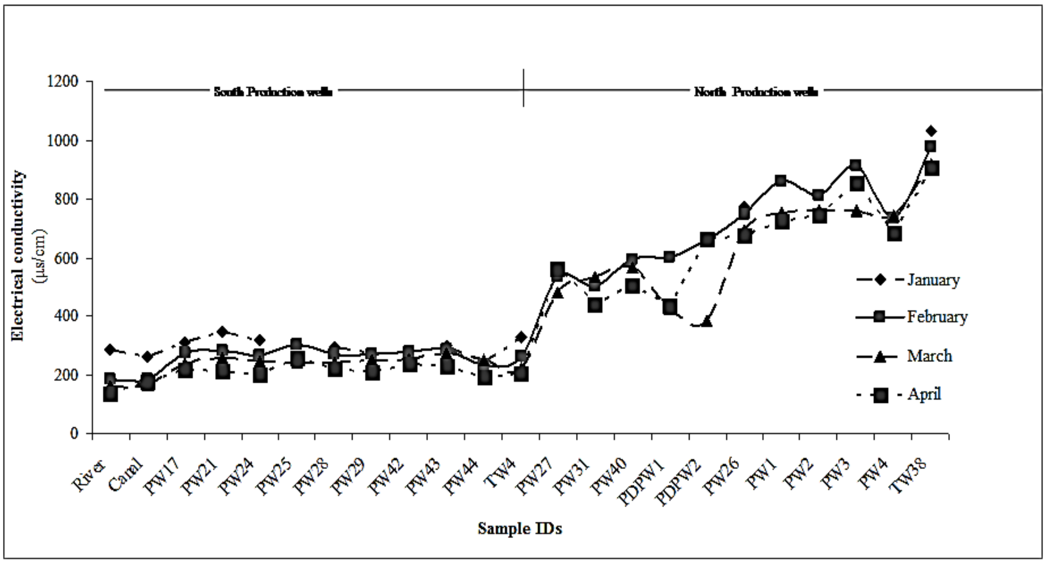


Fig.2 Electrical conductivity of water samples

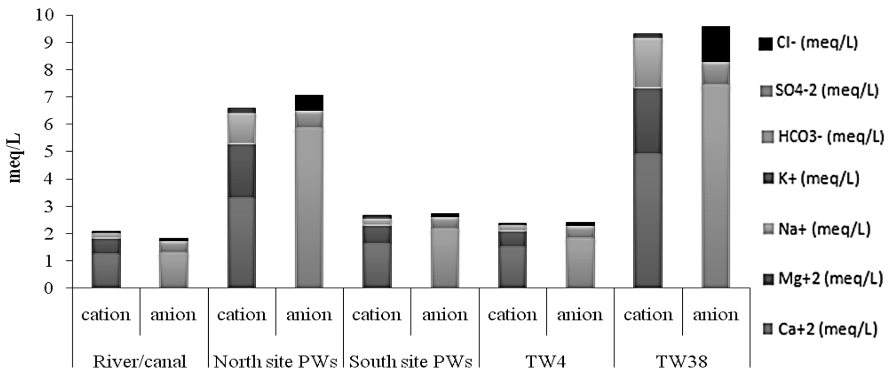


Fig.3. Comparison between ionic balance of water samples from river, TWs, PWs from south and north site.

4.Results and discussion

4.1. Water quality

4.1.1.Temperature, turbidity and pH

During the sampling months i.e. Jan., Feb., Mar., and Apr., 2011, air temperatures were recorded as 10, 17-19, 26-28 and 29-32 ºC respectively Temperatures of river/canal water and water collected from PWs and TWs in different months are shown in Table.1. The river water turbidity ranged from 8 to 38 NTU during sampling period.

Table 1 Temperature of water from river/canal, PWs and TWs

	Water Temperature, °C			
Samples	January	February	March	April
River/Canal	12	15	21	26
PWs	16-18	18-21	23-25	24-27
TWs	17-20	19-22	22-24	19-24

Turbidity of most of the samples from PWs and TWs was < 2 NTU. Only samples from PW 4, PDPW 1 and PW 25 in the month of Feb. were found to have turbidity ranging between 8 to 10 NTU. However, turbidity of samples from all the wells were in conformity with the drinking water standards IS 10500: 1993. pH of water samples from PWs did not exhibited significant variation during four months. Water of river/canal had slightly higher pH compared to water from PWs.

4.1.2.Electrical conductivity, major ions and TOC

EC of water samples collected in four months is shown in Fig. 2. There were two distinct ranges of conductivity values of water from PWs and TWs.

The conductivity values of water samples from 9 PWs located south of NSC were comparable to those of river water. However, samples from remaining 10 PWs located to the north of NSC had higher conductivity. The quality of water from one of the tube wells (TW 4) was similar to that of river and PWs water in the south whereas water from TW 38 was similar to those PWs in the north of

Table 2 Minimum, maximum and average values of water quality parameter

Parameter	River and UGC	North site PWs	South site PWs
pH	8.3-8.8 (8.5)	7.0-7.9 (7.4)	7.7-8.4 (8.0)
Turbidity (NTU)	6.8-38.5 (22.7)	0.18-10.2 (1.84)	0.36-9.33 (1.5)
Electrical Conductivity (µS/cm)	136-287 (196)	384-912 (649)	193.5-347 (259)
TDS (mg/L)	82-173 (119)	230-547 (389)	116-208 (155)
Total hardness (mg/L as CaCO3)	71-141 (98)	147-450 (284)	82-190 (119)
Ca^{2+} (mg/L)	19.5-33 (25)	32-127.7 (76.1)	24-49 (33)
Mg^{2+} (mg/L)	4.0-11 (7)	8.9-32.9 (22.2)	5-27 (9.0)
Na^{+} (mg/L)	3.2-6.0 (4.5)	12.7-40 (23.6)	4-10 (6.0)
K^{+} (mg/L)	3.2-5.8 (4.7)	0.1-25.1 (6.6)	0.1-11.0 (3.2)
HCO_3^- (mg/L)	50-83 (69)	155-420 (293)	80-150 (109)
SO_4^{2-} (mg/L)	12.4-31.9 (20)	15.4-75.1 (31.4)	14-30.2 (22.1)
Cl^- (mg/L)	1.2-2.6 (1.6)	5.1-45 (18.7)	1.6-5.4 (3.4)
UV absorbance at 254 nm (cm^{-1})	0.06-0.1 (0.08)	0.014-0.08 (0.05)	0.018-0.05 (0.03)
TOC (mg/L)	0.082-1.26 (0.39)	0.086-1.37 (0.863)	0.07-0.49 (0.233)
C_T (M/L) or (TIC)	0.0005-0.0008 (0.0007)	0.0016-0.0049 (0.0033)	0.0008-0.0016 (0.0011)
Total coliform (MPN/100 mL)	160-16000 (4305)	< 2-13 (3)	< 2-170 (60)
Fecal coliform (MPN/100 mL)	160-14000 (3434)	< 2-8 (5)	< 2-90 (34)

Water Quality: Comparison of Source Water and Production well Water at North

NSC. However, water from both TWs located south of NSC had different characteristics. Similar trend was also observed in case of major ions. Water samples have been grouped into river/canal, north PWs, south PWs, TW 4 and TW 38. Accuracy of results checked through ionic balance is shown in Fig. 3. TOC of all the water samples was less than 1 mg/L. Minimum, maximum and average values of water quality parameter are given in Table. 2.

4.1.3.Bacteriological quality

Total and fecal coliform in river/canal water were observed more than the PWs and TWs. Total and fecal coliform of most of the water samples from PWs and TWs were recorded < 2 MPN/100 mL. Data from Nov. 2005 to May 2011 also showed a variation in coliform from 300 to 9300 MPN/100 mL under flood conditions and at the time of Kumbh 2010 (Bhanuprakash, 2006; Thakur, 2007; and BHEL Haridwar, 2011).

4.2.Riverwater versus production wells water

4.2.1.Total coliform, fecal coliform and turbidity

Removal of total and fecal coliform during winter and spring months was log 1.3-1.4 and log 3.5-3.6 respectively (Fig. 4). It may be due to low concentration of total and fecal coliform in river/canal water during winter months. Turbidity of water samples from PWs was measured less than the river/canal water. Water quality of 96 % of samples from PWs conformed to drinking water quality standards as per IS: 10500: 1993. Electrical conductivity and major ions, It was observed that for all the PWs located north of NSC, the average EC in comparison to source water was 3.0 times (range: 2.2 to 3.9 times) in winter months and 3.8 times (range: 2.7 to 5.0 times) in spring months. As far as PWs located south of NSC are concerned, the average increment in EC as compared to the source water was 1.2 times (range: 1.0 to 1.4 times) in winter and 1.5 times (range: 1.4 to 1.6 times) in spring months. Similar trend was also observed in case of major ions. Northern wells are found to have high ions concentration in regards to the surface water and to the southern wells Perusal of data in Fig. 3 indicate that the composition of water from TW 38 (tube well) is similar to that of water from north wells. Concentration of ions in water samples from the river/canal, south PWs and TW 4 are similar. TWs pump water from an aquifer, which is 25 to 110 m deep. The difference in concentration in water samples from TW 4 and TW 38 may be due to the difference in depth of the aquifer from where water is drawn. The reason for the observed difference in water from north and south wells is not very well understood from the data. The difference in quality of water from north and south PWs cannot be correlated to the shortest distance from the river/canal. The physical distance (shortest) of nine out of ten PWs (in the north) from the river/canal varied from 30-60 m, one of the PW is located at 10 m. PWs in the south are located at distance of 4-30 m (Table. 3) All the PWs are in unconfined aquifer (3-21 m thick). As far as composition of water from north and south wells is concerned, it is difficult to say whether it is similar or different. According to data in Fig. 3, calcium is ~ 60 % of the total cations in the water samples from

Table 3 Dimensions and discharge capacities of PWs and TWs

Name of wells	Dia (m)[a]	Depth (mbgl)[a]	Distance from River (m)[b]	Distance from UGC/NSC (m)[b]	Installed capacity of pumps (L/min)[c]	Running hours Per day	Average Water drawn (KL/d)[c]
PW1	10.5	7	40	29	2250	2	270
PW2	10.5	7.5	50	32	2250	2	270
PW3	10.5	7.5	80	60	2250	1	135
PW4	10.5	9	10	30	2250	4	540
PDPW1	10.5	6	200	56	2250	7	945
PDPW2	10.5	6	150	30	2250	2	270
PW17	10	8.8	210	30	2800	24	4032
PW21	10.8	6.85	95	25	1400	20	1680
PW24	10.2	10.7	12	230	1700	20	2040
PW25	10.4	7.9	15	230	1700	24	2448
PW26	10	8.95	300	50	1400	20	1680
PW27	10.3	6.5	250	-	1650	20	1980
PW28	10.75	10.4	500	8	1600	20	1920
PW29	10.75	10.3	65	15	1500	19	1710
PW31	10.2	7.9	50	-	1400	24	2016
PW40	10.35	7.5	650	10	1500	20	1800
PW42	10.5	10.5	15	235	1800	18	1944
PW43	10.5	10.6	4	235	1800	16	1728
PW44	10.3	8.8	210	30	1600	20	1920
TW38	-	-	-	30	-	15	-
TW4	-	-	-	50	-	20	-

mbgl: meter below ground level; [a] from UJS; [b] from personal communication; [c] (as in 2011); PDPW: Pant Dweep production well

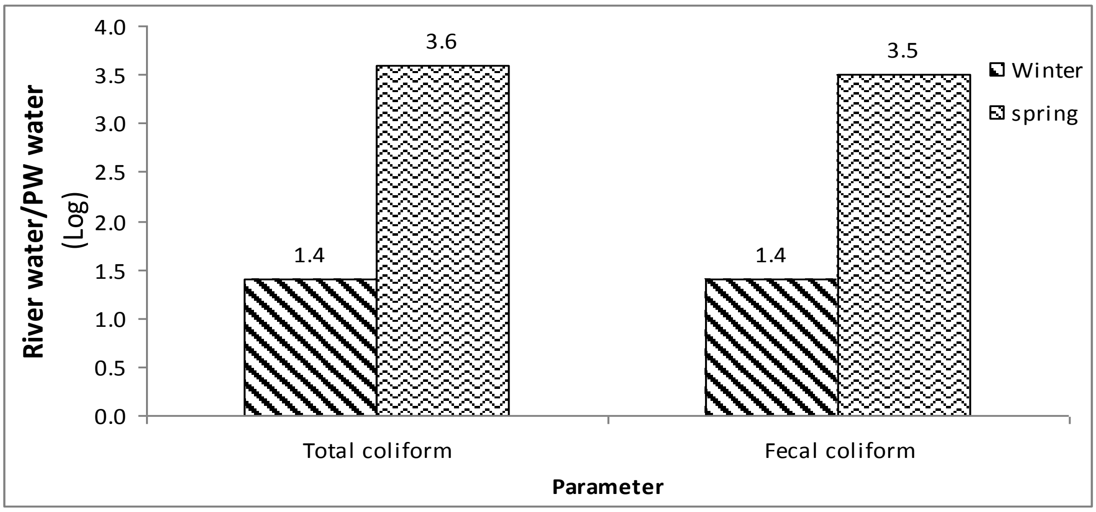


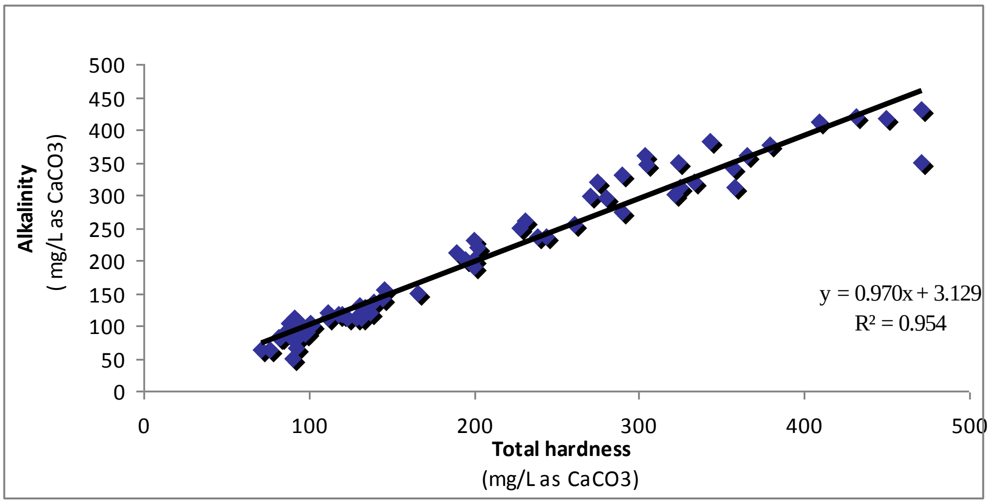
Fig. 4. Total and fecal coliform counts in river relative to production well water

river/canal, south PWs and TW 4 where as in other samples calcium is ~ 50 % of the total cations. Nevertheless, correlation shown in Fig.5 (a) and (b) indicate similar composition of all the water samples.

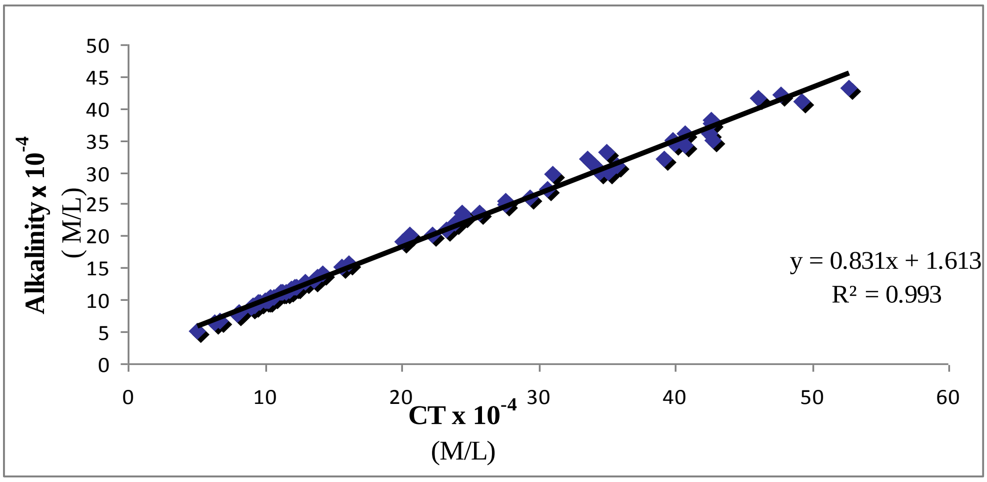
Based on these, the difference between water quality of north site PWs and south site PWs may be due to the following:

Mixing of ground water: PWs located to the north of NSC have a higher percentage of ground water in comparison to the PWs located to the south of NSC.

Clogging of river bed: Clogging of the riverbed (including river branches, natural or artificial canals) essentially



(a)



(b)

Fig.5. (a) Correlation between alkalinity and total hardness. (b) Correlation between alkalinity and total inorganic carbon (TIC).

influences recharge abilities and the quality of the water recharging an aquifer (Mucha et al., 2006).The hydraulic conductivity of the bed material of the NSC has been found to range from 0.2×10^{-6} to$\times10^{6}$m.s^{-1}. This is representative of fine sediment material deposited by the Bhimgoda barrage outflow as a result of the lower flow velocity (<1 m.s^{-1}) and gradient compared to the UGC (Sandhu et al., 2010). Decreased velocity would (i) increase travel time of water thereby (ii) the contact time of water with the aquifer material and subsequently (iii) increase the leaching potential of aquifer material.

Steady state ground water flow modelling.

Results from groundwater flow modeling establish that the PWs in the north are mostly fed by the river through induced infiltration. The model predicts the flow path of the groundwater from river to canal (Fig. 6). The drawdown contours shows that the recharge is predominantly from the river. The influence of the pumping regime on the others PWs located ~ 90 m away can also be addressed by the plot (Fig. 6A). The possibility of interaction between two PWs (PW 31 and PW 27) when the drawdown is more than 0.98 m can't be ruled out. The possible flow path simulated in the model predicts travel time of 77-104 days for the movement of water from river to well. Travel time calculated from Darcy's formula has been found to range from 15-275 days for north PWs (UJS, 2011) and for wells located south of NSC (distance 4-30 m) ranges from 1.1-6.5 days which is much less than that of wells in north. The conductivity of wells in north may be due to fine material and relatively longer travel time.

Conclusions

EC and major ions were found to be more in PWs than the surface water (River/canal). Similarly north PWs also have higher concentration of EC and major ions than the south PWs. Water quality trend of six new PWs was observed similar to the old PWs located to the north of NSC. The quality of water from PWs in south of NSC didn't exhibit any change. Large variation of coliforms found in river/canal during winter and spring months did not influence the performance PWs. Turbidity, Total and fecal coliform of water from the PWs were not found to vary significantly in winter and spring months. RBF site at Haridwar is efficient for the removal of turbidity and coliform bacteria, the impurities of concern in the river water. Ground water flow was observed from riverside to the canal side. PWs 27 and 31 can be influenced by each other while PW 26 is not influenced by PW 27 and PW 31 or vice versa.

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