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IMPLEMENTATION OF RIVER BANK FILTRATION TECHNOLOGY IN AGRA, INDIA

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ABSTRACT

The present work is a success story of river bank filtration technology implemented on the bank of a polluted river stretch of the Yamuna in Agra (India) with neighboring area having problem of intrinsic groundwater salinity. Agra is located in the floodplain of the Yamuna river and river water is directly pumped and supplied for domestic purposes after conventional treatment. High values of microbiological, organic and inorganic pollutants present in the river water are forcing the drinking water consumers to install household reverse osmosis filters. In areas where there is no piped water supply, residents use either groundwater or water delivered in tankers.

The paper showcases the results of a study conducted in Agra from 2016–2019 on the feasibility of river bank filtration (RBF) and its efficacy for drinking water supply. An extensive field investigation was carried out for sampling of riverbed sediments, river and groundwater in and around selected locations. Samples were analysed to determine chemical parameters. Isotopic characteristics of groundwater samples were also determined to confirm the river water component in groundwater. River and groundwater samples were occasionally analysed for DOC.

Based on the results of chemical analyses, one site on the bank of the Yamuna was selected for drilling an exploratory borehole of 450 mm diameter up to a depth of 40 m BGL. Soil core samples were taken at intervals of 1.5 m. Soil core samples were analysed for trace metals. The quality of abstracted water from the exploratory well indicated that most of the parameters were within drinking water limits (IS 10500:2012), except chloride and manganese. Chloride exceeded the acceptable limit but remained below within permissible limit in absence of an alternate source of water. However, manganese exceeded the permissible limit slightly. In case of continuous abstraction of bank filtrate from one or more wells a wash-out effect in the aquifer between the riverbank and wells are expected resulting in lower manganese concentrations. Otherwise manganese has to be removed in a post-treatment step using sand filters. Other metals were found within the acceptable limit. While 17 OMPs (Organic Micro Pollutants) were detected in nearly every river water sample, their concentration was substantially lower in RBF well samples compared to the river samples. The river water quality indicated high turbidity, chloride, iron and manganese. Occasionally arsenic and lead were also found to exceed the acceptable limit in river but are within permissible limit. The developed RBF scheme is monitored regularly through continuous well operation to examine improvements in the abstracted water due to the more time varying induced water from the river, and thereby to promote it as a successful demonstration site.

***Keywords*:** river bank filtration, dissolved organic carbon, organic micro-pollutants, Yamuna river, Agra

INTRODUCTION

Water demands all over the world has been increasing with the rising population. Among the various sources of water, groundwater is the largest fresh water resource and more than half of the world population depends on it. But its continuous and irresponsible usage leads to over exploitation causing its depletion and contamination (MacDonald et al., 2016). On the other hand, urbanization and industrialization are polluting the surface water sources and same cannot be used without proper treatment. Most of the conventional drinking water treatment plants are technically unable to remove the high concentrations of micro-biological, organic and inorganic pollutants present in the river water (Sandhu et al., 2011). Therefore, there is a need to look out for a viable technique that can remove micro-pollutants, organic and inorganic pollutants satisfactorily and also cost effective and acceptable to society. River bank filtration (RBF) where wells are installed on the banks of river has the advantage of easy access to large volumes of induced surface water (SW) with the benefit of an improvement in water quality due to natural processes occurring during aquifer passage. RBF has successfully been used for many decades in Europe and the United States to provide drinking water to communities located on riverbanks (Hiscock and Grischek, 2002; Sharma and Amy, 2009). A number of field investigations carried out under different projects (Dash et al, 2010; Sandhu et al, 2011; Saph Pani, 2011-2014) showed that India has very good potential to develop RBF in the Ganga Plains, many other river stretches and also in coastal areas where favourable hydrogeologic conditions exist, to provide drinking water supply to many cities and also in rural clusters. To develop a RBF scheme, a detailed investigation on feasibility of the site including assessment of quality of existing surface and ground water is essentially required.

The aim of the present work is to showcase the results of detailed field investigations for implementation of RBF technology and identification of a feasible site along the bank of the river Yamuna in Agra where neighbouring groundwater has the problem of intrinsic salinity and the river stretch has high values of organic micropollutants and organic and inorganic contaminants. The population in the area have the problem of accessing safe drinking water. Further scientific investigations and technical measures necessary to develop the site into a model demonstration scheme are tied up with a collaborative Indo-German RBF network project (2020–2023) funded by the German Federal Ministry of Education and Research.

Study area

The study area is the floodplain of the Yamuna river between the National Capital Region of Delhi and the city of Agra (located approximately 200 km south of Delhi), which is one of the most densely populated urban and rural regions in India (COI, 2011). Large quantities of impartially to partially treated domestic and industrial wastewater are discharged into the Yamuna between these two cities resulting in a critical river water quality (Agarwal and Trivedi, 1995; CSE, 2002; Seth and Babu, 2007). Despite the Yamuna's poor water quality, the river is a major source of raw water for domestic purposes in the Agra city and for irrigation in the rural and semi-urban areas (GONCTD, 2013). Groundwater has high total dissolved solids (TDS) making it not fit for use without filtration (Krishan et al., 2017). Keeping in view these issues, Agra area was selected for developing a RBF site on the banks of the Yamuna river under the project “Pey Jal Suraksha” sponsored by the Ministry of Jal Shakti, Government of India.

The Agra-RBF site, located in the premise of Agra Jal Kal (water works) of UP-Jal Nigam Limited (UP-JNL) at latitude of 27.202657° N and longitude of 78.031522° E on the right bank of the river Yamuna (when faced toward flow direction) approximately 165 meters from the lean period river water line., was finalized in consultation with the UP-JNL based on the preliminary survey and analysis of surface and ground water quality parameters. The location of the RBF site at Agra is shown on the Google map (Figure 1).

PRELIMINARY INVESTIGATIONS FOR FINDING A FEASIBLE RBF SITE AT AGRA

Resistivity survey

First a resistivity survey was carried out using Aquameter (CRM-500). The results for vertical electrical sounding (VES) for 2 places on the site are given in Fig. 2. VES 1 indicated coarse grained sand of a thickness of 1.29 m in the upper layer followed by fine sand with silt of 2.31 m thickness which is underlained by coarse grained sand of 6.77 m thickness. VES 2 indicated occurrence of coarse grained sand with silt up to 1.88 m depth from ground surface followed by4.71 m thick coarse sand under dry condition.

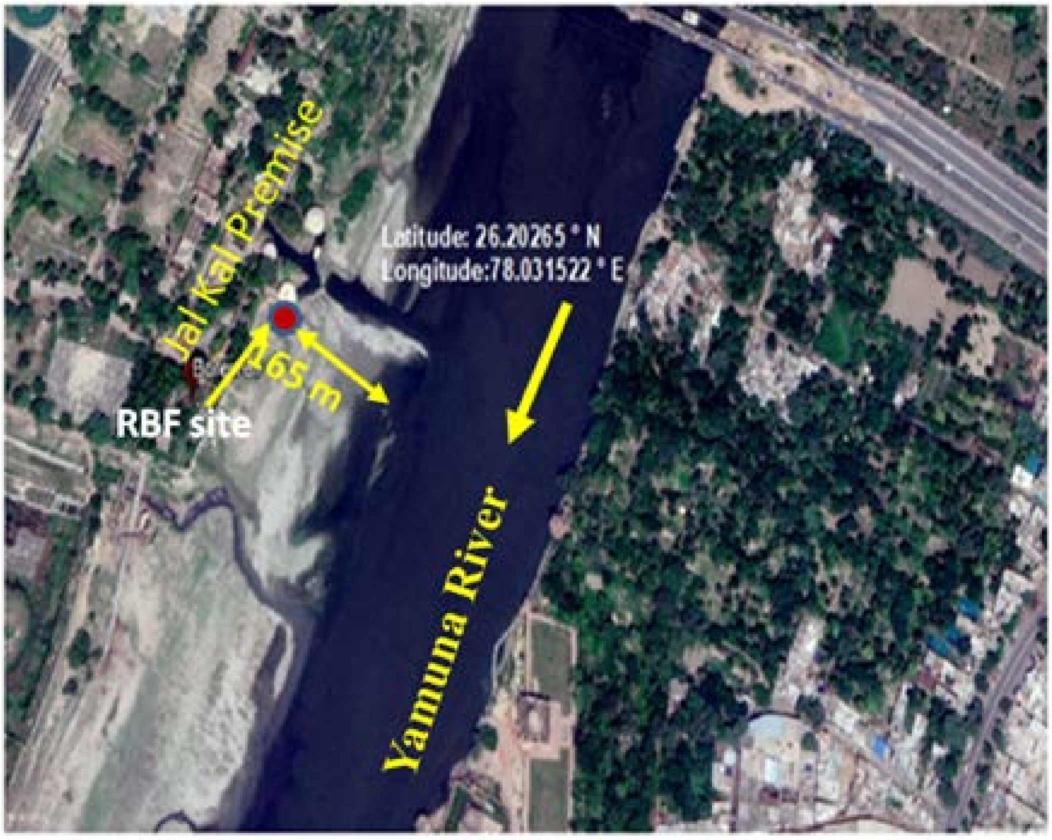

Fig. 1. Yamuna river and selected RBF site in Agra the Jal Kal premise (Google maps)

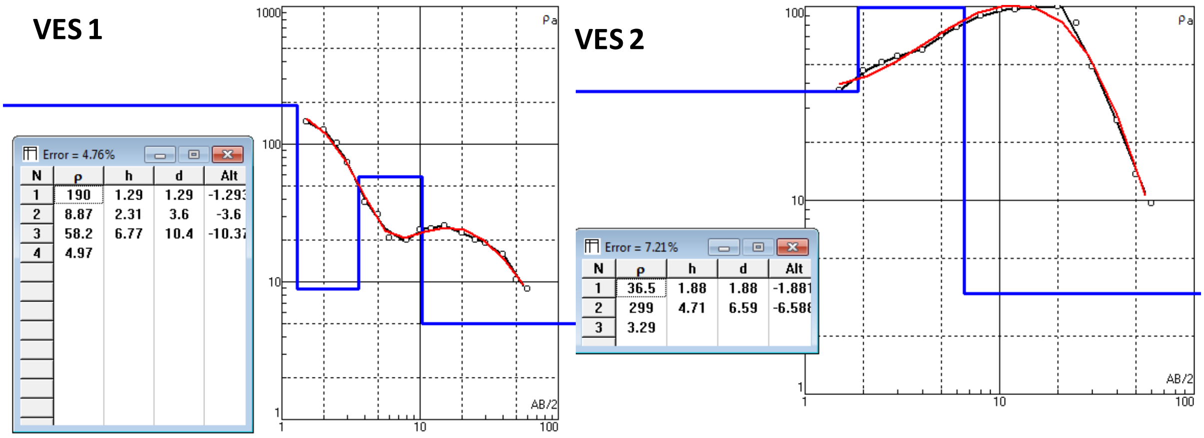

Fig. 2. Resistivity survey results for the Agra site

Sampling and analysis

Before finalizing the site sampling of riverbed sediments, river and groundwater in and around selected locations were conducted in a total of 6 sampling campaigns in the months of January, February, April, June, July and September 2016. Samples were analysed to determine chemical parameters. Isotopic characteristics of groundwater samples were also determined to confirm the river water component in groundwater. River and groundwater samples were occasionally analysed for dissolved organic carbon (DOC) and organic micropollutants (OMPs) in September 2017 and June 2018. Details of all the sampling locations are given in Fig. 3. DOC and OMP samples were only collected from location 1 in Fig. 3 that is an existing vertical well in the water works premises and from the river. Although the existing vertical well (Fig. 3, location 1) is located at a relatively far distance of 140 m from the main course of the river, it is only a few tens of metres away from the channel that supplies surface water from the Yamuna river to the intake structure of the water treatment plant (Fig. 1). The samples were analyzed by the Institute for Water Chemistry at the TU Dresden (Glorian et al., 2018).

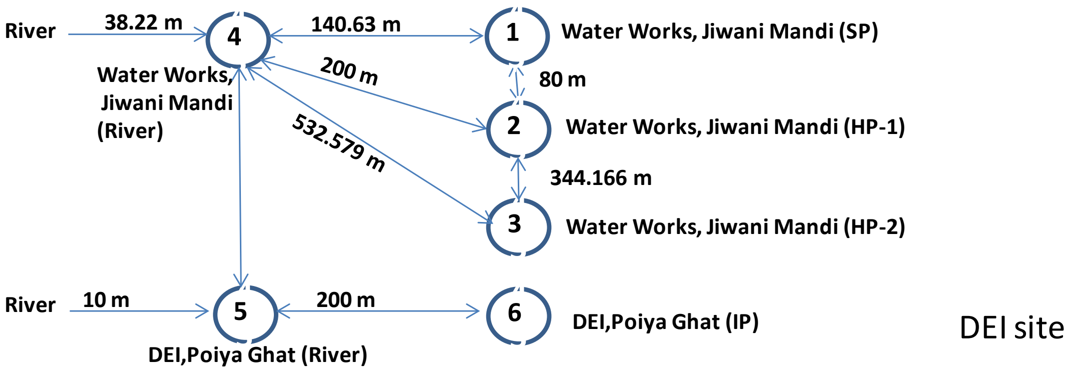

Fig. 3. Agra sampling locations

Both river and groundwater samples were analyzed to determine the parameters EC, cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (HCO_3^-, Cl^-, NO_3^- and SO_4^{2-}) and trace metals (total As, Fe, Mn, Zn and Cu). TDS was estimated from the measured EC values. Sediment samples were analyzed to detect total organic carbon (TOC), Cu, Zn, Mn, Fe, Ca, Mg, Na, CO_3, Cl^-, and SO_4^{2-}. Based on the analyzed water quality, a Water Quality Index was developed to categorize the acceptability of water (Singh et al., 2015). The isotopic characteristics of water was detected using δO^{18}, δD and D-excess and analyzed to categorize sources of groundwater (Krishan et al., 2020a, b).

It has been found that groundwater samples have higher values of TDS, cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), anions (HCO_3^-, Cl^-, NO_3^- and SO_4^{2-}) and trace metals (total As, Fe, Mn) as compared to river water (Fig. 4) as a result of dissolution of minerals (Krishan et al., 2020b).

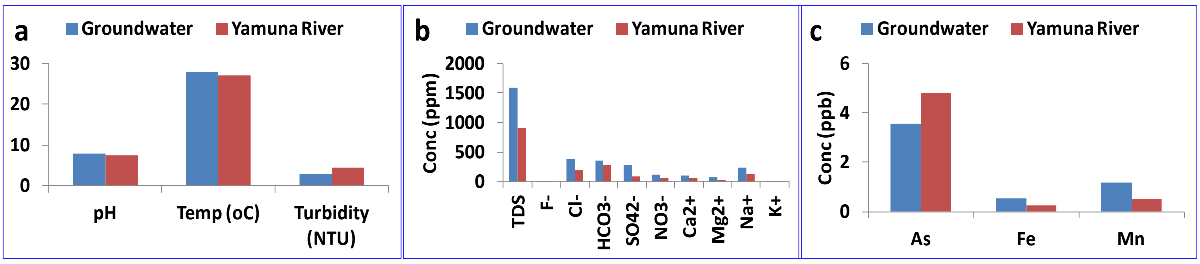

Fig. 4. Mean values of (a) physic-chemical parameters, (b) ions, (c) trace metals in groundwater and Yamuna river water at Agra in 2016

Based on above parameters, Water quality index (WQI) was computed (Fig. 5) and it was found that groundwater samples near to the river have higher values of WQI and fall in good category.

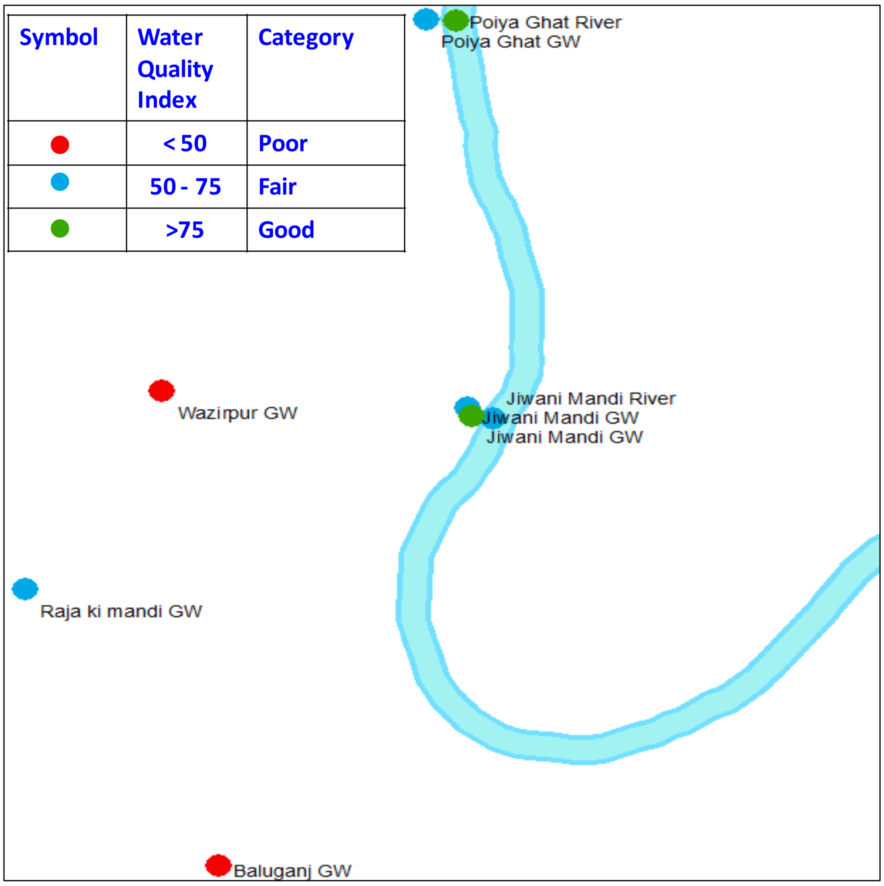

Fig. 5. Water quality index of water samples collected in Agra in 2016

Seventeen OMPs were detected in every sample (Fig. 6). These OMPs are categorized as compounds of pharmaceuticals (carbamazepine, diclofenac, gabapentin, ibuprofen, metoprolol, naproxen, paracetamol, sulfamethoxazole), herbicides and pesticides (diuron, acetaprimid, imidacloprid) and industrial products (1H-benzotriazole and tolyltriazole).

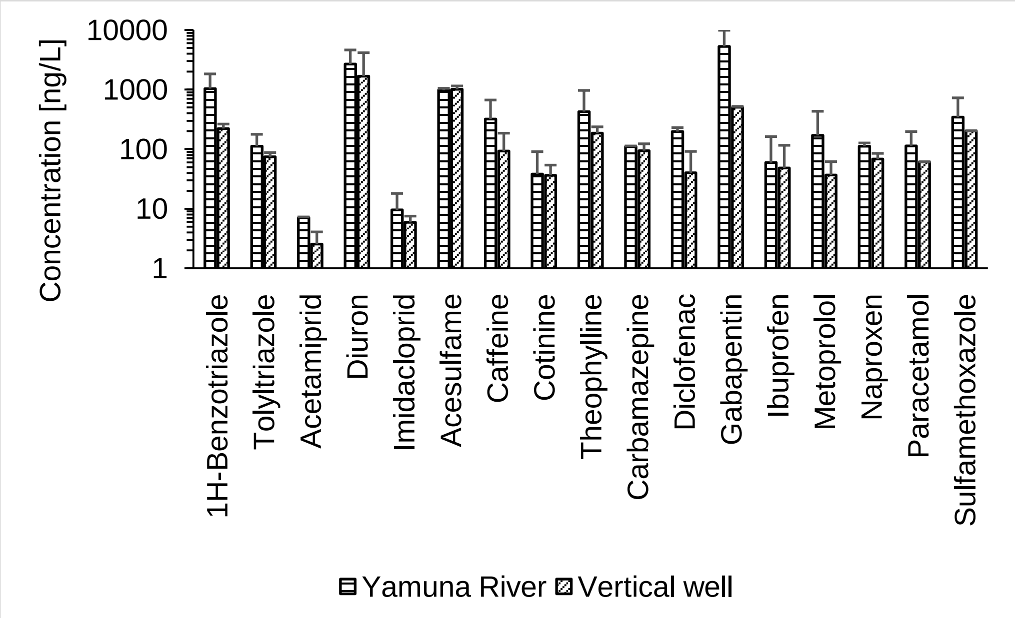

Fig. 6. Mean concentration of OMPs in Yamuna river and well water (n=2). The error bars indicate the maximum concentration (figure prepared with tabular data from Glorian et al., 2019).

The other compounds of acesulfame (artificial sweetener), caffeine and its degradation product theophylline, and cotinine that is a degradation product of nicotine, can be regarded as qualitative indicators for untreated wastewater. Nearly the same number of OMPs was detected upstream in the Yamuna and nearby well water in Mathura and Delhi (Glorian et al., 2018), indicating their ubiquitous presence in the wastewater discharged into the river.

All OMPs from pharmaceutical compounds were present in the well water samples at lower concentrations as compared to the river samples. As reported in Glorian et al. (2018), the well water showed a decreased mean concentration by 91 % for gabapentin, 80 % for diclofenac and 78 % for metoprolol, thereby implying a good removal of these OMPs. Lower removal rates were observed for paracetamol (46 %), sulfamethoxazole (41 %), naproxen (39 %), ibuprofen (19 %) and carbamazepine (15 %). Amongst the herbicide and pesticide compounds, acetaprimid showed the highest decrease in mean concentration by 64 %, compared to 37 % and 38 % for diuron and imidacloprid respectively. The industrial OMPs 1H-benzotriazole and tolyltriazole showed a decreased mean concentration by 79 % and 33 % respectively. Only acesulfame showed a marginally higher mean concentration at 1020 ng/L in the well water as compared to river water (mean concentration 989 ng/L). The mean concentration of DOC in Yamuna water was 8.59 mg/L and 5.18 mg/L in well water (n = 2; Glorian et al., 2018).

The overall mean removal for the OMPs in the groups pharmaceuticals, herbicides and pesticides and industrial products is 51 % and is lower compared to RBF sites in Delhi and Mathura (mean removal 81 %). One reason for the overall medium removal efficiency is that most of these compounds possess a wide variety of functional groups and are therefore medium to highly polar and very mobile in water. Consequently, adsorption on suspended particles and sediment is limited and many pharmaceuticals are resistant to degradation in the human body as well as in wastewater treatment plants to a great extent (Schwarzenbach et al., 2006; Lapworth et al., 2012; Glorian et al., 2018). Based on data for acesulfame and supported by data for chloride and other ions in Glorian et al. (2018), the portion of bank filtrate in this particular vertical well (location 1 in Fig. 3) located only a few tens of metres from the surface water intake channel of the water works is very high (nearly 100 %). Thus there is marginal effect of mixing with less polluted groundwater. A reason for the very high portion of bank filtrate could be the good hydraulic connection between nearby the intake channel and the vertical well. This can also imply a short travel time of the bank filtrate and consequently a lower removal rate of OMPs.

Isotope analysis of the water samples was carried out for characterization and is shown in Fig. 7.

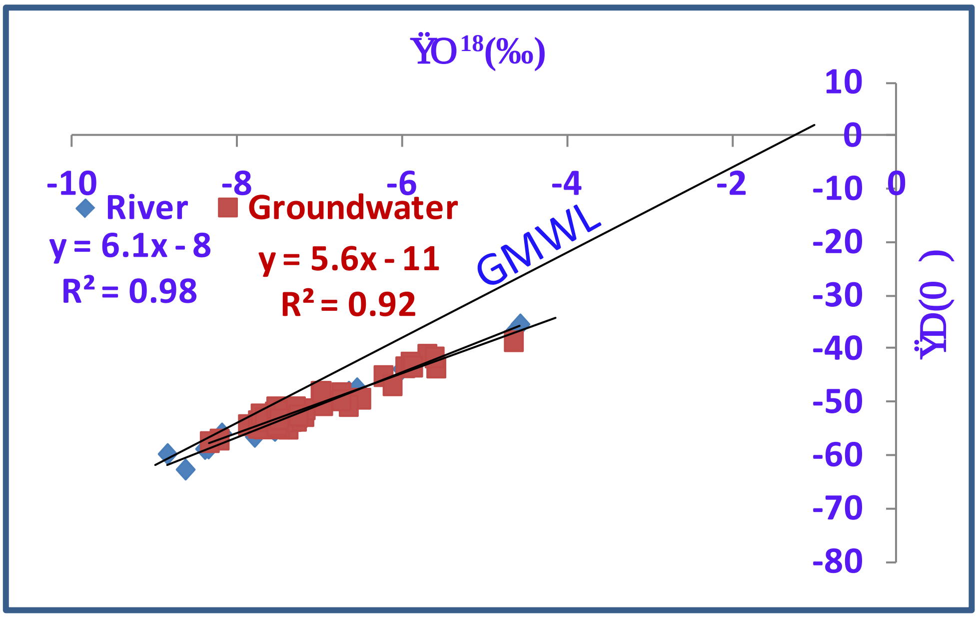

Fig. 7. Isotope characterization of the water samples collected from Agra

Seasonally differential fractional inputs of water from surface and groundwater sources is evident from Fig. 7 and low seasonal amplitudes in $\delta^{18}O$ on the order of <6‰, indicating also important groundwater base flow contributions with well-mixed summer and winter precipitation. The percent contribution of river in groundwater was determined to be in the range of <25% to >75%, it was >75 % at the proposed site (Fig. 8).

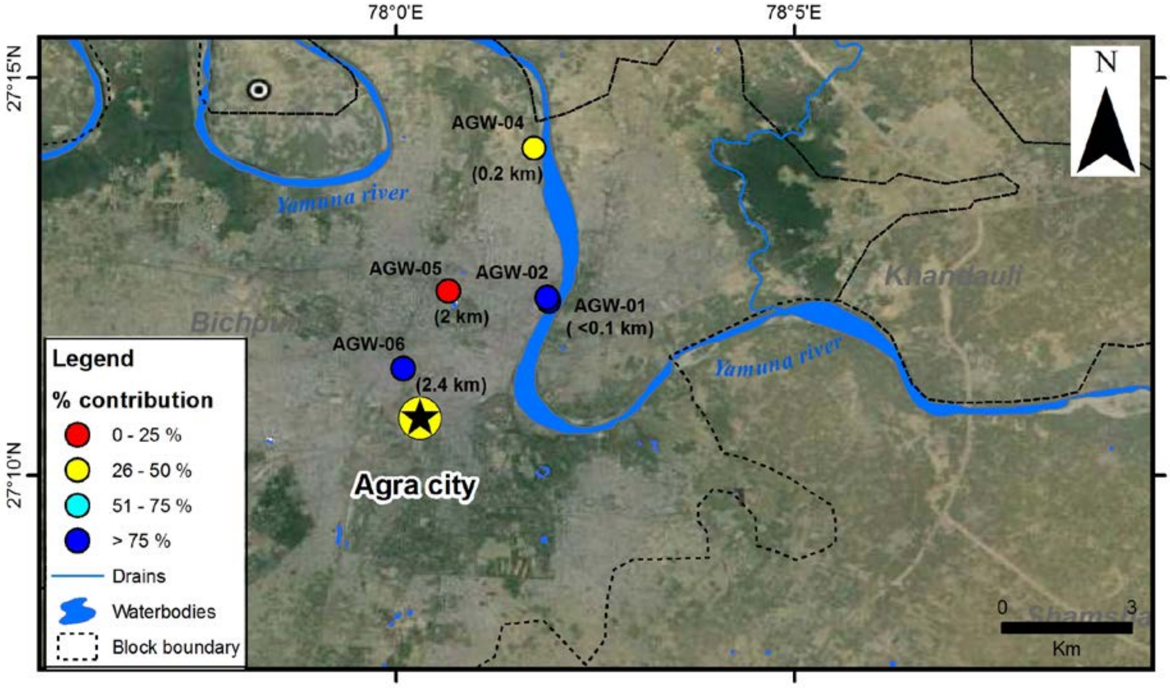

Fig. 8. Percent contribution of river water in groundwater

Site development

Subsequently, one site on the bank of the Yamuna was selected for drilling an exploratory borehole of 450 mm diameter up to a depth of 40 m BGL.

After identifying the potential layers of aquifer using spontaneous potential (SP) and Integrated Geophysical Resistivity Logger (IGRL) (Fig. 9a), the well filter screens for tapping the aquifer were decided and depth of slotted pipes was designed. The slotted pipes for the Agra site were placed in two depth ranges; one between 15 m and 24 m and the other one between 30 m and 33 m (Fig. 9b). The yield of the potential layers was estimated to be 240 to 360 m^3/day.

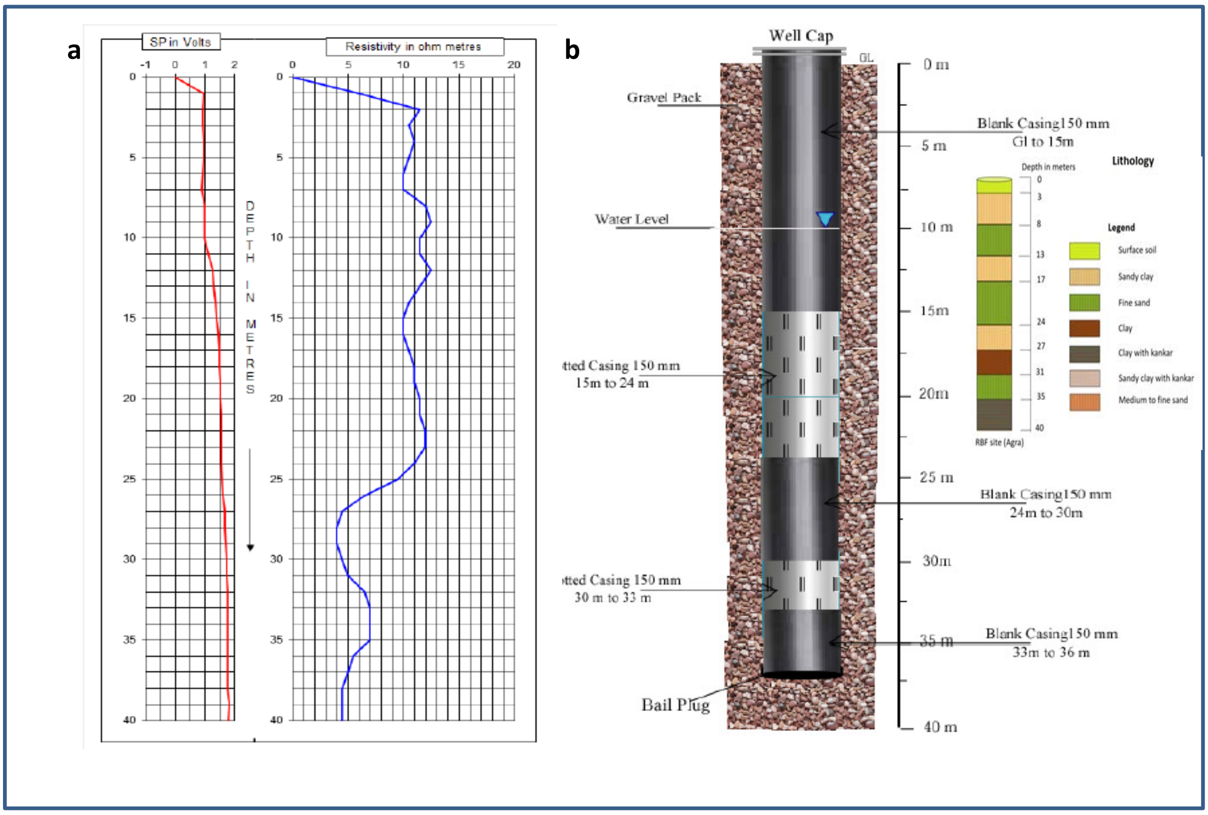

Fig. 9. (a) Design and lithology of the exploratory bore well showing tapping zone, (b) SP and resistivity profiles of bore well at Agra site

Soil core samples were taken at intervals of 1.5 m. Soil core samples were analysed for trace metals. While, there are no limits prescribed by the Bureau of Indian Standard (BIS) for trace metals in soils, their concentration in the extracted water from the exploratory well was below the permissible limit defined in the Indian Standard for drinking water (IS 10500:2012). However, the depth wise variation of concentration of trace metals measured in the grain size fraction of <2 mm of the soil core samples from the Agra RBF site showed that soil column of the Agra site has high concentration of Fe, Ni, Cu, Zn and Mn may be due to the mineral dissolution (Fig. 10).

The well was developed and water samples were taken at interval of 12 hrs, 24 hrs, 36 hrs, 48 hrs and 60 hrs and analysed for As, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn. As, Cd, Cr and Cu were not detected in the water samples but elevated concentrations of Cu, Mn and Pb were observed. Since RBF provides a scope for contaminant attenuation, post-treatment may or may not be required on the basis of degree of purification of the RBF filtrate. Variation of concentration of other trace metals in the extracted water (Fig. 11) was found below the permissible limit prescribed by BIS for drinking water (BIS, 2012). Thus, the site is recognized as feasible site for developing a RBF scheme.

After RBF site identification and first assessment, work was carried out for installation of a 5HP submersible pump, establishment of pump house and chlorination chamber, water supply line, construction of pump house, stand post, electric connection, fittings, etc., to develop Agra as RBF site.

Post Development investigations

As the water from this well was to be supplied to the nearby communities, water sampling was carried out again for Yamuna river and RBF well during the months of March, April, June, August, and November in the year 2019. The unpreserved 0.45 µm filtered water samples were used for the analysis of major cations (Na^{+}, K^{+}, Ca^{2+} and Mg^{2+}) and anions (F^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}, etc.) were analysed by using ion chromatography (IC) technique. For trace metals analysis (Fe, Mn, Zn, Cu, Cd, Cr, Ni, Pb, etc.), inductively coupled plasma-optical emission spectrometer (ICP-OES) was used. Cations and anions analysis were performed in three replicates for each sample. An overall precision, expressed as percent relative standard deviation (RSD), was obtained below 10% for the entire samples.

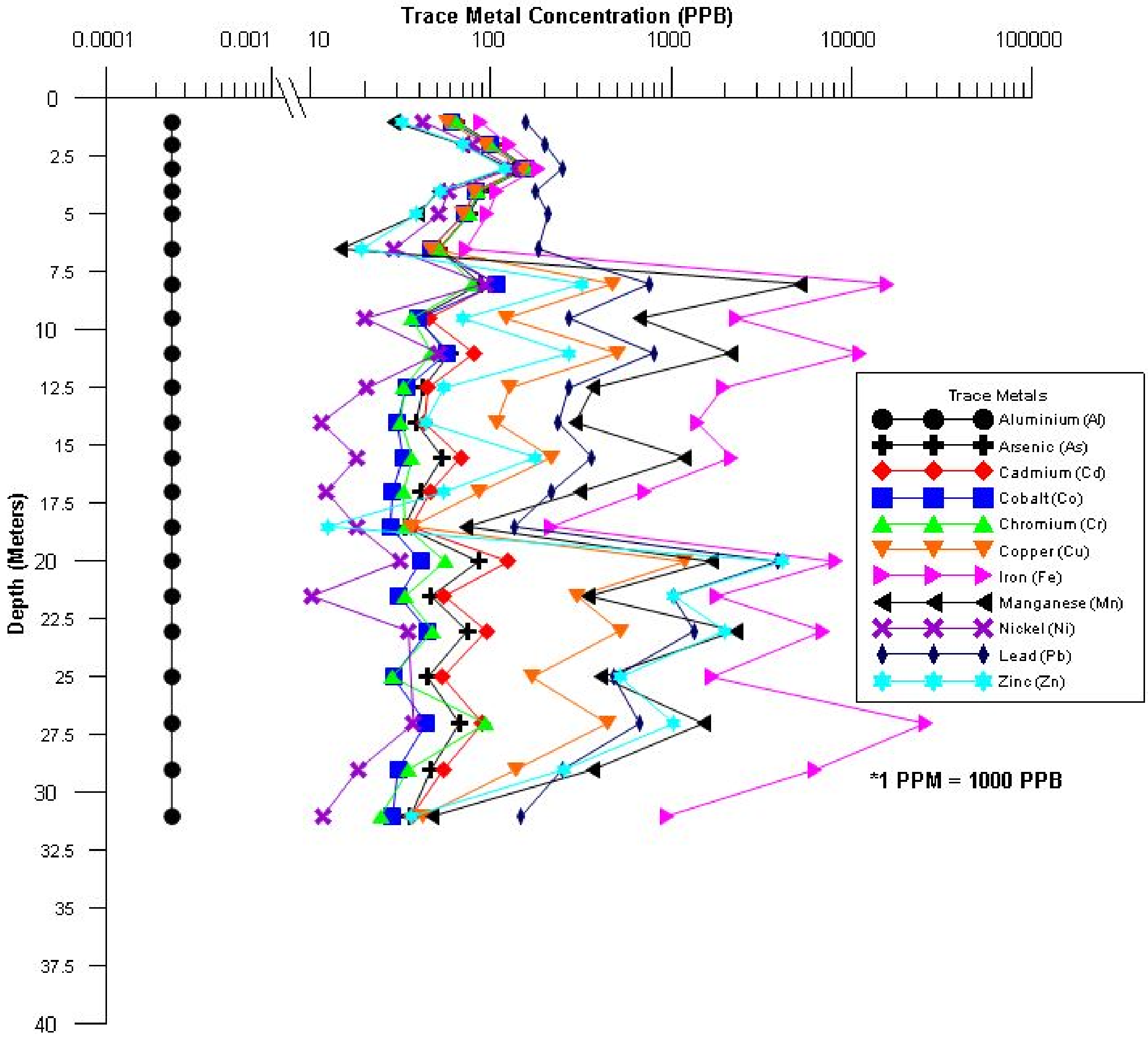

Fig. 10. Trace metal concentration in soil core samples at Agra site

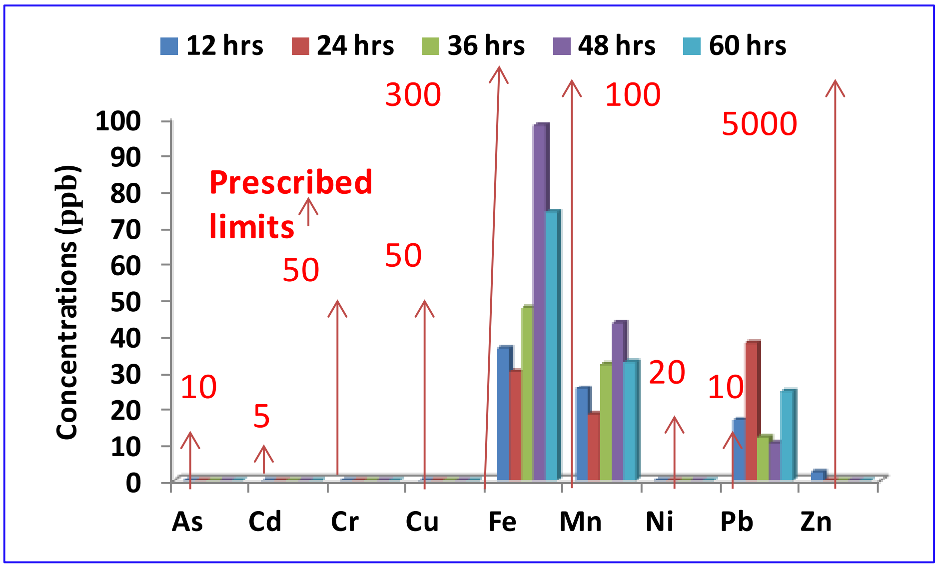

Fig. 11. Trace metal concentration in bore well water at Agra site

The quality of abstracted water from the exploratory well indicates that most of the inorganic parameters are within drinking water limits (IS 10500:2012), except chloride and manganese (Fig. 12). Chloride exceeds the acceptable limit (200 ppm) but falls within permissible limit in absence of an alternate source of water. However, manganese exceeds the permissible limit slightly. In case of continuous abstraction of bank filtrate from one or more wells a wash-out effect in the aquifer between the riverbank and wells are expected resulting in lower manganese concentrations (Paufler and Grischek, 2018). Otherwise manganese has to be removed in a post-treatment step using sand filters. Other metals are found within the acceptable limit.

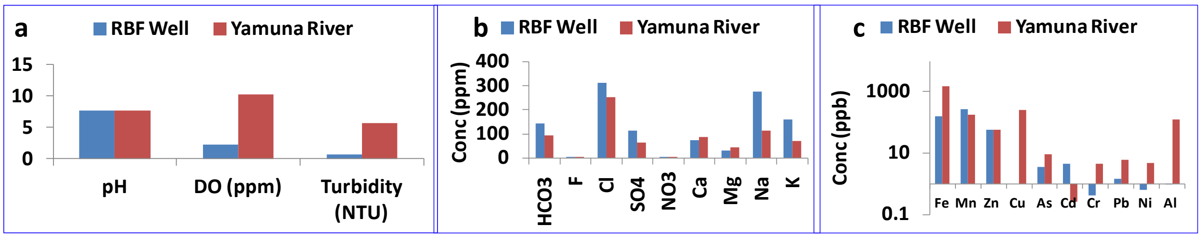

Fig. 12. Average measured values of (a) physico-chemical parameters, (b) ions, (c) trace metals in RBF well and Yamuna river at Agra in 2019

CONCLUSIONS

The potential of RBF to remove organic micropollutants in Agra has been shown on the basis of investigations conducted on an existing vertical well (location 1 in Fig. 3; study by Glorian et al., 2018) at a distance of 140 m away from the Yamuna river but close to the surface water intake channel leading to the water works and on the basis of a recently (2018/2019) constructed exploratory well located 165 m from the river (Fig. 1). The overall removal for 13 OMPs in the categories pharmaceuticals, herbicides and pesticides and industrial compounds was found to be of medium efficiency at a mean removal of 51 %. Nevertheless, the results support findings from RBF sites worldwide proving the pre-treatment efficiency of RBF to improve raw water quality for drinking water production. However, post-treatment such as activated carbon or advanced oxidation could be necessary. These post-treatment methods are expected to be less costly and easier to maintain if RBF is used for pre-treatment.

Consequently, the objective in the CCRBF project “Expansion of the Indo-German Competence Centre for Riverbank Filtration” (07/2020–06/2023) is to demonstrate further improvements in the quality of abstracted water from the exploratory well located at a further distance from the river (165 m), through continuous well operation and thereby to induce more water from the river. On the other hand, the river water quality indicates high turbidity, chloride, iron and manganese. Occasionally arsenic and lead are also found to exceed the acceptable limit in river but are within permissible limit.

Concurrent to the scientific investigations, the objective is to create a demonstration site for RBF in Agra within the CCRBF project. This site will demonstrate the upper limit for the removal of pathogens, DOC, OMPs and improvement in inorganic parameters by application of RBF along one of the most polluted rivers in India. For the creation of a demonstration site, a larger data set generated over a longer monitoring period is required. Water quality monitoring during the CCRBF project will also help to identify appropriate post-treatment options. Subsequently these findings along with results from a few other demonstration and case-study sites across India will be integrated into a masterplan for RBF aimed at the further application of RBF for sustainable drinking water production in India.

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