Riverbank Filtration for Sustainable Drinking Water Supply

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INTRODUCTION

Groundwater is mostly preferred for drinking water supply in many countries because, in comparison to surface water source, it is well protected against most types of pollution and its abstraction can easily be adjusted to short-term fluctuations in consumption. However, exploration of groundwater sources is restricted with regard to its quantity. Surface water particularly river water is exposed to dangers of permanent and sudden pollution by wastewaters or disturbance due to storage, transport or application of water endangering substances. Riverbank filtration (RBF) has been used for many decades in Europe and the United States to provide drinking water to communities located on riverbanks. In Europe, RBF technique has been operating since the 1870's and in the US, they have been operating at selected locations for nearly 50 years. More recently, there has been a renewed interest among large to medium-size utilities to employ bank filtration as a mechanism of water production to reduce treatment costs and to meet the regulations on disinfection by-products. In India, the development of RBF has the potential to provide drinking water to many cities located along river and currently using surface water as a source for their public water supply.

To know more about the RBF technique and to gather understanding on its potential, working principles, mechanism and its scope for implementation in various hydrogeological setups in India, some details are elaborated in this lecture note. It is hoped that this note will help readers to understand and get some insights on RBF, which may motive for its large scale implementation to supply safe drinking water to people located along and around banks of surface water bodies.

What is riverbank filtration or bank filtration?

Riverbank filtration (RBF) or simply bank filtration (BF), a unified term for river and lake bank / bed filtration), is a process by which surface water from rivers, channels and lakes is induced by pumping from nearby production wells to flow through the natural aquifer soil, undergoing many positive changes in water quality before finally mixing with local groundwater from the land side and being abstracted for direct use or further treatment.

PROCESSES OF BANK FILTRATION

RBF is a process in which pumping of wells located along riverbanks induce a portion of the river water to flow toward the pumping wells. The process has many similarities to the slow sand filtration process. River 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 of BF as shown in Fig 1, is initiated by the lowering of the ground water table below that of an adjoining surface water table which causes surface water to infiltrate through the permeable river bed and bank or lake bed into the aquifer as a result of 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). The infiltration may be the direct result of an influent river under natural conditions or be induced by ground water abstraction wells (tube wells). These wells extracting bank filtrate can be vertical or horizontal. Ground water and surface water levels, geologic data pertaining to the aquifer and river bed and hydrogeological modelling help in describing flow conditions during bank filtration.

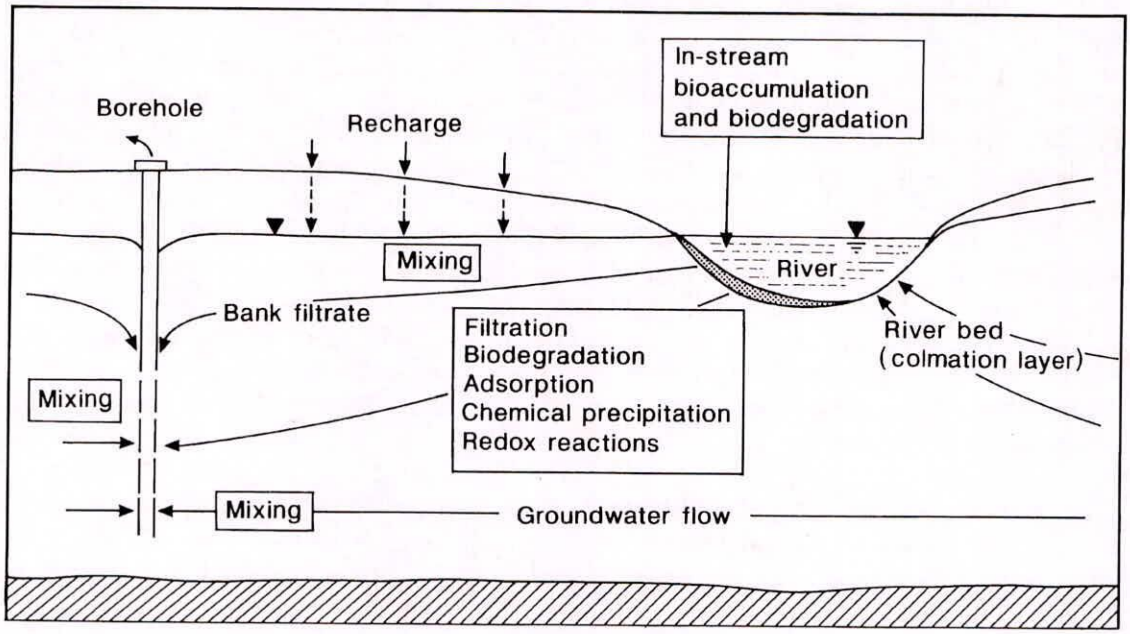

Fig. 1 Schematic diagram of processes affecting water quality during bank filtration (Hiscock & Grischek, 2002).

The aquifer serves (Fig.2) as a natural filter and also biochemically attenuates potential contaminants present in the surface water. Compared with direct surface water abstraction, bank filtration with its effective natural attenuation processes eliminates suspended solids, particles, biodegradable compounds, bacteria, viruses and parasites; partly eliminates adsorbable compounds and equilibrates temperature changes and concentrations of dissolved constituents in the bank filtrate (Hiscock & Grischek, 2002). The removal of microbial pathogens from drinking water is crucial. Pathogens such as *Cryptosporidium*, *Giardia* and viruses are not completely inactivated through common drinking water disinfection using chlorine or UV radiation. Thus expensive filtration technologies (e.g. nanofiltration) are needed to produce safe drinking water. RBF effectively removes these pathogens by natural processes during subsurface passage depending on flow path length, residence time and environmental factors. Hence it can serve as a pre-treatment step in drinking water production, and in some instances, also as final treatment before disinfection.

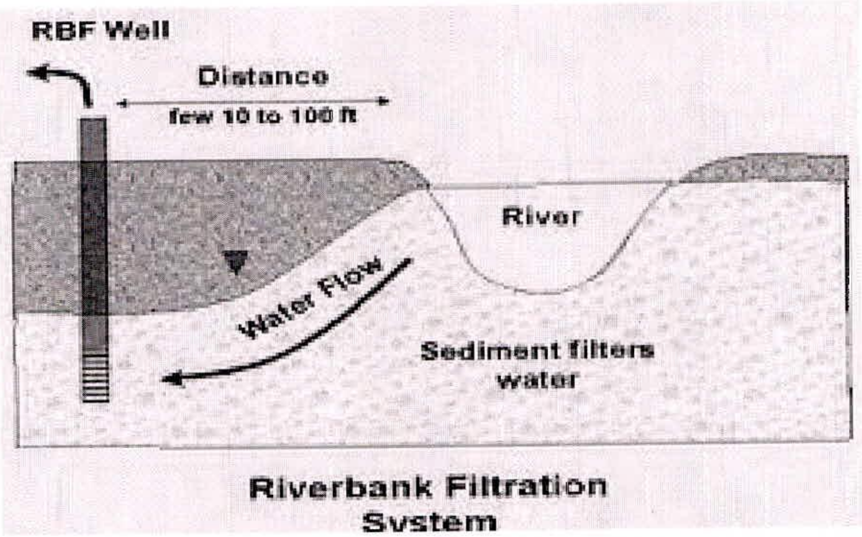

Fig. 2 Schematic diagram of a RBF well showing its connectivity with the river and aquifer (source : internet images on BF)

TREATMENT PROCESSES OF BANK FILTRATION

Several physical, chemical and biochemical processes are involved in the improvement of water quality during subsurface passage (Sharma & Amy, 2009). The processes that remove substances in the bank filtrate include:

- **Straining or filtration**: The mechanical filtration process retains suspended matter in the soil, depending on pore throat size.
- **Biodegradation and decay:** biodegradation and radioactive decay are the only sustainable removal processes. Biodegradation is the main driver for redox processes occurring during subsurface passage and is responsible for the breakdown of dissolved and/or sediment-bound organic matter.
- **Sorption and desorption:** Trace elements such as iron, manganese and various heavy metals are eliminated during ground passage, mainly by sorption processes (Schmidt et al., 2003) and by accumulating on the surface of an adsorbent or substrata. Biological contaminants such as protozoa, bacteria and viruses are reduced by a combination of processes including adsorption to aquifer materials and inactivation (Schmidt et al., 2003).
- **Ion exchange:** In aerobic aquifers, removal is achieved by ion exchange processes at negatively loaded surfaces of clay minerals, amorphous ferric oxides and alumina and organic solid matter (Schmidt et al., 2003).

The removal of biological contaminants through BF is most efficient when groundwater velocity is slow and when the aquifer consists of granular materials with high grain surface contact. Levels of many organic micropollutants can be reduced or even eliminated during both aerobic and anaerobic underground passages (Mueller et al., 2010; Maeng et al., 2009). Attenuation is extremely dependant on the underlying redox processes (Schmidt et al., 2004). The purification capacity of BF schemes regarding surface-water pollutants depend on (Schmidt et al., 2003):

Quality of the surface water

- Geological conditions
- Porosity of the soil (flow velocity)
- Covered distance determined by the permeability
- Hydraulic residence time of the water in the soil
- Hydraulic potential in the aquifer
- Temperature
- PH-values
- Oxygen concentration

Despite BF being widespread in Central Europe, knowledge about processes during BF is still scarce. Especially information about the physical, chemical and biological processes of water purification, extension of the active sand filter zone, significance of bank vegetation for water purification, hydraulic permeability with its clogging phenomenon (Guenter, 2011) and influence of changing environmental conditions on the operation of BF schemes is rare.

BENEFICIAL EFFECTS OF BANK FILTRATION

Due to its easy implementation and little maintenance requirements, BF is considered to be a useful drinking water (pre-)treatment method for sustainable water supply particularly in developing countries. BF systems are particularly known for the efficient removal of pathogens, suspended solids, toxic algae, or organic trace compounds (e.g. pharmaceutical products) from surface water.. Experience from Europe has demonstrated that BF is suitable to remove a range of organic and inorganic contaminants while an exhaustion of cleaning capacity has not been observed (Schmidt et al., 2003).

BF offers freshwater storage in times of heavy precipitation (e.g. during monsoon) or elevated stream run-off. Underground freshwater stocks are protected from evaporation and deterioration (Jimenes, 2008). They can be stored until dry weather conditions require groundwater abstraction to meet water demand (Huelshoff et al., 2009).

Because of its relatively low cost and the fact that neither high-tech nor highly skilled labour is required, BF is suitable as a water purification tool in developing countries (Spreger et al., 2006).

SITES SUITABLE FOR BANK FILTRATION

Hydrogeologic conditions impact the effectiveness of BF. The permeability of the sediment affects seepage velocity and often internal clogging is associated with sediments having low hydraulic conductivity and small vertical gradients. Sediments that have excessively high conductivity will not be efficient in removing contaminants.

The followings are the primary requirements to select a BF site:

- River/stream or water body should be perennial,
- River/stream or other surface water body should be hydraulically connected to the aquifer,

- Alluvial formations,
- Well should be in the concave side of the river/stream,
- More retention time of water between river/stream or water body and well,
- Well field should be free from contamination of pathogenic and geogenic pollution,

APPLICABILITY OF BF

For the operation of a BF system, some basic requirements have to be met. The availability of surface water as a primary source is essential. A second major consideration is the groundwater level in the surroundings of the BF well. They should not decline below an ecologically and economically justifiable threshold value due to operation. Water abstraction should not result in adverse effects on the aquifer (overexploitation, damage to ecosystems) or the river downstream of the BF site (e.g. dependent settlements being water-deprived).

The design of BF systems usually requires a detailed hydro-geological site investigation and knowledge about the hydrological characteristics of the catchment. A successful BF operation depends on surface water quality, soil texture and soil quality. The quality of water (e.g. salinity) and the soil at the geologic site (e.g. amount and solubility of arsenic content, redox conditions) are factors to be assessed prior to water abstraction for potable use. Pollutants in soil may be of geogenic (e.g. arsenic) or anthropogenic origin (e.g. heavy metals from an industrial site, nitrate from agriculture) and render bank filtrate objectionable.

Further, the soil texture should have filter properties. Limestone and dolomite bedrocks, for instance, are rich in fissures and allow for rapid water travel times. They are therefore unfavourable for the removal of water contaminants. Suitable soil textures for BF are sand and gravel aquifers with hydraulic conductivities kf (permeability) greater than 0.0001 m/s, a minimal thickness of 5 m and a good hydraulic connexion to the adjacent surface water (TZW 2006).

Using alternative well technology, such as horizontal or angle wells, opens up numerous RFB applications depending on the site characteristics and soil conditions.

- Fresh water intakes beneath river and lake beds
- Saltwater intakes beneath ocean floor
- Offset well head from wetlands, buildings and floodplains
- High capacity single well pumping
- Utilize aquifers beneath river and lakes to provide pre-filtration and enhance raw water quality
- Tap aquifers from a distance where land constraints prevent drill rig access.

Advantages of RBF

- Natural pre-treatment through bank filtration.
- Reduce chemical usage for pre-treatment.
- Decrease construction and operation costs - lowest costs among supply options .
- Consistent water quality and temperatures - no spikes.
- Maintenance cost savings (no leaf debris which is common to surface water intakes).
- Resistance to contaminant threats.

- Minimal color, odor, turbidity, algae and other microorganisms.
- Reduction in disinfection by product precursors.
- Reduced need for disinfection.
- Ease of maintenance.
- Not susceptible to invasive plant infestation .
- Low profile and aesthetically pleasing - no scar to landscape or nearby recreational or environmental interests.
- No impact to fisheries.
- Reduction in sludge generation.
- Achieves treatment removal credits.

Disadvantages

- Enhanced clogging of the infiltration zone is likely to be observed with high levels of suspended solids that may render BF unsustainable
- High organic pollution and higher mean temperatures (often found in developing countries) both promote microbial growth and may lead to oxygen depletion, thereby lowering the removal efficiency of BF systems.
- The presence of dissolved heavy metals (e.g. arsenic) may severely impair BF quality.
- Polar, persistent organic substances are often not completely removed during underground passage (dependent on residence time, length of subsoil passage, redox status).(Schmidt et al., 2003)
- Other post-treatment methods are necessary such as oxidation and adsorption to reach drinking water quality.

BANK FILTRATION IN EUROPE

BF provides about 50% of potable water supplies in the Slovak Republic and 45% in Hungary (Hiscock & Grischek, 2002). In Germany, more than 300 water works use BF and about 16% of German drinking water is produced from bank filtrate.

In Central Europe, increasing chemical pollution, high concentrations of ammonia, organic compounds and micropollutants in the river water called for the introduction of supplementary pre- and post-treatment steps to build up a multi-barrier system. Aeration or ozone may be used to oxidise iron and manganese, or to activate carbon for adsorption of and protection against more persistent contaminants.

Today nearly all water utilities situated along large rivers use granular activated carbon filters, often combined with isolation and filtration (Schmidt et al., 2003).

BANK FILTRATION IN INDIA

Bank filtration is used in India as a reliable method of providing drinking water since long in terms of the volume of (pre-) treated water obtained. Since 2005, existing bank filtration schemes in north India had been studied by Sandhu et al, (2010) at eight locations. Figure 4 and Table 1 provide information on some of these existing bank filtration systems studied by Sandhu et al., (2010).

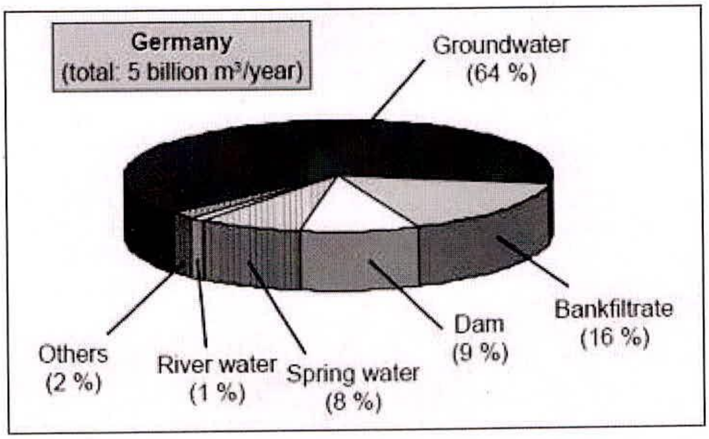

Fig. 3 Sources used for drinking water production in Germany (source: Schmidt et al. 2003)

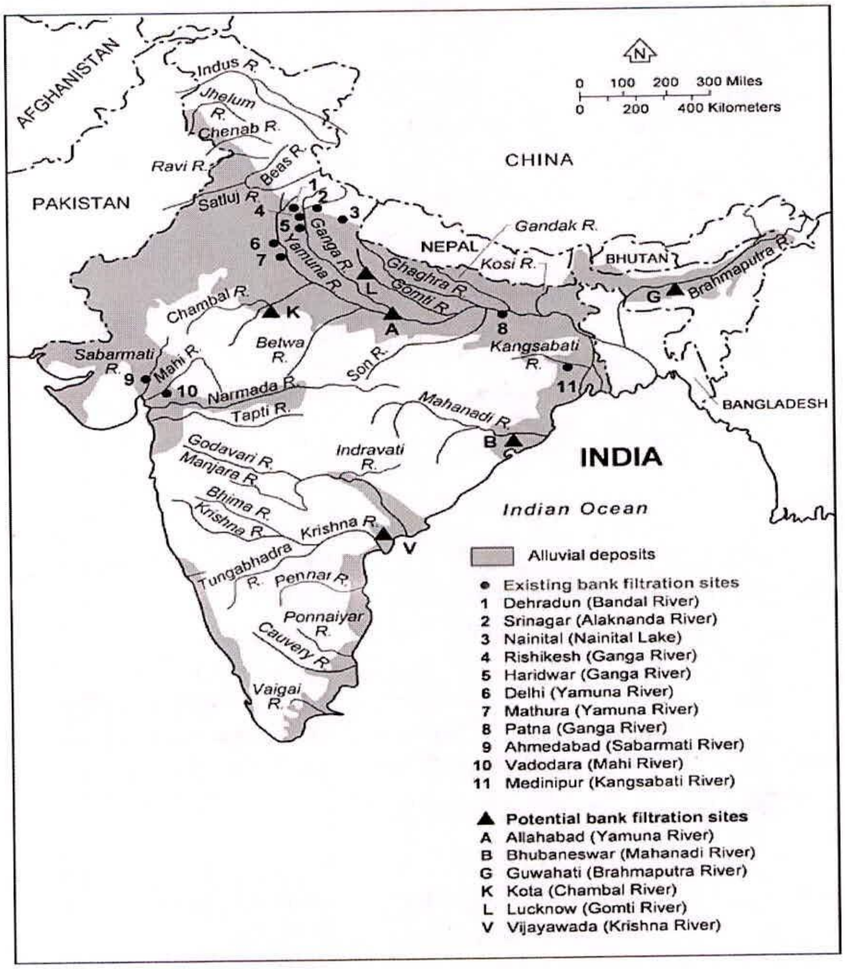

Fig. 4 Location of existing and potential riverbank filtration sites (Source: Sandhu et al, 2010)

Table 1. Summary of siting and design parameters of some existing operational small- and large-scale bank filtration systems in India (Source: Sandhu el al., 2010)

Location	Source water body	Well-type	Production capacity in m^3/day	Depth in m	Distance from source water in m	Travel time of bank filtrate
Haridwar	Ganga	CW	33,000	7–10	15–110	2–>100 days
Patna	Ganga	VFW	>3500	150–300	9–236	–
Srinagar	Alaknanda	VFW	259–518	32–86	47–390	–
Nainital	Lake Nainital	VFW	24,100	22–37	5–84	8–30 days
Dehradun	Bandal	RCW(s)	140–430	1.5–2	Beneath riverbed	2–4 min
Muzaffar Nagar	Kali	VFW	29–300	8–15	68	–
Mathura	Yamuna	RCW	2400	15.5–18	Beneath riverbed	1.5–3 days
Ahmedabad	Sabarmati	RCW	110,000	10–11	Beneath riverbed	–

CW large-diameter (10 m) caisson well; VFW vertical filter well (tube well); RCW radial collector well; RCW(s) small-scale radial collector well

Case Study of Bank Filtration in Haridwar, Uttarakhand

Haridwar is an important religious centre in India. Besides the permanent population of more than 2,25,000 inhabitants [Census of India 2011] living in the core city area, Haridwar is characterized by a 'floating' population of more than 5,50,000 people [Dash et al. 2010] visiting the region daily and an additional number of persons who reside temporary in retreat centres and hotels. More than 35% of the total drinking water production (64,000 m^3/day as estimated in the year 2009) is provided by riverbank filtrate through 22 RBF-wells constructed along the river Ganga and the Upper Ganga Canal. The bank filtrate water is partly chlorinated and subsequently routed into the distribution network before supply to the people. The large-diameter (10 m) caisson wells are located next to the river or canals with a distance of 15 to 210 m. The bottoms of the wells are located at a depth between 6 and 10 m below ground-level (bgl), they are open and packed with gravel and sand to allow water to enter. Each well is equipped with 2 to 3 fixed speed vertical line shaft pumps which have a rated discharge of 20.0 to 41.7 L/s each. Their operating hours and production rates depend upon the water demand but principally upon the supply available at the source, which again depends upon the meteorological season (monsoon and non-monsoon). To avoid malfunctions, the pumps within each well are operated on a rotating basis for a fixed number of hours each day, which is necessary for the other pump(s) to cool down. Figure 5 shows the RBF-site including the wells and the surface water flow-system of the study area.

The RBF scheme at Haridwar (Figure 5) has some significant features, which are; (i) 22 RBF large diameter (10 m) caisson wells of depth range between 6 and 10 m spaced closely in series in an island type area having hydraulically connected boundary at both sides to different distances , (ii) wells located at different distances from the bank abstract part of same river's water, and (iii) bank filtrate water pumped continuously is directly supplied to the distribution network by injecting Sodium hypochlorite (NaClO) at the well as disinfectant or bleaching agent particularly, during monsoon season when the river water normally has high turbidity. Wells being spaced closely, there is every possibility of interference of flow field of one well by another. The wells with river hydraulic boundary at both sides will have different flow patterns than the wells drawing water from one sided river boundary.

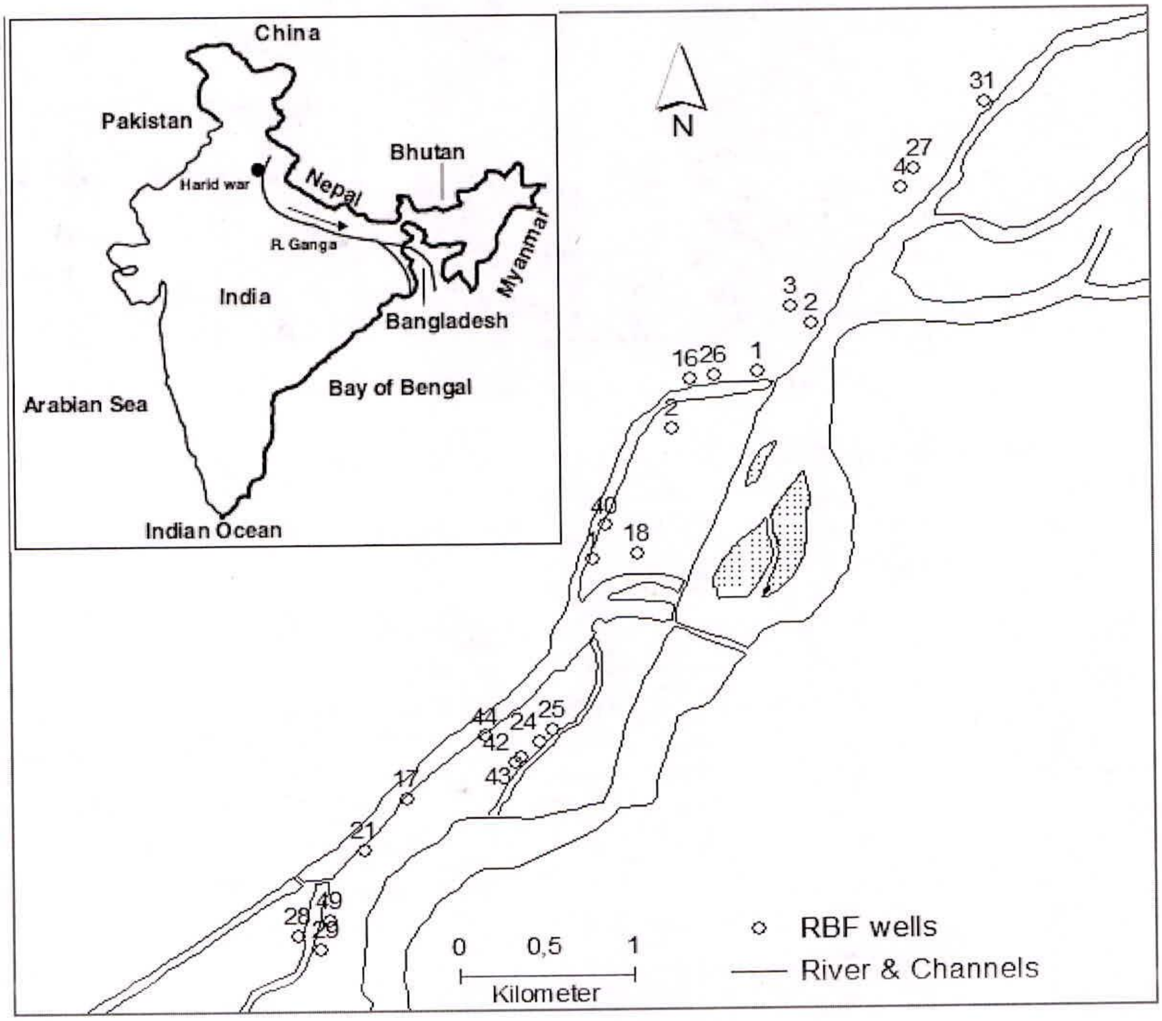

Fig. 5 Riverbank filtration site showing 22 production wells in Haridwar, India (Source: Dash et al, 2010)

Performance of RBF Sites in Haridwar

During monsoon, the total and faecal coliform counts and turbidity of the Ganga by the RBF wells in Haridwar are significantly higher than during non-monsoon periods. It has been reported Dash et al. (2010) that bank filtrate abstracted from production well -18, when compared to raw Ganga River water, showed 2.5-log removal of total coliforms, 3.5-log removal of faecal coliforms, 0.7-log removal of turbidity in the non-monsoon period (November 2005–June 2006) for the shortest travel time of 84–126 days at a minimum distance of 115 m, and 4.7-log removal of total coliforms, 4.4 log removal of faecal coliforms, 2.5-log removal of turbidity and 1.0-log removal for organics as measured by UV absorbance during the monsoon period (July–September 2006) for the shortest travel time of 77–126 days.

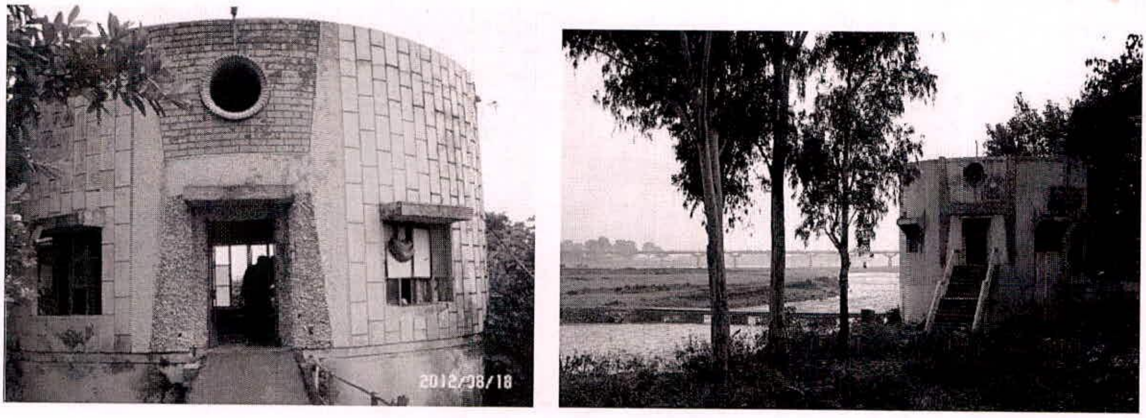

Fig. 6 Riverbank Filtrate pumping stations in Haridwar.

Other studies on RBF in Haridwar (Sandhu et al., 2011) have revealed bank filtrate having very low dissolved organic carbon content of < 1 mg/L under aerobic conditions, an arsenic concentration of less than 0.01 mg/L and other trace metals and major ions below the Indian Standard IS 10500 (1991) limit.

Table 2. Values of relevant parameters and their removal during RBF in Haridwar.

Parameter	Range of concentration [Min. – Max. (mean ^{n})]			Proportion of bank filtrate [%]	Removal [% or Log_{10} for pathogens & turbidity]	Reference
	Surface water	Observation well(s)	Production well			
Total coliform [MPN/100 mL]	4,300 – 230,000	<2 – 23	<2 – 93	> 70 %	2.5 (non-monsoon) – 4.7 (monsoon)	Dash et al., 2010
Faecal coliform [MPN/100 mL]	1,500 – 93,000	0 – 23	0 – <2		3.5 (non-monsoon) – 4.4 (monsoon)	Dash et al., 2010
Turbidity [NTU]	1 – 200	0.1 – 13.1	0.2 – 0.6		0.7 (non-monsoon) – 2.5 (monsoon)	Dash et al., 2010
n = number of samples	22	22	11	-	-	-

Some more technical details, examples and results of RBF shall be discussed during the class room presentation.

SUMMARY

The article discussed about basics of riverbank filtration, its physical processes and mechanism involved in treatment of water including requirement for site selection, and applicability. The advantages and disadvantages of the RBF technique have also been presented. Its scope studied in the India's context has also been presented as example.

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