Riverbank Filtration for Sustainable Water Supply in India

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Abstract

Riverbank Filtration (RBF) or Bank Filtration is defined as a natural low cost pre-treatment technique, which enables the utilisation of surface water sources such as lakes or rivers water to pass through the natural porous sub-surface (aquifer) formation to the production well. The porous media serves as a natural filter and reduces the suspended solids and pathogens. RBF technique is gaining popularity in India for drinking water supply particularly in rural and sub-urban areas. India has a lot of potential to apply this technique particularly in the alluvium and coastal areas. Implementation of this technique in feasible areas requires an in-depth study a-priori on the hydraulic properties of the river and the hydrogeological characteristics of the aquifer including water quality of both the domains. This paper brief through the RBF technique, processes involved and elaborate on the feasibility, potentials and constraints of promoting bank filtration in India.

Keywords: Riverbank Filtration, natural pre-treatment, natural filter, aquifer, feasible

1.Introduction

Riverbank Filtration (RBF) or simply Bank Filtration (BF) as a unified term is a natural pre-treatment technique, which enables the utilisation of surface water sources such as lakes or rivers water to pass through the natural porous sub-surface (aquifer) formation to the production well. The porous media serves as a natural filter and reduces the suspended solids and pathogens.(BF) applied to a river or lake, is a reliable, natural and multi-objective treatment process which removes particles, biodegradable organic compounds, trace organics, microorganisms as well as ammonia and nitrate to some extent. During RBF, pumping pressure in the alluvial aquifer adjacent to the river will force the water to percolate from the river into the aquifer. In this path, a series of physical and biogeochemical processes take place, including physical filtration, adsorption, absorption, biodegradation, and dilution. Thus, riverbank-filtrate often shows better quality than river water, making its treatment for human consumption a lot easier and less expensive (Jaramillo.M, 2012). Furthermore, it also dampens temperature peaks and concentration peaks associated with spills. BF could replace or support other treatment process, thus could provide a robust barrier within a multi-barrier system and also decreases the costs of water treatment. BF is a traditional, efficient and well accepted method of surface water treatment in Europe. For more than 100 years, river bank filtration has been used in Europe for public and industrial water supply along Rhine, Elbe, and Danube rivers (Grischek et al., 2002). Bank filtrate monitored in recent years has shown a significantly higher quality compared to water abstracted directly from surface or groundwater sources. For conventional treatment, high concentrations of organic contaminants requires high doses of chlorine (40-60mg/L) prior to flocculation thus it has created a greater risk for formation of carcinogenic disinfection by-products, as reported in Mathura (Singh et al. 2010) . BF in such situation has been reported advantageous as a pre-treatment in order to reduce the necessary doses of chlorine prior to flocculation. Additional advantages of BF may also be seen during the monsoon season principally in the removal of turbidity and pathogens, as well as in the removal of colour and dissolved organic carbon (DOC), UV absorbance, turbidity, total and thermo tolerant coliform counts (Dash et al. 2008 ; Sandhu et al. 2010 ; Thakur et al. 2009a, 2009b ; Dash et al. 2010). Bank filtration, however, does not present an absolute barrier to other substances of concern (e.g. ammonium) and some inorganic trace elements may even be mobilized. In Delhi, which has poor surface water quality, extensive post-treatment has been reported to be a potential solution to remove high levels of ammonium (Sprenger et al. 2008). Similar aquifer contamination has also been observed in Europe (e.g. Berlin) downstream of sewage irrigation fields. Detailed investigations (Hamann 2009) have shown that even after source water improvement, ammonium continued to leach from the soil for decades. India has a lot of potential for employing 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 aquifer, and aquifers have good soil pores.

2. Bank Filtration and its processes

The bank filtration technique takes advantage of existing geologic formations adjacent to water bodies to filter drinking water. Wells are dug in fine, sandy sediments next to water bodies and water is extracted from these wells. Water in the water bodies filters through the sediments removing contaminants. The water obtained is often of much higher quality than the raw surface water. The removal of contaminants in surface water is important because when the water is chlorinated these contaminants can be converted to harmful chemicals referred to as disinfection by-products (DBPs). Chlorine must be added to most drinking water supplies to kill pathogens. The emphasis on controlling DBPs began when research showed that trihalomethanes (THMs) were produced by the reaction of chlorine with aquatic humic substances during the chlorination of drinking water. THMs include some known and suspected carcinogens (chloroform and dichloroacetic acid). National surveys by USEPA indicated the presence of THMs in virtually every chlorinated water supply tested. Research was initiated in the 1970's, and continues today, into identification of significant DBPs and methods to avoid their formation in the drinking water. Bank filtration wells can either be horizontal or vertical depending upon the hydrogeologic setting, required production rate, and the utility's preference. Shallow alluvial deposits and a higher rate of pumping from a given location often favour horizontal wells, sometimes called Ranney wells or laterals. The laterals of the collector wells can all be directed towards the river or distributed in all directions.

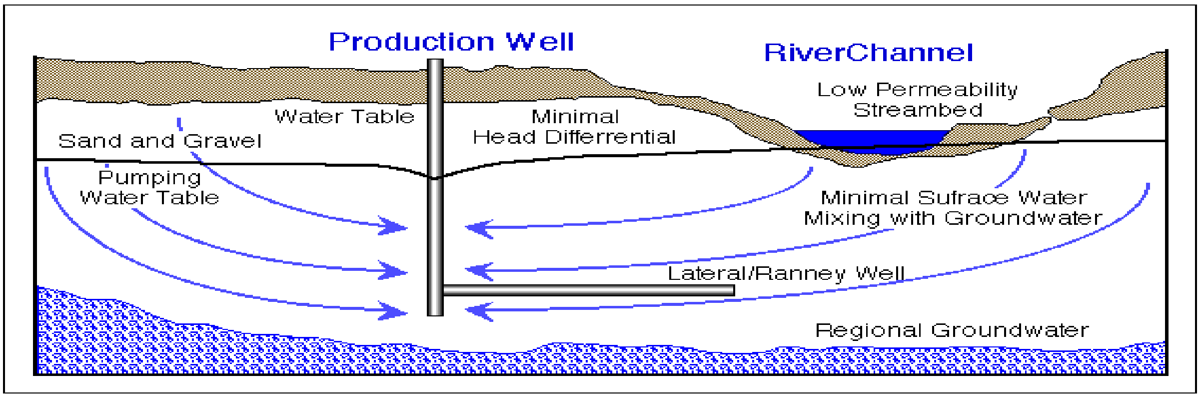

Figure1. Schematic diagram of a bank filtration well

In Europe, particularly in Germany, bank filtration as a water treatment process has been applied since the 1870's and the first research project on bank filtration started in 1898. In the United States there have been bank filtration wells operating for nearly half a century. Since Sandoz Pharmaceutical's accidental spill of herbicides into the Rhine River in 1986, a rigorous 3-year study involving 6 water works, five research institutes, and several universities was conducted by Prof. Heinrich Sontheimer at the University of Karlsruhe, Germany. The study focused on hydrology, removal of organic compounds that included natural organic matter (NOM) and DBP pre-cursors, removal of particles, and the simulation of ground water passing through test filters. (Dr. Ray 2008).

2.1 Processes involved in Bank Filtration

Three filtration mechanisms are possible. Physical filtration or straining takes places when suspended particulates are too large to pass through interstitial spaces between alluvial soils particles. Biological filtration occurs when soil microorganisms remove and digest dissolved or suspended organic material and chemical nutrients. Chemical filtration or ion exchange may take place when aquifer soils react with soluble chemicals in the water (Metcalf & Eddy (1972). Most 'normal' contaminants (microbial organisms and inorganic or organic pollutants) will be removed by bank filtration, either because they get filtered out by the sand/earth of the bank, or because the passage/travel time (which may be days or potentially weeks) is sufficient to render them inactive.(Ray et al, 2008).The research has shown that the removal efficiency depends not only on the contaminant, but also on the "hydraulic and chemical characteristics of the bottom sediment and the aquifer, the local recharge-discharge conditions, and biochemical processes". (Heberer, Thomas et al. 2001)**.**Several mechanisms are responsible for improvement of water quality during BF. During Pumping and travel through the soil and aquifer sediments, surface water is subjected to a combination of physical, chemical and biological processes such as (i) filtration, (ii) solution-precipitation. (iii) ion-exchange, (iv) sorption-desorption, (v) complexation, (vi) redox reactions. (vii) Microbial biodegradation and (viii) dilution that significantly improve water quality. A schematic diagram of processes affecting water quality during bank filtration is presented in Figure 2.

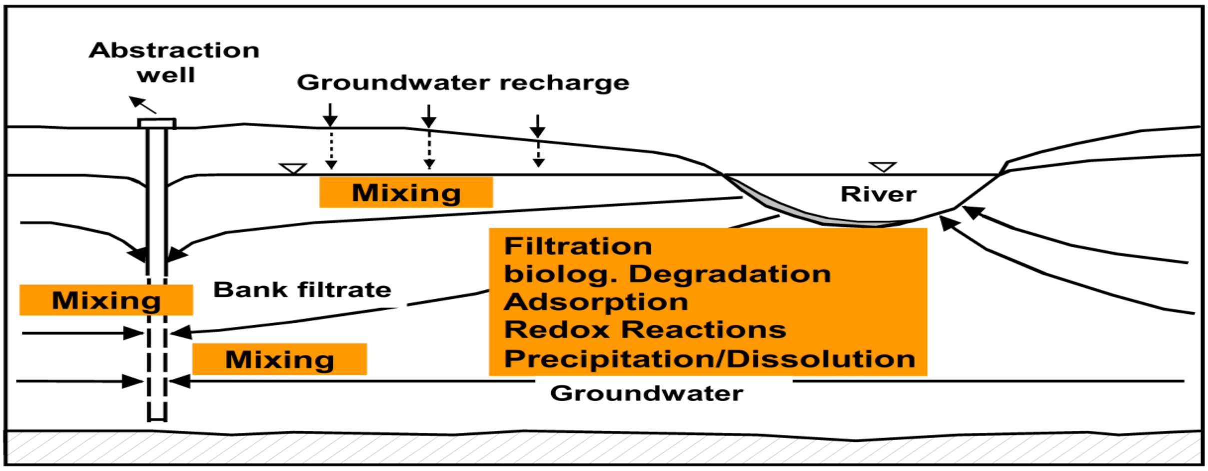

Figure 2. Schematic diagram of processes affecting water quality during bank filtration
Source: Hiscock and Grischek (2002)

In Europe, many cities have implemented BF as one of the main steps for drinking water treatment (Eckert and Irmscher, 2006). RBF technique is in use in Europe along the Rhine, Danube, Elbe, and Seine rivers (Kuehn and Mueller 2000; Doussan et al. 1997). Along the Rhine, the first RBF plants in Du¨sseldorf, Germany was implemented to supply drinking water to a population of about 600,000 (Schubert 2002). In India, RBF technique has been implemented in many places viz., at Haridwar (Ganga River), Satpuli, Agastmuni, Srinagar (Alaknanda River), and Karanprayag all in Uttarakhand, on the bank of river Yamuna in Delhi, and in Ahmedabad (Sabarmati River) and their performances have been found promising (Ghosh et al, 2015) Table 1 presents some compiled data of potential RBF sites of Indian cities.

Table 1. Summary of sitting and design parameters of some existing operational small- and large-scale bank filtration systems in India. (Source: Sandhu, et al.2011)

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	1.5–3 days

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
					riverbed	
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

2.2Factors affecting Bank Filtrations

The performance of BF with respect to water quality improvements depends on a number of variables; (i) hydrogeological conditions including characteristics and composition of alluvial aquifer materials, (ii) river/lake water quality, (iii) groundwater dilution, (iv) filtration velocity and distance of the well(s) from river/lake, (v) temperature of the water, (vii) pumping rate, and (viii) soil/sediment characteristics at the river/lake-aquifer interface (ix) Hydraulic connection between river and aquifer (x) Unconfined or confined aquifer (xi)Aquifer thickness and hydraulic conductivity(xii)Continuous river flow, stable river banks (xii)Sand and gravel river bed, bed erosion(xiv)Average Pumping rates $< 0.2\ m^3/(m^2 \times day)$ (xv) Sand and gravel aquifers with a hydraulic conductivity $> 1 \times 10^{-4}$ m/s (about 10 m/d) (xvi)Aquifer thickness > 10 m.

2.3 Factors to be considered for BF in India

- Naturally occurring factors affecting BF:

(i)Dynamic river discharge: scouring of riverbed, flooding of wells, travel time of bank filtrate (ii) High sediment transport in monsoon: clogging of the riverbed(iii)Shifting river courses: travel time & flow path of bank filtrate(iv)Arsenic, nitrate and other harmful substances in groundwater(v) Discharge of untreated sewage: pathogens

- Institutional factors concerning BF site selection:

(i) Access to data: documentation, not in public domain (ii) Availability of high-cost riverside land for constructing wells (conflicting interests)

2.4Attributes and Limitations of BF

The main attributes and limitations of bank filtration systems are listed below (Ray et al. 2002; IAH and IHP, 2005):

Attributes:

• BF is a natural treatment process, avoids or reduces the use of chemicals and produces biologically stable water.

• BF improves water quality by removing particles (suspended solids), organic pollutants, microorganisms, heavy metals and nitrogen.

• BF dampens concentration peaks associated with spills (in river/lake) and dampens temperature peaks.

• BF replaces or supports other treatment processes by providing a robust barrier and reduces the overall cost of water treatment.

Limitations:

• BF is site specific, and is feasible only when the local hydrogeological conditions are favourable.

• There can be leaching of the aquifer materials under reducing conditions, sometimes leading to increased concentration of iron and manganese in extracted water.

• One of the main problems is clogging of the aquifer due to accumulation of suspended matter that is filtered out when river/lake water enters the aquifer, especially when the system is not properly designed.

• BF and groundwater recharge may be only a limited barrier for certain contaminants.

• Influences of surface water and operation on quality are poorly known.

3. Domestic Water Demand in India

Domestic water consumption in India in the year 2000 was 93 billion litres per day as per the estimation given by(*Note: 1All projected figures indicate water demand Source: 'Water for People Water for Life', United Nations World Water Development Report, 2003; 'The Global Water Crisis: A Question of Governance', Policy Research Division, Department of Foreign Affairs and International Trade Canada; 'Statistical Yearbook for Asia and the Pacific 2007', United Nations Economic and Social Commission for Asia and the Pacific; 'India"s Water Future to 2025 –2050: Business as Usual Scenario and Deviations', International Water Management Institute; OS-Connect Database; US Geological Survey -Water Resources; Aquastat Database*)and is expected to grow 277 billion litres/day by 2050(Figure 2a). The per capita domestic water consumption for India in the year 2000 was 88.9 litres/day whereas by 2050 it is expected to grow 167 litres/day. Hence a demand for domestic consumption of water is projected to increase by 78.1 litres/day by 2050(Figure 2a). Therefore, the country may face exponential decline in per capita availability of water (for drinking as well as domestic purposes).

According to the census reports of Indian Census 2011, the population of India is 1,210,193,422. As the India's population has crossed 1.2 billion marks it faces daunting challenges in the growing water supply needs of an increasing population. From 2001 to 2011 population increased by 17.64 %(COI 2011) with net addition of 91 million to the Urban population. (Source: Census 2011-Provisional population totals-India).The problem of water is acute for the urban population- about 31.16 % of the total population (COI 2011).Given the current demographic trends India's population is projected to be nearly 1.4 billion by 2025 (COI 2011).

Table 2. Existing and projected water-use patterns of India **(Government of India *1999*)**

	1990		**2010**		**2025**		**2050**	
Category	10^9 m^3/year	%	10^9 m^3/year	%	10^9 m^3/year	%	10^9 m^3/year	%
Irrigation	460	88.6	536	77.3	688	73	1008	70.9
Industries areas	34	6.6	41.4	6	80	8.5	121	8.5
Domestic and others	25	4.8	115.6	16.7	174	18.5	293	20.6
Total	519	100	693	100	942	100	1422	100

A Including power generation

Domestic water demand in India (excluding agricultural and industrial use) amounted to only 4.8% of the total demand in 1990 and is projected to increase to 20.6% of total water use by 2050 (Table 2). This is projected to show an increasing trend from 25 × 10^9 m^3/year in 1990 to 116 × 10^9 m^3/year in 2010 and reach 174 × 10^9 m^3/year by 2025. The country is thus expected to face an exponential decline in per capita availability of water (for drinking and other domestic purposes). (Sandhu et al, 2011).

Considering the current domestic water supply scenario, India can benefit from the wider use of riverbank filtration (RBF) technique by many communities where favourable hydrogeological conditions exist. Even if only used as a pre-treatment step for conventional water treatment plants, RBF could provide a long-term solution saving or reducing large infrastructure investments. The overall water usage and per capita domestic consumption of water is expected to increase due to various factors by 2050 hence there is necessity of better water management measures and reduction in per capita water consumption in India to meet the water demand of the day to day increasing population through sustainable supply of water and better pre and post treatment techniques which are cost effective, hence RBF can serve as one of the alternatives and efficient technique to fulfil the above goal.

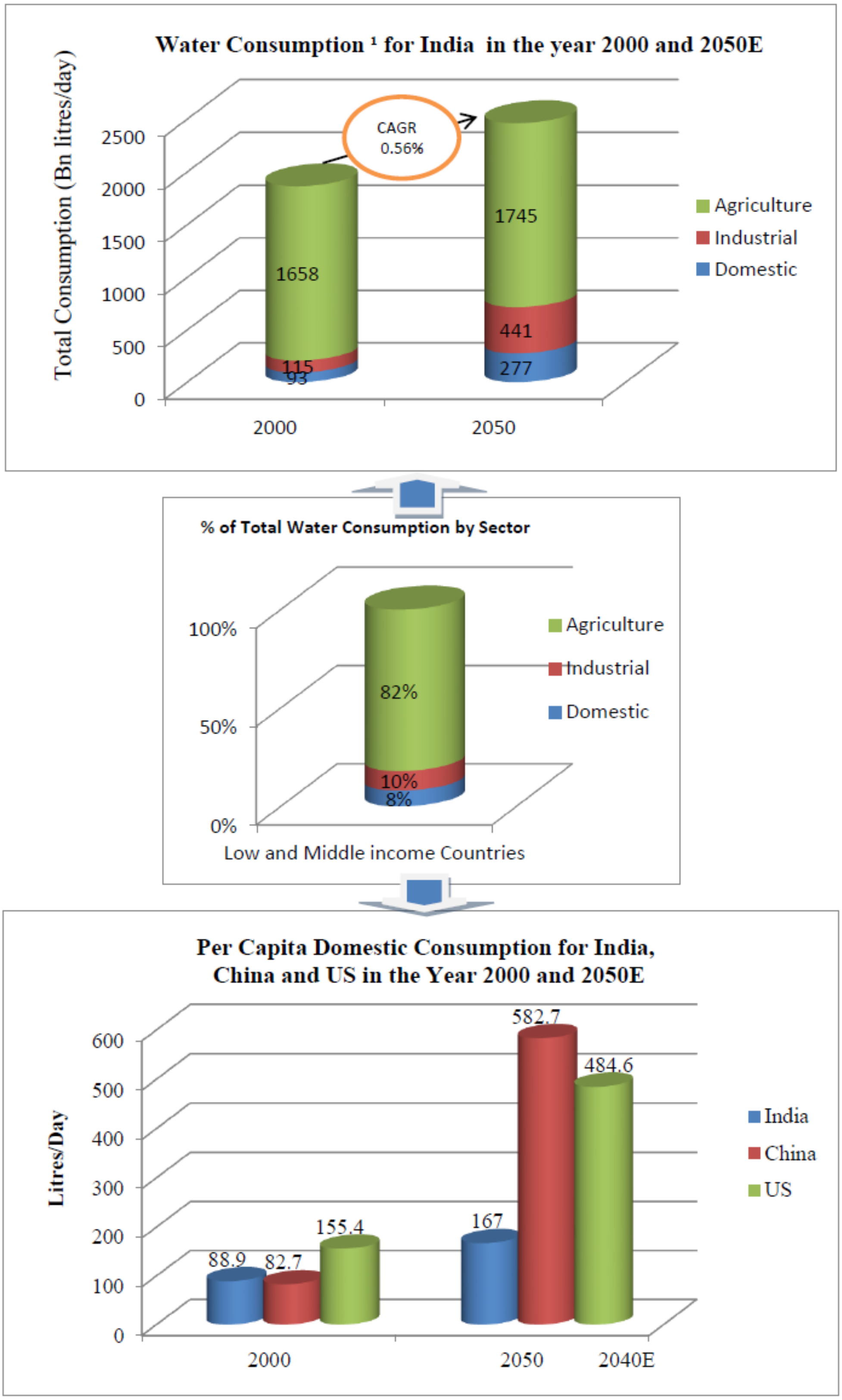

Figure2a. Water consumption in India and Per Capita Domestic Consumption for India in the Year 2000 and 2050E

[Note: 1 All projected figures indicate water demand
Source: 'Water for People Water for Life', United Nations World Water Development Report, 2003; 'The Globa Crisis: A Question of Governance', Policy Research Division, Department of Foreign Affairs and Internationa Canada; 'Statistical Yearbook for Asia and the Pacific 2007', United Nations Economic and Social Commission for A the Pacific; 'India's Water Future to 2025 –2050: Business as Usual Scenario and Deviations', Internationa Management Institute; OS-Connect Database; US Geological Survey -Water Resources; Aquastat Database]

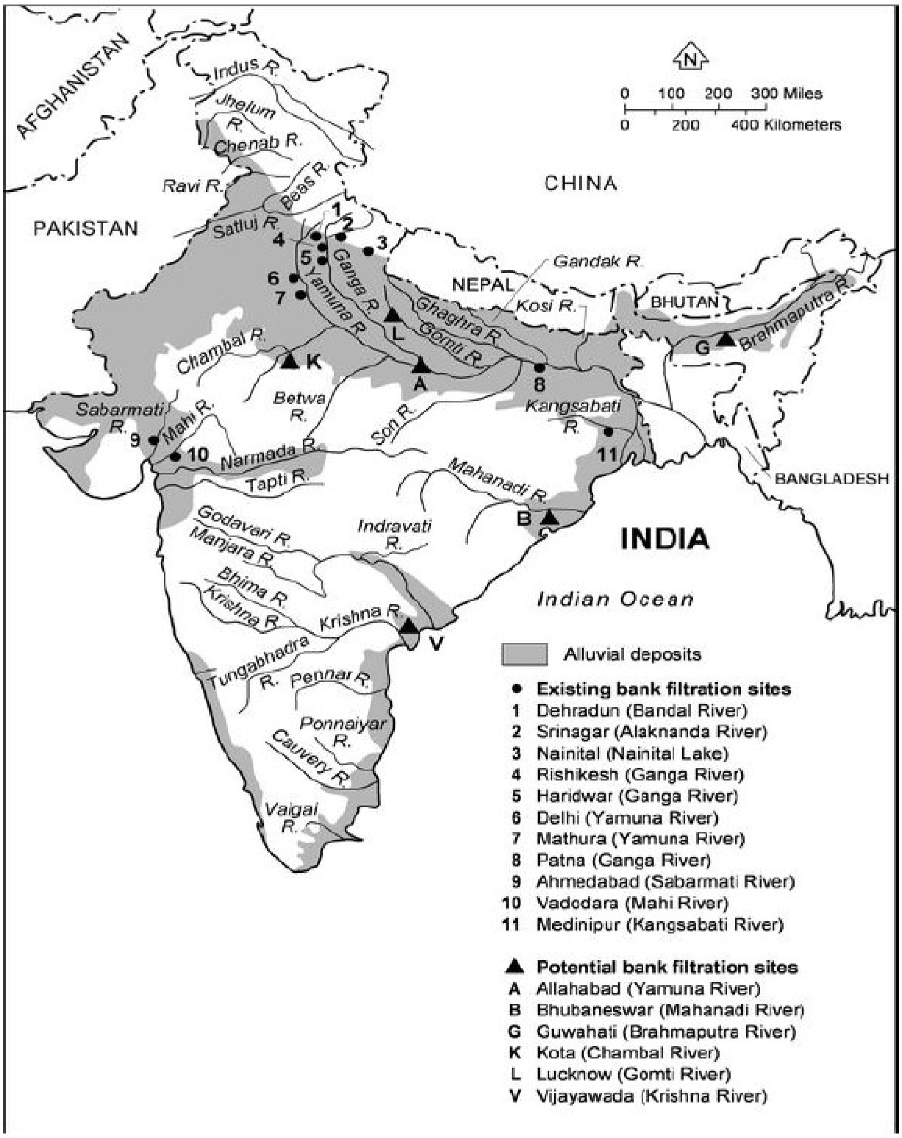

Figure 2b. Location of potential riverbank filtration sites (Source: Sandhu et al, 2011)

Deterioration of water quality, both surface and ground water, is almost a common evidence in every state in India mainly because of: (i) uncontrolled and unabated discharge of untreated sewage into rivers/streams; (ii) overexploitation of groundwater resources and depletion of groundwater level causing problems of groundwater quality originated from anthropogenic and geogenic sources; (iii) increasing demands in all sectoral uses coupled with population dynamics and insufficient sanitation services provision are other reasons, etc. On the other hand, water quality guidelines are getting more stringent due to the increasing number of emerging contaminants in water and consequently the cost of water treatment is increasing. In many developing countries, disinfection (very often by chlorination) is the only treatment applied to public water supply, where there is no planned treatment facility available. In this context, there is a need for a robust water treatment technology such as riverbank filtration which is effective, low cost and could be operated and maintained relatively easily.

4. Riverbank Filtration in Northern India

At a few places in India, existing riverbank filtration schemes that have been in operation for many years currently serve as a sustainable alternative, or as a supplement, to existing surface water and groundwater sources for drinking water supply. Water diversion for irrigation, hydro-power generation and discharge of partially treated and untreated wastewater to surface water bodies with extremely low flows has aggravated the water supply situation for many Indian cities relying on surface water. On the other hand, some existing RBF sites do not require any significant additional treatment to the filtrate for their water supply. The further development of RBF in India has the potential to provide drinking water to many cities and towns located at hydrogeologically suitable sites by perennial surface water bodies (Sandhu et al., 2011a).

As part of an EU project, an initial survey and site assessment of existing bank filtration facilities in North India was carried out between 2005- 2006 as well as from 2011-2015 . Existing bank filtration facilities at 8 sites were tested. In 2010-2011 new bank filtration schemes were constructed at four new sites in the mountainous state of Uttarakhand in North India

It was noted that rivers of Northern India even though drain by wastewater, sewages shows low content of DOC thus making viable for application and implementation of RBF technique. Hydrogeological and water quality investigation in Haridwar for the period 2012-2013 showed that between non-monsoon period from October to June total coliforms between 28 and 2.4×10^3 MPN/100mL and Faecal coliforms between 43 and 2.4×10^3 MPN/100 were measured in surface water. During the monsoon period from July to Sep the total coliform counts were 1×10^3 and 2.4×10^3 whereas Faecal counts were 93 and 2.4×10^3.Number of Faecal count in bank filtrate was from 3and 498 in non-monsoon and

6.7and 2.4×10^3 in Monsoon period implying the need for robust RBF schemes during monsoon is necessary in order to ensure sustained operation even during flood events.

Preliminary investigations show promising conditions for RBF in Srinagar. Especially during monsoon season the Alaknanda River exhibits high turbidity. The bacteriological contamination of the river, in terms of the most probable number of total and fecal coliform counts, ranges from 350/100 ML to 79×10^3 / 100 mL and from 1.6×10^3/100 mL to 17×10^3/100 mL, respectively (Sood et al. 2008; Sandhu et al. 2009b). A very low turbidity and no indication of bacteriological contamination have been detected in the water generated by the two existing drinking water production wells as well as prominent alluvium stretch in the Alaknanda River basin around Srinagar documented by Jha 1992 constituted the background for successful implementation of RBF schemes at Srinagar in 2015. Only 1.9 log (98.6%) reduction of total and fecal coliform counts was achieved by the sand filter units whereas 5.2 log (99.999%) and 4.2 log (99.99%) reductions, respectively, were measured while using bank filtration at Nainitaal Lake. Water from the tube wells is sufficiently free from coliform bacteria such that chlorination is not required (Dash et al. 2008). Investigations on RBF at Mathura (Luckins et al. 2009; Singh et al. 2010) determined that water from the Yamuna River contained 2.5–29 mg/L of DOC and had a color of 40–185 color units (CU) Although the river water turbidity fluctuated significantly during the monitoring period (3.83–86.0 Nephelometric Turbidity Units [NTU]), in the filtrate it remained less than 1 NTU. The breakthrough of microorganisms was observed to be much higher during the monsoon period.RBF effectively reduced color, DOC (by around 50%), and UV absorbance thus effective in attenuation of microorganisms, organics, and turbidity. It is also a good alternative to pre-chlorination of polluted waters for the oxidation of organics.

5. An example of Riverbank Filtration in rural pocket of Southern India

A simple and innovative method of water treatment known as the Riverbank Filtration (RBF) technology was demonstrated by TERI-WRC - Goa, to treat the polluted water of river Kali. The project, sponsored by the World Bank under the Development Marketplace 2007 award, is the first-of-its-kind in Southern India. It is a perfect example of safe, low-cost, and reliable technology for providing potable water in rural areas of a developing country like India.

The river Kali originates near Diggi village of Supa taluka on the borders of both Karnataka and Goa, and joins the Arabian Sea at Sadashivagad near Karwar. Discharges of effluents from a nearby paper mill and the domestic sewage have severely polluted the river, leading to water-borne diseases and major public health problems. The lack of reliable access to clean water and widespread water shortages due to failed infrastructure pose additional burden on the local population. The affected area covers 10 villages downstream from Dandeli, which is a major industrial city of Karnataka. Dandeli is situated in the Haliyal taluka of Uttara Kannada district of Karnataka and has approximately 1,500 inhabitants. It is here that the RBF technique was implemented to provide safe drinking water.

RBF is a (pre) treatment technique in which water is withdrawn from one or more wells near the riverbank (typically within 50-200 metres). By pumping an RBF well, river water is induced to flow through porous riverbed sediments. As the raw surface water passes through the sediments beneath the river and travels towards the RBF well, dissolved and suspended contaminants, as well as pathogens, are removed or significantly reduced in quantity due to a combination of physical, chemical, and biological processes. Sample household surveys were carried out to test the acceptance of the RBF system and to assess possible changes in the health and economic status of the villagers served by it. The survey data revealed that there was significant improvement in the overall health of the population, and that the RBF system has gained widespread acceptance. The quantity of water treated was about 8 m^3/hr, which was sufficient to serve 4,000 people with the required 55 L/d/capita. The technology significantly improved the quality of water in the river - it was clear and free from odour. It was also discovered that the RBF had succeeded in removing 93.5% of the total coliform and 98.7% of E. coli as compared to the water in river Kali and the open well. There were no detectable traces of dioxins, chlorinated phenols, pesticides, and arsenic in the RBF well.

6.Riverbank Filtration Technology in India-Way Forward

Pey Jal Suraksha –Development of Six Pilot Riverbank Filtration Demonstrating Schemes in Different Hydrogeological Settings for Sustainable Drinking Water Supply, research project sponsored by Ministry of Water Resource is being carried out by National Institute of Hydrology, Roorkee under which following six RBF sites namely Laksar(on bank of Solani River),Uttarakhand; Mathura(on bank of Yamuna River),Uttar Pradesh; Agra(on bank of Yamuna River),Uttar Pradesh; Sahebgunj(on bank of Ganga River),Jharkhand; Samaria Ojhapatti(on bank of Ganga River), Bihar; Visakhapatnam(on bank Godaveri River),Andhra Pradesh are being developed for Sustainable Drinking Water Supply.

Conclusion

During RBF, pumping pressure in the alluvial aquifer adjacent to the river will force the water to percolate from the river into the aquifer and as it undergoes subsurface passage a series of physical and biogeochemical processes take place, including physical filtration, adsorption, absorption, biodegradation, and dilution which renders riverbank-filtrate better quality than river water, making its treatment for human consumption a lot easier and less expensive.

Studies of RBF systems in India demonstrate that such systems already play a significant role in providing drinking water to several cities. Where RBF is used, the RBF (along with much more limited post-treatment chlorination) is accepted as the sole purification treatment. Bank filtrate from a few sites monitored in recent years has shown a significantly higher quality in RBF water when compared to water abstracted directly from surface or groundwater sources.

One limitation on the efficiency of RBF is the clogging of the bed and the banks of the river, which decreases the hydraulic conductivity in the hyporheic zone hence removal of the clogging layer due to heavily regulated surface flows and discontinuous well operation due to lack of continuous electricity supply or electricity saving measures is imperative.

Although the practice of riverbank filtration has been used in India for more than a century, the current understanding of the processes and mechanisms behind this technique are still very empirical, hence concerted efforts to fully realize the potential of RBF and understand and scientifically document the processes involved is required. One such effort is being made by NIH, Roorkee in the form of Pey Jal Suraksha –Development of Six Pilot Riverbank Filtration Demonstrating Schemes in Different Hydrogeological Settings for Sustainable Drinking Water Supply and exploring the RBF technology in more details.

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