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RIVER BANK FILTRATION FOR NATURAL TREATMENT OF WATER IN INDIA: A REVIEW

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ABSTRACT

River Bank Filtration is one of the methods of Managed Aquifer Recharge in which the surface water undergoes natural treatment by subsurface flow through the aquifer medium. In this study an attempt is made to review the studies carried out on River Bank Filtration in India. The geological conditions, well types and the effect of bank filtration on physical, chemical and biological quality of water were discussed in detail. It has been found that bank filtration effectively function as a natural treatment method in India. This technique can be adopted in many other locations in India after thorough study. River Bank Filtration will be a better and viable solution to partly meet the present water demand in India.

Key words: Groundwater recharge, Managed Aquifer Recharge, water quality, Natural water treatment, Geochemistry, Microbiology.

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1. INTRODUCTION

Groundwater is the largest fresh water reserve in the world, which is under stress due to the overuse. Over dependence on groundwater to meet increasing population, industrialization and agricultural activities has also led to deterioration of its quality. More than 60% of irrigated agriculture and 85% of drinking water supplies are dependent on groundwater in India. Increasing water needs are met by tapping groundwater; the depletion of resources is of major concern. Managed Aquifer Recharge (MAR) is a one of best option to mitigate the problem of groundwater over exploitation [1]. There are number of MAR methods that can be adopted to improve the groundwater table as well as its quality. MAR techniques includes infiltration ponds; infiltration galleries, aquifer storage transfer and recovery, River Bank Filtration, aquifer storage and recovery; soil aquifer treatment; percolation dams and check dams. The selection of a method in a particular are is depend on the topography, drainage

conditions, land use, aquifer type, quality and quantity of the water as well as other factors [2]. Even the regions that are dependent on surface water resources face problems due to the degradation of the quality of water. River Bank Filtration (RBF) is one among the MAR methods which is inexpensive and sustainable means to improve the quality of surface waters during bank infiltration, thus it helps to overcome the problems of contaminated surface water resources [3]. During RBF, the water in the river with various contaminants is naturally treated as it passes from river through the river banks and the aquifer to the pumping well. RBF results in removal of suspended, colloidal and dissolved particles as well as reduction of bacteria, viruses, micro pollutant, organic and inorganic compounds during its passage through aquifer medium [3]–[8]. Thematic diagram illustrating the process of RBF and process responsible for improving the quality of water is illustrated in Figure 1. In combination with activated carbon filters, RBF was proved to be a one of the valuable treatment step for drinking water supply along Rhine River in Germany [9]. Doussanet al. (1997) indicated that, bank filtration led to reduction of nitrogen in the aquifer of Seine River, France [10]. Miettinen et al. (1994); Kuehn and Mueller (2000); Hiscock and Grischek (2002); Verstraeten et al. (2002) also reported the efficiency of RBF in treating river water polluted by baker's yeast and pharmaceuticals [10]–[14]. Even microbes and viruses present in river water were also removed during RBF in Missouri well field in United States [15]. In fact, RBF systems provide 16% in Germany, 45% in Hungary, 55 % in Netherlands and 50% in Slovak republic of drinking water supply [16]. Such RBF systems have also been historically practiced in India and its scientific advantages are observed since recent years [17]. RBF is a viable option for India as most of the surface water resources are of poor quality [18]. Water supply systems depending on river/lake water will require huge operational costs for the treatment. Whereas, RBF is advantages as the same contaminated water is tapped taking advantage of the natural filtration process of the aquifer formation.

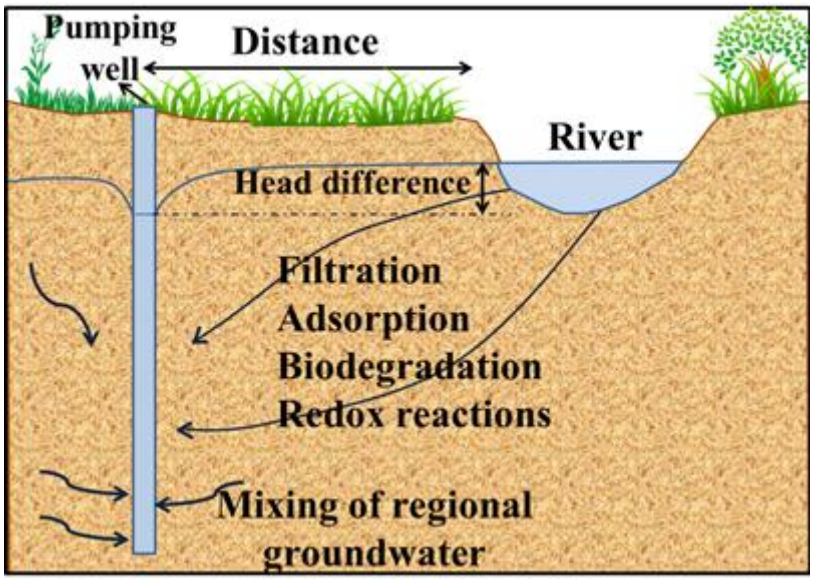

Figure 1 Schematic diagram of showing river bank filtration processes

In India, it was reported that the dose of ozone required for the treatment of Yamuna River was found to be considerably less due to RBF [19]. Further, RBF resulted in reduction in concentration by sorption of arsenic, reduction in nitrate due to denitrification, precipitation of fluoride and reduction of microbial content by two orders of magnitude in the megacity of Delhi [20]-[21]. Though several researches have carried out investigation on RBF, no systematic collation and review of studies carried out on RBF in recent past has been made. As compared to Europe and United states, usage of river bank filtration for water supply in

India is very less. Sandhu et al. 2011 has reported the potential advantaged of RBF in India [17]. Bartak et al. (2015) also reported the performance of RBF systems especially in India [22]. However, these researches have not reviewed all the work carried out on RBF in India especially by considering the water quality aspects with respect to physical, chemical and biological contents. Hence, the present study was carried out with the objective of reviewing the research carried out on RBF in India on the natural treatment process of water in order to meet the rural water needs.

2. METHODOLOGY

The study was carried out based on the literatures that are available in the public domain as well as the research article published in various journals. In order to collect the research study a thorough search was made in the internet using various the browsers such as Google chrome, Microsoft edge and Firefox. The various search engine used in this study are Google, bingo and yahoo. Further the bibliographic search was made in Google scholar, Scopus, Science direct, Springer link etc. During all these searches the key words used are River Bank Filtration, surface water treatment, Managed Aquifer Recharge methods, removal of microbiological load from surface water, improvement of groundwater quality etc.,. These searches resulted in over 1750 documents. It was decided to consider publications from the year 1990 in India as the potential of RBF in India is scientifically identified after this period only. The reviews of all the articles published were made to understand the optimum distance of RBF well from the river, based on the infiltration velocity and improvement in quality of water.

3. RESULTS AND DISCUSSION

3.1. Review of Bank Filtration sites in India

RBF in India has evolved since early 1900s. The various studies on RBF carried out since the 2008 are listed in Table. 1 along with the source of water and descriptions. Though the initial researches were published in 2008, the data in the research is from 1997 [23]. The review of research on RBF indicates that all the studies have been carried out in northern part of India. Most of the RBF sites are located in northern parts of India since the rivers are perennial over there. This indicates the importance of RBF for water supply in the city/towns along the perennial rivers. Only two studies are from the non-perennial rivers in the southern part of India. River Ganga has more RBF sites in comparison with the other rivers. Among all the locations Delhi and Ahmadabad are benefitting from RBF by extracting more groundwater. Nainital and Bhimtal Lake the two sites were bank filtrations are carried out near the lake.

3.2. Geological Conditions

The rate of bank filtration mainly depends on the aquifer characteristics, hydraulic conductivity and distance of the well from water body at where the aquifer can provide water with more quantity and better quality. Geological conditions in and around the RBF sites have been understood by the collected literature. The bank filtration near Nainital Lake contains higher percentage of gravel, fine sand and medium sand and coarse sand up to 36 m from the ground level. Below 36 m it contains fine sand and fractions of clay in it [23]. It has been found that average hydraulic conductivity as 250, 327 and 394 m/day Hazen (1893), Beyer (1964) and Alyamani and Sen (1993) respectively. Whereas in Ganga plains at Haridwar, 17 m thick of gravel sand function as unconfined aquifers [28].

Table 1 Details of RBF sites in India

Location of RBF sites	State	Name of the River / Lake	Aquifer characteristics	Distance of RBF well (m)	Type of well	No. of wells	Depth of well (m)	Travel Time (days)	Quantity of extraction (m^3/day)	Reference
Nainital	Uttarakhand	Nainital Lake	Fine sand, medium sand and coarse sand upto 36 m	< 100	Vertical filter well	9	22.6 to 36.7	8 to >30	> 24100	[23]; [24]
Muzzafarnagar	Uttar Pradesh	Kali River	NA	68	Vertical filter well	NA	8 to 15	NA	29 to 300	[25]
Mathura	Uttarpradesh	River Yamuna	NA	Beneath riverbed	Radial collector well	1	15.5 to 18	1.5 to 3	2400	[19]
Delhi	Delhi	River Yamuna	NA	About 600	Vertical filter well	About 90	45 to 54	few weeks	~ 100000	[20]
Haridwar	Uttarakhand	River Ganga	17 m thick gravel sand (unconfined aquifer)	15 to 110	Caisson well	22	7 to 10	2 to > 100	> 43000	[24] [28]
Rishikesh	Uttarakhand	River Ganga								[17]
Patna	Bihar	River Ganga	Fine to coarse sand with intermittent gravel bed	9 to 236	Vertical filter well	6	150 to 200	NA	> 3500	[26]
Dehradun	Uttarakhand	Bandal River	NA	Beneath river bed	Radial collector wells		1.5 to 2	2 to 4 minutes	140 to 430	[17]
Ahemedabad	Gujarat	Sabarmathi River	NA	Beneath river bed	Radial collector well	7	10 to 11	NA	110000	[17]
Vadodara	Gujarat	Mahi River								[17]
Medinipur	West Bengal	Kangsabathi River	NA	Beneath river bed	Radial collector well	1	6 to 11	NA	15900	[17]
Kharagpur	West Bengal	Kangsabathi River	NA	Beneath river bed	Radial collector well	1	6 to 8	NA	22700	[17]
Srinagar	Uttarakhand	Alaknanda river	Medium to coarse sand, medium gravels and small boulders	3 to 165	Vertical filter well	6	18 to 20	NA	> 4000	[24] [30]
Satpuli	Uttarakhand	East nayar river	NA	43 to 45	Vertical filter well	1	26	2 days to 2 weeks	720	[24]
Agastmuni	Uttarakhand	Mandakini river	NA	33	Vertical filter well	1	30	NA	> 280	[24]
Karanprayag	Uttarakhand	Pinder River	NA	53	Vertical filter well	1	20	NA	> 700	[24]
Bhimtal	Uttarakhand	Bhimtal lake	NA	16	Vertical filter well	1	48	NA	> 320	[24]
Kesarwala	Uttarakhand	Song River	NA	40	Vertical filter well	1	48	NA	> 900	[24]
Sahaspur (Dehradun)	Uttarakhand	Swarna River	NA	Beneath river bed	Radial collector well (s)		3 to 4	> 150 minutes	210 to 570	[24]
Dandeli	Karnataka	Kali river	14 m thick alluvial sediments	NA	NA	NA	NA	NA	NA	[27]

While in the same Ganga plains at Patna the aquifer becomes semi confined and confined in Alluvia deposits consisting of fine to coarse sand with intermittent gravel beds[26]. [29] reported that the maximum hydraulic conductivity of the aquifer near Patna has 1.7 x 10^{-3} ms^{-1}. River beds of Alaknanda River at Srinagar region consist of phyllite and schist bed rocks with quartzite veins in between. Medium to coarse sand, medium gravel and small boulders are aquifer materials in this region. The weathered rock in this region are found up to a depth of 17 m in this site [30]. Geological profile at RBF site near Kali River in Karnataka is of formation of meta-sedimentary origin which is overlain by [31]; [27]. Further alluvium of about 14 m thick is also present. It is obvious that most of the RBF sites are located in alluvial formation consisting of sand and gravel. Table. 1 lists the details with regard to the geology, type of well, distance of wells from the source and other information.

3.3. Well types and other considerations

Caisson wells, radial collector wells and vertical filter wells are the general types of wells used for RBF in India. Caisson wells were of 7 to 10 m depth and 10 m in diameter. The caisson wells are constructed by reinforced brick work of about 65 cm thick. These bricks are

with weep holes filled with graded filter media. The water enters into the wells from the bottom, which is packed with coarse sand and gravels [28]. Radical collector wells are also used as RBF system which has the horizontal pipes penetrating towards the river. The filtrate water enters the connector well through these horizontal pipes. These wells are used in comparatively low permeable aquifers.

Vertical collector wells are the typical water extracting structures used widely around the world including India. Low cost, easy for construction and maintenance, more water withdrawal are the major advantages of these wells. The diameter and depth depends upon the aquifer conditions and surface water hydrology. These wells are preferred in comparatively high permeable aquifers.

The distance of the RBF well is decided by considering the expected hydraulic gradient between the river and the well, as well as hydraulic conductivity. If the groundwater from the river bank takes more than 50 days to reach the production wells the microbial content will be reduced tremendously which will save the cost of post treatment [32]. In order to maximize the production several wells can be located at optimum distance parallel to the river course as practiced in Ahmedabad [33] and Delhi [20].

3.4. Bank Filtrate Quality

It is generally understood that RBF results in filtering relatively contaminated surface water during flow through the aquifer material. The filtration capacity depends on the aquifer material, the constituents in the water and its interaction with aquifer medium as well as the flow velocity. Hence, the researchers have come across different results with regard to the improvement in quality of water extracted from RBF well. This section reviews the results obtained in the various studies on the improvement in the water quality with regard to several parameters and different constituents in India.

3.4.1. Physico-chemical parameters

Physicochemical parameters such as turbidity, pH, ORP, EC, TDS, total alkalinity, total hardness and COD were considered in RBF studies. Table 2 shows the effect of RBF on physicochemical parameters. Turbidity level had reduced tremendously because of the effective filtration of water by the aquifer formation. As turbidity of groundwater will be generally near zero, many studies on RBF have not considered this parameter as shown in Table 2. In general, pH of groundwater which are not affected by any anthropogenic activities are around 6.5 to 8.0. The studies (Table 2) revealed that pH was within the range of 7.0 to 8.23 in the RBF well though it were between 7.0 and 8.64 in the river water. This indicates that the RBF process effectively maintains the pH level with in the limit. TDS, EC, hardness and alkalinity were increased noticeably after RBF due to the ion exchange processes that are taking place during bank filtration. If there is no bank filtration in these region the groundwater would have much higher range of TDS, EC, hardness and alkalinity than the bank filtrated groundwater. Thus physicochemical quality of water is improving considerably in bank filtration process.

Table 2 Comparison of river water and RBF well water quality in different sites

Name of the town/City	Turbidity (NTU)		pH		ORP (mV at 25°C)		EC (µS / cm)		TDS (mg/l)		Total alkalinity (mg/l)		Total Hardness (mg/l)		COD (mg/l)	
	SW	BF	SW	BF	SW	BF	SW	BF	SW	BF	SW	BF	SW	BF	SW	BF
Nainital[c,d,m]	4.9 – 7.1	0.2 – 0.25	7.9 – 8.64	7.68 – 8.16	225	308	577 – 640	655 - 869	376 – 407	501 – 580	NA	NA	277 – 328	387 - 405	31 – 57	BDL
Haridwar[b,c,d,e,f]	1.9 – 2745	0 – 1	6.9 – 8.6	6.5 – 8.4	NA	NA	160 – 575	339 - 650	104 – 125	213 – 270	32 – 116	158 - 225	76 – 99	148 - 177	NA	NA
Patna[a,b,d]	NA	NA	6.9 – 8.4	7.0 – 8.0	NA	NA	168 - 549	219 - 940	NA	NA	57 – 284	57 – 2777	90 – 506	84 - 364	NA	NA
Delhi[l]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mathura[d,k]	3.83 – 13.6	0.9 – 4.29	7.7 – 8.2	7.18 – 8.23	353 – 390	354 – 364	1170 – 1454	1356 - 1483	725 – 902	840 – 934	248 – 360	312 - 342	260 – 358	324 - 396	NA	NA
Dandeli[i,j]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Muzzafarnagar[d,e]	45 – 525	0.16 – 0.65	6.96 – 7.77	6.77 – 7.81	NA	NA	424 – 599	477 - 606	NA	NA	205 – 279	238 - 250	NA	NA	NA	NA
Srinagar[d,g,h,n]	207 – 240		8.1 – 8.2	7.2 – 7.5	NA	NA	159	454 - 1318	109 – 110	650-679	NA	NA	78 – 84	270 - 425	NA	NA
Satpuli[g,n]	22	0.7	8.1 - 8.4	7.8 – 8.0	NA	NA	NA	NA	86 – 95	104 - 105	NA	NA	66 – 74	72 75	NA	NA
Agastmuni[n]	NA	NA	7.9	8.1	NA	NA	NA	NA	68	195	NA	NA	39	116	NA	NA
Karanprayag[n]	13	0.6	8.2	7.8	NA	NA	NA	NA	105	212	NA	NA	82	169	NA	NA
Periyapalayam (Near Chennai)[o]	NA	NA	7	7.1	NA	NA	625	774.5	NA	NA	NA	NA	NA	NA	NA	NA

Sources : a(C. Sandhu et al., 2011), b(Sandhu and Grischek, 2012), c(Dash et al., 2007), d(Cornelius Sandhu et al., 2011), e(Ojha and Thakur, 2010), f(Dash et al., 2015), g(Sharma et al., 2014), h(Gupta et al., 2015), i(Tyagi et al., 2013), j(Cady et al., 2013), k(Boving et al., 2014), l(Singh et al., 2010), m(Sprenger et al., 2014), n(Dash et al., 2008), o(Parimalarenganayaki et al., 2015)

3.4.2. Nutrients

Generally the river water will have comparatively high nitrogen and phosphorus as rainfall runoff originates from the agricultural lands where use of fertilizers and manures are common. Nitrate content of river Ganga, Alaknanda, Nayanar varied between 0.7 mg/L and 5 mg/l [23],[26], [30], [37], [38], whereas in the same RBF site the nitrate content of bank filtrate varied between 1 and 28 mg/l. However, the other forms of Nitrogen, particularly nitrite and organic nitrogen compounds can also affect the river water quality. A few studies reported that the ammoniam concentration in Alaknanda River and its bank filtrate water as less than 0.5 mg/l [23], [30]. Studies from Nainital lake showed a Phosphate concentration of 0.044 o 0.19 mg/l in lake water and 0.001 to 0.02 mg/l in lake bank filtrate [23], [35]. Thus

among the nutrients the concentration of nitrate is reported to increase during the bank filtration due to the certain geological conditions of the location like quartzite bedrocks and phyllite bedrocks [30].

3.4.3. Dissolved Organic Carbon

A few studies have attempted to measure the Dissolved Organic Carbon (DOC) during RBF process. A study conducted in river Ganga at Patna reported a range of DOC as 1.9 to 2.1 mg/l during monsoon in river water and 0.2 to 2.8 mg/l in bank filtrate. Whereas, 4.9 mg/l and 0.6 to 1.6 mg/l in river water and bank filtrate respectively during non-monsoon [26]. A study from Yamuna River at Mathura indicated a DOC concentration of 4.04 to 6.80 mg/l in river water and 1.65 to 3.28 mg/l in bank filtrate. Thus in general the RBF reduce the DOC [19].

3.4.4. Microbial Constituents

The effect of river bank filtration process on Total coliforms and Fecal coliforms were shown in Table. 3. It showed a tremendous reduction on removal of coliforms from water. A study attempted to evaluate the changes occurring in the coliphages count and enteric viruses present in the water.

Table 3 Reduction in microbial constituents due to bank filtration in various sites

Name of the town/city		**Nainital[c] ,d,m**	**Haridwar[b,c] ,d,e,f**	**Patna[a,b] ,d**	**Delhi[l]**	**Mathura d.k**	**Dandeli i,j**	**Srinagar[d,g] ,h,n**	**Satpuli[g] ,n**
Total coliforms (mpn / 100 ml)	SW	14.3 x 10^4 – 17 x 10^4	10200	24000 – 160000	1200	2300 – 15 x 10^5		240 - 900	240 - 900
	BF	2	26	8 – 300	< 1	43 – 75 x 10^3	6.6 – 180	Nil	Nil
Fecal coliforms (mpn / 100 ml)	SW	19 x 10^3 – 14.5 x 10^4	6760		1000 – 3000	150 – 23 x 10^4	44 – 47		
	BF	2	1		< 1	43 - 93 x 10^2	0.18 – 1.3		

SW- surface water BF – Bank filtrate

It reduced the coliphages count into 1.2 – 47.1 genome copies / 500 ml from 102,358 genome copies / 500 ml. The enteric viruses HAdV and NoV presented in river water were 3.6 x 10^4 and 5.4 x 10^4 genome copies / 500 ml respectively. Whereas the bank filtrate showed nil result. These results evident that bank filtration can be used as an effective method to reduce the microbial loads from water.

4. CONCLUSIONS

This paper highlighted the status of river bank filtration in India. The geological conditions of the existing sites were discussed and alluvial aquifers are generally selected for the construction RBF sites to fulfill the community water demand. The effect of bank filtration on water quality parameters such as pH, Turbidity, Total Hardness, EC, TDS, Nutrients and Organic compounds, COD, major ions and biological load in various sites were discussed in this paper. The discussion revealed that the bank filtrate quality is better than the surface water quality and that can be used for community supply. It is suggested that this technique can be adopt in many other Indian localities near surface water bodies after thorough

feasibility study. All the RBF sites were fulfilling the water needs of the community significantly. Physical, chemical and biological contaminants were decreased dramatically during the bank filtration process. Thus, the potential of RBF to treat the surface water during flow through the aquifer is very evident. The feasibility of bank filtration need to be assessed in various other locations in India. This will be a better and viable solution to at least partly meet the present water demand in India.

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