Chapter 12

Pre- and post-treatment of bank filtration and managed aquifer recharge in India: Present and future

Saroj Kumar Sharma, Cornelius Sandhu, Thomas Grischek, Ankush Gupta, Pradeep Kumar, Indu Mehrotra, Gesche Grützmacher, P. J. Sajil Kumar, Lakshmanan Elango and Narayan C. Ghosh

12.1 INTRODUCTION

Soil aquifer-based natural treatment systems namely bank filtration (BF), artificial recharge and recovery (ARR) and soil aquifer treatment (SAT) are managed aquifer recharge (MAR) systems that are robust, reliable, capable of removing multiple contaminants and sustainable (Dillon, 2005; Amy & Drewes, 2007; Ray, 2008). In addition to replenishing groundwater aquifers and depending on the quality of the water source used for recharge (river or lake water, storm water, wastewater treatment plant effluents) and local hydrogeological conditions, these MAR systems can serve at least as a pre-treatment or sometimes even as a total treatment system (Sharma & Amy, 2010; Sharma *et al.*, 2012).

Very often the treated water from these natural treatment systems (NTSs) may not meet the required local water quality guidelines or standards for intended use and thus require additional post-treatment. Furthermore, some contaminants present in the source water may pollute the aquifer or influence the performance of NTSs and therefore pre-treatment of source water is often carried out before the application of natural systems. Pre-treatment and post-treatment thus form an integral part of the NTSs. Depending upon the raw water quality, local hydrogeological conditions, process conditions applied and intended use of the treated water a NTS can have pre-treatment or post-treatment or both.

Pre-treatment refers to removing or reducing the concentrations of some of the critical contaminants in the source water to enhance the performance of subsequent treatment systems. Pre-treatment may be required in NTSs to avoid clogging and contamination of the aquifers, to increase the run time, and to enhance the removal efficiencies of different contaminants. Post-treatment refers to further upgrading the quality of the "treated water" from different NTSs so that it meets the water quality requirements for different applications. Requirements for post-treatment of "product water" from natural systems vary significantly depending on the quality of the source water used, type, design, and operation of NTSs employed, process conditions applied and applicable water quality guidelines or standards for intended use. The type of pre-treatment and post-treatment that should be applied, however, depends mainly on the source water quality, the type of NTSs being used, the process conditions applied as well as the intended use of the treated water from the NTSs.

Table 12.1 provides an overview of the main water quality concerns for different natural systems used in India and pre- and post-treatment applied.

Table 12.1 Pre-treatment and post-treatment applied to different NTSs in India.

NTS	Pre-Treatment Applied	Main Water Quality Concerns in Abstracted Water	Post-Treatment Methods Applied
BF	Not applicable	Pathogens, hardness, ammonium, nitrate (organic micropollutants)	Disinfection, lime softening, aeration, coagulation, sedimentation, Rapid sand filtration
Artificial recharge	Sedimentation, sand filtration	Iron, manganese, fluoride and arsenic in local groundwater (of geogenic origin)	Disinfection, aeration + sand filtration, several adsorption and coagulation-based systems for treatment of specific contaminants like arsenic and fluoride

12.2 PRE- AND POST-TREATMENT OF BF AND MAR IN INDIA: PRESENT STATUS

12.2.1 Present status of post-treatment of BF in India

BF (river or lake) has been utilized as a technology for water abstraction and treatment in some water supply systems in India. Very often wells are constructed on the riverbank as an intake to facilitate water collection from the rivers with varying water depth and quality. Table 12.2 summarizes the main water quality concerns and post-treatment applied at some selected sites in India (based on literature review and field data collection).

At some other BF sites investigated in 2013 and 2014 in the states of Andhra Pradesh and Jharkhand as part of the Saph Pani project, the BF wells are of a radial collector design and are located within the riverbed (Chapter 2, Table 2.1 and Saph Pani D1.4, 2014). Due to the relatively shallow depth (3–6 m) of the radial collector pipes and consequently short travel time of the filtrate especially during monsoon, a breakthrough of pathogens and turbidity can occur. Thus, at all these sites the abstracted filtrate is post-treated by aeration, flocculation, rapid sand filtration and finally disinfection. Although an elaborate post-treatment is applied at these sites, the existing BF schemes are in some areas the only viable means of obtaining water compared to direct surface water or even groundwater. Thus, BF buffers the quantity of water required through bank-/bed-storage and can thus be considered as an element of MAR and integrated water resources management (Sandhu *et al.*, 2015).

Post-treatment at BF case study sites

Detailed descriptions of the Saph Pani Project BF case study sites as well as results of the water quality analysis from different sampling campaigns during the project are included in the previous chapters. This section summarizes the post-treatment aspects of these case study sites.

Haridwar: The BF system in Haridwar (Uttarakhand) consists of 22 bottom-entry caisson wells located at varying distances between 4 and >490 m, along the Ganga River and the Upper Ganga Canal, which accounts for at least two-thirds of the total drinking water production for the city of Haridwar. Additionally, groundwater is abstracted using 56 vertical wells from the deeper confined aquifer to meet the water demand of the city. Post-treatment at the case study site Haridwar is limited to disinfection of the water abstracted from the production wells by using sodium hypochlorite. Each production well (caisson well or tube well) has its own sodium hypochlorite dosing system/pump. Adequate stock of 12.5% sodium hypochlorite solution (for 2–3 weeks) is maintained at each production well or dosing point. The operators are provided with a dosing chart/table for estimating the pumping rate of the hypochlorite dosing pump depending on the capacity of the well or size of the reservoir. Sodium hypochlorite is injected (using a dosing pump) directly into the distribution pipeline immediately after the abstraction pump (see Figure 12.1). However, when the disinfectant dosing pumps are defunct or non-existent, sodium hypochlorite is poured manually directly into the caisson wells or into water storage tanks/reservoirs.

Srinagar: Srinagar (in Uttarakhand) is located on the south bank of the meandering Alaknanda River. The combined drinking water production for Srinagar and the town of Pauri (the water for which is abstracted and treated in Srinagar before being pumped 29 km to Pauri) was around 3,750 m^3/d in 2010 while the demand was estimated as 4,880 m^3/d (Kimothi *et al.*, 2012). More than 80% of the total raw water for the drinking water supply of Srinagar and Pauri is abstracted upstream of the town directly from the Alaknanda River. The abstracted surface water is first coagulated with alum and then flows to sedimentation tanks followed by rapid sand filters and is finally chlorinated before being supplied to the distribution network. In May 2010, one river bank filtrate well was constructed in the South-West part of the town, which abstracts 852 – 937 m^3/d of water, depending upon the operating hours of the well, to supplement the existing surface water supply (Kimothi *et al.*, 2012). The well is located 170 m from the riverbank and was drilled down to a depth of 18 m. After abstraction of water from the production well and on-site disinfection using sodium hypochlorite, the water is pumped into a storage reservoir where it is mixed with the conventionally treated surface water and then supplied into the distribution network by gravity. Water quality investigations of the production well up to September 2012 have shown that the nitrate concentration was in the range of 53–123 mg/L, with a mean concentration of 86 mg/L, in the abstracted water (see Chapter 2). Although the mean hardness concentration monitored was 439 mg/L as calcium carbonate ($CaCO_3$), in the absence of an alternative drinking water source it is still within the permissible limit of 600 mg/L (Bureau of Indian Standards (BIS) 10500, 2012). Thus the main parameters of concern for post-treatment are the occasional presence of coliforms in very low numbers (prior to disinfection), and high nitrate concentrations (>45 mg/L; BIS 10500, 2012) in the abstracted water.

Table 12.2 Summary of the post-treatment applied in selected BF systems in India.

BF Site	Source of Water for BF	Main Water Quality Concern after BF	Post-Treatment Applied	References
Haridwar (Uttarakhand)	Ganga River and Upper Ganga Canal	Occasional presence of pathogen indicators in some wells in very low concentrations	Chlorination only	Sandhu *et al.* (2011a), Dash *et al.* (2010), Saph Pani D4.3 (2014)
Nainital (Uttarakhand)	Nainital Lake	As above and occasional hardness	Water softening and chlorination	Saph Pani D4.3 (2014), Dash *et al.* (2008)
Srinagar (Uttarakhand)	Alaknanda River	Nitrate >45 mg/L in abstracted water due to geogenic origin	Chlorination of river bank filtrate water and subsequent mixing with conventionally treated surface water (coagulation-sedimentation-filtration-chlorination)	Saph Pani D4.3 (2014)
Satpuli (Uttarakhand)	East Nayar	Occasional presence of pathogen indicators in very low concentrations	Chlorination only	Ronghang *et al.* (2012), Chapter 2
Mathura (Uttar Pradesh)	Yamuna River	Organic matter (Dissolved organic carbon) Hardness; Pathogens; Arsenic; Organic micropollutants (OMPs)	Aeration- filtration-chlorination	Singh *et al.* (2010), Kumar *et al.* (2012), Saph Pani D1.4 (2014)
Patna (Bihar)	Ganga River	Occasional presence of pathogen indicators in some wells in very low concentrations	Chlorination only	Sandhu *et al.* (2011a & b)
Ahmedabad (Gujarat)	Sabarmati River	Pathogens; Organic matter	(i-a) SW abstraction in monsoon: Chlorination (2 times)-filtration-chlorination (i-b) Abstraction from river bank filtrate wells is discontinued when breakthrough of turbidity is high (ii) Non-monsoon: Chlorination (of bank filtrate) only	Sandhu *et al.* (2011a), Saph Pani D1.4 (2014)
Medinipur (West Bengal)	Kangsabati River		Chlorination only	Sandhu *et al.* (2011a)
Muzaffar Nagar (Uttar Pradesh)	Kali River	Pathogens	Chlorination only	Thakur *et al.* (2009)
Delhi – Palla (National Capital Territory)	Yamuna River	Iron, manganese, fluoride (present in deeper aquifer) Pathogens during monsoon	Chlorination only	Sprenger *et al.* (2008), Lorenzen *et al.* (2010)

Figure 12.1 Typical sodium hypochlorite dosing system for RBF wells in Haridwar.

Nainital: Uttarakhand Jal Sansthan (Government of Uttarakhand) utilizes water from the Naintal Lake employing BF technology to supply water to the city of Nainital. Disinfection using bleaching powder is the main post-treatment step in Nainital. The operators are provided with a chart/table for estimating the amount of bleaching powder to be added per day. There are standard size tanks for feeding bleaching powder and the prepared solution which is dosed by a hydraulic method with an overflow weir (without a pump). 2 kg of bleaching powder is added every hour to a 2,000 L tank to obtain a bleaching powder concentration of 2 mg/L. With 25% chlorine content in the bleaching powder, the estimated chlorine at the initial stage is 0.5 mg/L. Bleaching powder is dosed at 5 locations in the water supply system, namely in the (i) Main pump house, (ii) Children park pump house, (iii) Phasi gadera, (iv) Sukhatal tube well and (v) Sukhatal old water works. After bleaching powder solution dosing, the residual chlorine content in the reservoirs (before supplying water to the distribution system) is not measured. However, samples are taken from different points in the distribution system to monitor residual chlorine concentrations. There is an ion-exchange system for water softening at Mallital pumping station (near the Children Park) where about half of the total production at this site is treated and then the two streams are mixed again before disinfection and supply (see Figure 12.2). It was reported by the operators that the ion exchange system is not in operation regularly because of the high costs. A new ion-exchange treatment system for hardness removal is under construction (near the main pump house) under an Asian Development Bank project.

Delhi: Previous studies at the BF case study site located on the East bank of the Yamuna River in East Delhi opposite the Nizamuddin area on the West bank of the river (Chapter 1, Figure 1.4) as well as sampling campaigns during Saph Pani have shown that presence of elevated levels of ammonium, nitrate, arsenic, fluoride, iron and manganese are the main water quality concerns for wells in the area. Furthermore, source water samples (Yamuna river) also showed the presence of some organic micropollutants (OMPs) in significantly high concentrations compared to other BF sites, which are, however, substantially removed during the soil passage. Traces of some OMPs were also found in samples from observation wells and hand pumps. Very low concentrations of some OMPs were found in the production wells compared to significantly higher concentrations in the river water (Saph Pani D1.4, 2014).

The water abstracted from the production wells (radial collector wells) around this site is mixed with the surface water from other sources and treated extensively at full-scale water treatment plants (e.g. Okhla and Common Wealth Games water treatment plants). No major water quality problems are expected. People using hand pumps or tube wells in this area are, however, advised to use household level ammonium, nitrate, arsenic and fluoride removal systems to ensure that water from these local wells are meeting the drinking water quality requirements. Furthermore, water authorities using production wells around the case study sites for municipal water supply are advised to monitor the presence of OMPs in the well waters and in the treated water, to ensure that these pollutants are sufficiently removed during the treatment process.

Table 12.2 clearly shows that removal of pathogens, hardness, and organic matter are the key elements of post-treatment systems for bank filtrates in India. Furthermore, as the rivers/lakes in India are often polluted with untreated or poorly treated sewage and industrial wastes, the presence of bulk organic matter and micropollutants could be one of the main requirements of post treatment systems. Limited information is available on the concentrations of OMPs in the raw water and filtrates at the BF sites in India. Nevertheless, a snap-shot screening of dissolved organic carbon and 54 OMP compounds (of environmental relevance in Europe) in surface water and BF well water was conducted for the Saph Pani project BF case study sites and some other existing and potential BF sites in the states of Bihar, Jharkhand, Andhra Pradesh, Madhya Pradesh, Gujarat and the city of Jammu in the state of Jammu and Kashmir during the dry pre-monsoon season in May-June 2014 and during the monsoon in June-July 2013 (Saph Pani D1.4, 2014). In this context, of all the investigated sites, it was found that the stretch of the Yamuna River starting in Central Delhi (ITO Bridge) up to ~200 km downstream of Agra had the highest occurrence and also the near highest concentrations of OMPs comprising pharmaceutical, medical contrast media, personal care products, corrosion inhibitors, insecticide and herbicide compounds. The removal efficiency of OMPs by BF can be demonstrated by taking the Mathura BF site as an example where the Yamuna River has comparably higher concentrations of OMPs than Delhi and Agra. Consequently, the concentrations of some OMPs in the BF well's (Radial collector, fast travel time) water were 13–99% lower than in river water, whereas others were not present in well water (Saph Pani D1.4, 2014). On the other hand, in the surface water in Haridwar, Srinagar and Nainital in Uttarakhand and in Gumla, Ray Bazaar and Daltonganj in Jharkhand most of the 54 OMPs were either not present at all or only detectable in very low concentrations (for a few types OMPs) (Chapter 2, Table 2.1; Sandhu *et al.*, 2015). None were detectable in the BF wells at these sites. Another potential source of contamination is the dissolution of iron, manganese, arsenic or fluoride from the aquifer due to low, dissolved oxygen in river water and/or anoxic conditions created by the infiltrating river or lake water.

Figure 12.2 Ion-exchange water softening system treating bank filtrate at Nainital.

At a majority of the BF sites at perennial surface water bodies (snow-melt and spring-fed) in India's hilly or foothill regions chlorination is the only treatment applied (Chapter 2, Table 2.1; Sandhu *et al.*, 2015). In BF wells of radial collector design constructed within the riverbeds of very polluted rivers with fast travel times (e.g. Yamuna River in Mathura), relatively high concentrations of natural organic matter in (river) bank filtrates is usually found. Because of this formation of trihalogenmethanes or other disinfection by-products is another major water quality concern (Kumar *et al.*, 2012). In summary, depending on the raw water quality (of rivers or lakes), local hydrogeological conditions and the contaminant removal efficiency at a particular site, the post-treatment of filtrates of the BF sites in India would require improvement of one or more of the following group of parameters:

- Pathogens
- Hardness
- Iron, manganese, ammonium, nitrate, arsenic and fluoride
- Bulk organics and OMPs.

12.2.2 Present status of pre- and post-treatment of MAR systems in India

India has a long tradition in water harvesting and artificial recharge. A variety of ARR structures are used either in connection with rooftop rainwater harvesting (RWH) or with normal surface run-off. The structures used for MAR are recharge pits, open wells, Aquifer storage and recovery wells, injection wells, gravity wells, recharge shaft and tube wells (Shivkumar, 2006; Holländer *et al.*, 2009).

MAR systems in India are mainly designed for and constructed toward using rainwater or flood water for groundwater augmentation and therefore pre-treatment is mostly limited to sedimentation basins and sand filters to avoid clogging and to maintain the infiltration rate. Pre-treatment, if any, often forms a part of the recharge structure. Consequently, clogging is widely encountered in a majority of the MAR systems. Identified pre-treatment methods for surface run-off are sedimentation, sand filters, wrapped polyvinyl chloride (PVC) pipes and metallic filters:

- *Sedimentation*: A trapezoidal shaped grassed water way of 40 m length and 0.63 m depth was used to store excess water and to increase the sedimentation by reducing the flow velocity in the Balasore district (Holländer *et al.*, 2009).
- PVC pipes of 20 cm diameter with slots (3 mm × 75 mm) used in recharging water at Sirsa branch canal. These slots were wrapped with the coconut coir to prevent the entry of suspended solids. An annular space between the bore hole and the pipe was filled with gravel of 9 mm to 12 mm in diameter (Kaledhonkar *et al.*, 2003).
- Sand filtration is a common pre-treatment method in many of the rooftop RWH schemes. In RV College of Engineering Bangalore, at the bottom of a gravity recharge settling tank a sand bed for a depth of 150 mm and stone aggregate for a depth of 200 mm were filled as filter media (Shivakumar, 2006).
- Kanhe and Bhole (2006) used metallic filters made up of copper were used as filter media.

In cases where rainwater is used for recharge, differences in the rainwater chemistry can be observed between rural and urban areas. Sulphate, sea salt (i.e. sodium, chloride) and ammonium are present in higher concentrations in urban regions than in rural areas. Microbial concentration was also found to be much higher in water from roof top for urban areas. In RWH and recharging systems, elimination of the first flush from the roof tops is a common practice to minimize negative impacts on source water quality (Vasudevan & Tandon, 2006; Shivkumar, 2006). The aim of this method is to remove the first rain with lots of impurities from the interaction between atmosphere and also from the dirty roof tops. There is an inbuilt filter system in most of the rooftop harvesting systems practiced in India. This is fixed immediately after the first flush separator and acts as a primary treatment method.

Reuse of treated wastewater to recharge groundwater is not a common practice in India. Considering the high potential of this method as a future option, several pilot studies on this topic are in progress. In the case of wastewater effluent recharge systems, pre-treatment may be preliminary with settling and aeration or secondary treatment including physical, chemical and biological process. Jamwal and Mittal (2010) reported a primary and secondary treatment for the sewages from Delhi city. They used the activated sludge process as the major primary treatment step together with an oxidation pond for a selected sewage treatment plants. As secondary treatment a fluidized bed, BIOFORE (i.e. aerobic or anaerobic biological reactors) was used for bacteriological removal.

The results of the pre-treatment structures used in the 8 investigated case studies (literature-based) are presented in Table 12.3. Analysis of MAR systems studied revealed that a high percentage (38%) of the recovered water was used for drinking purposes. Among the other uses, 37% were used for irrigation and 25% were used for other domestic purposes. It should be noted that all the harvested rooftop rainwater is used for the either drinking or domestic purpose after MAR. Still, no post-treatment was mentioned.

Table 12.3 Pre-treatment in selected MAR systems in India (based on 8 case studies).

Location and Reference	Structures	Pre-Treatment	Use of Effluent
Ranga Reddy district, Hyderabad (Dwarakanath, 2006)	Rooftop rainwater harvesting (RWH), Recharge pit with boulders and sand	Boulder and sandy filter in recharge pit	Drinking water
Osmania University Campus, Hyderabad (Dwarakanath, 2006)	Rooftop RWH, Infiltration with 5 pits and 5 recharge wells	Sand and metal filters	Domestic
Padmavathi Nagar, Chennai (Jebamalar & Ravikumar, 2006)	Rooftop RWH connected to open wells	Filter, possibly sand filter	Drinking water
Balasore district (Holländer *et al.*, 2009)	Aquifer storage and recovery-wells, channels for catchment	Sedimentation and desilting Filter	Irrigation
RV College of Engineering Campus, Bangalore (Shivakumar, 2006)	Rooftop RWH to gravity injection well	Two settling tanks with sand bed and stone aggregate as a filter	Drinking water
Dhuri Drain, Punjab (Chadha, 2003)	Vertical Shafts and Injection Wells	Sand and gravel pack as filter	Not specified, presumably used for irrigation
Sirsa branch canal (Kaledhonkar *et al.*, 2003)	Two recharge tube wells	Filter pit and coconut coir wrapped on the slotted PVC pipe	Presumably for irrigation
CSV, Wardha, Maharashtra (Kanhe & Bole, 2006)	RWH tank bore well, dug well, soak pit	Ground filters and metallic filters	Mainly for domestic purposes

Groundwater is considered as safe drinking water source in many parts of India. Often people use untreated or inappropriately treated groundwater for drinking. The major water quality issues identified in groundwater in India are elevated concentrations of salinity, iron, fluoride, arsenic and nitrate. The treatment of fluoride deserves special attention due to its hazardous effects on human health. In general, rainwater recharge (normally acidic to neutral pH) will dilute the fluoride-rich water and reduce the concentration. However, this depends entirely on the chemical composition of the source water. In Maheswaram, both rain water and surface run-off contribute to the total recharge. In case the acidic pH of rainwater changes to alkaline during the interaction with the aquifer, the fluoride from the source rock will be mobilized. Moreover, the sodium:calcium ratio in the study area is higher than 1, which also an important factor in elevating the fluoride concentration. A possible treatment method would be to elevate the calcium concentration to a higher level than sodium in the source water, so that the fluoride will precipitate as calcium fluoride (CaF_2) and reduce the fluoride in groundwater.

Pre- and post-treatment needs at MAR case study sites

Details of the Saph Pani MAR case study sites, groundwater quality data and their suitability for drinking water supply and irrigation as well as treatment requirements are included in previous chapters and presented in detail in Saph Pani D4.1 (2013). Summaries of the pre- and post-treatment needs at selected sites are presented in the following paragraphs.

Chennai: Salinity and high magnesium concentrations are the major quality problems when using Chennai groundwater for drinking purposes. Concentrations of sulphate and nitrate exceeded the guideline value in 20% of the wells, raising problems for use as drinking water. This suggests that the groundwater needs pre-or post-treatment in terms of these parameters prior to distribution, although widespread implementation of MAR structures might improve this problem. As in Raipur, the microbial quality is not monitored. If needed, chlorination is a cheap and effective post-treatment option to eliminate microbial contamination. In the case of irrigation suitability, salinity and total dissolved solids are relatively high in a few samples. High magnesium levels/concentrations are observed in the majority of the samples (80%) in terms of MAR. Although data on turbidity in the source water is lacking, experience from Anna University shows that reduction of suspended solids improves infiltration rates. A pilot study conducted at Anna University, Chennai using SAT showed high removal efficiency for nitrate (up to 98%) after 15 cycles (Deepa & Krishnaveni, 2012) under reducing conditions. Under these conditions SAT can be a cost-efficient treatment method for the removal of nitrate, which is encountered in few locations in the study area.

Groundwater samples were taken from two dug-cum bore wells and four deep bore wells around the Periapalayam Check Dam area (Chennai). A relatively high number of pathogen indicators are the main water quality concern for water from wells. Surface water stored by the check dam had very high turbidity and a high a number of pathogens due to the collection of run-off from various land uses. It is likely that these contaminants were not sufficiently removed during soil passage. It is recommended that people using water from these wells should employ household-level, low-cost disinfection methods like boiling, chlorine tablets or chlorine solutions, solar disinfection, ceramic filters or bio-sand filters to ensure that the water is microbiologically safe to drink and meets the drinking water quality requirements.

Maheswaram: The available data shows that, in general, most of the water quality parameters of the groundwater are suitable for drinking purposes. However, a few parameters, like calcium and magnesium, were high at certain times. At the watershed scale the major health hazard is due to the year-round high fluoride concentration. This situation is not an isolated one as high levels of fluoride are reported from 16 of 28 states (Mariappan *et al.*, 2000), and are encountered particularly in granitic terrains in southern India. So these three contaminants (calcium, magnesium and fluoride) need to be treated after recovery. Among the numerous methods developed, lime softening is the most common and cheapest treatment method for fluoride-enriched groundwater (Crittenden *et al.*, 2005). Coagulation and precipitation and activated alumina are also used in certain regions depending on the cost and geological conditions (Meenakshi & Maheshwari, 2006). With respect to irrigation, the low salinity values show that the high KI and Na% can be discarded and no post-treatment of any kind is needed. Furthermore, as clay deposits in the tanks used for irrigation are reported, it is recommended to remove suspended solids present in the source water. There is no information about the microbial quality of the well water used for small-scale (household level) applications and irrigation. Microbial quality of the well water must be monitored and sufficient disinfection needs to be provided if necessary.

Raipur: In general and also for the parameters investigated, groundwater quality is suitable for drinking purposes except for a few samples which showed concentrations of sodium, chloride, nitrate, iron and manganese exceeding the guideline values. The study of Groeschke (2012) shows that nitrate, iron and manganese present in water probably need post-treatment before distributing the water through the public water supply system. Based on the experience at other sites in India, pre-treatment is required to remove suspended solids so as to improve the efficiency of infiltration. Also, disinfection of the recovered water will most probably be necessary before it can be distributed as drinking water.

12.3 PRE- AND POST-TREATMENT OF BF AND MAR IN INDIA IN THE FUTURE

Some of the future scenarios or global change pressures like (i) population increase and urbanization, (ii) climate change, (iii) emerging contaminants, (iv) energy crisis and (v) increasing environmental awareness and stricter regulations are likely to affect the performance of natural systems for water and water treatment as these factors have direct and indirect impact on the quantity and quality of different types of water (TECHNEAU, 2007; Lozàn *et al.*, 2007; Cooley *et al.*, 2013). Effects of these influencing factors on the performance of NTSs in India and requirements for pre- and post-treatment systems were studied in detail under the Saph Pani project (Saph Pani D4.3, 2014) which are summarized in the following sub-sections.

12.3.1 Post-treatment requirements for BF sites in India in the future

Inferences about the potential impact of future scenarios on pre- and post-treatment systems for BF systems in India can be drawn from various plausible sources/scenarios as well as from published literature on BF and climate change (Schoenheinz, 2004; Schoenheinz & Grischek, 2011; Sprenger *et al.*, 2011). The impact of future scenarios or influencing factors on the quantity and quality of water, the consequent impact on BF systems and the coping strategies as well as potential post-treatment requirements for BF sites in India are described in Table 12.4. It is clear from Table 12.4 that proper care should be taken in the planning and design of BF system (protection zones, well placement, construction of wells, flood proofing) and higher levels of post-treatment (including robust disinfection and specific treatment for emerging contaminants) will be required in the future, which is very much site specific.

12.3.2 Pre- and post-treatment requirements for MAR sites in India in the future

Environmental and socioeconomic developments such as increasing population, rapid urbanization and industrialization, along with climate change are important issues in the world's developing and newly industrialized countries. It is expected that these factors affect quality and quantity of water resources, thus directly or indirectly affecting MAR systems. Table 12.5 summarizes the possible impacts of population growth and urbanization on MAR systems and coping strategies including pre- and post-treatment requirements.

Table 12.4 Future scenarios and post-treatment requirements for BF in India.

Influencing Factors (Future Scenarios)	Effect on Water Quality	Effect on Water Quantity	Impact on BF	Coping Strategies
Population increase:				
Increased water demand for different uses Urbanization	– May increase pollution in river and wells – Clogging of riverbeds by organic matter and gas bubble formation	– May cause lower groundwater levels and surface recharge	– Limit on water abstraction from a single well	– Constructing more wells along the river Ensuring construction of well head & source protection zones
Climate change factors:				
Increase in average temperature	– Increased mineralization and dissolution; lower oxygen concentration may cause anoxic conditions	– Little higher portion of bank filtrate due to lower water viscosity may be compensated by higher clogging of riverbeds	– Floods may increase the portion of bank filtrate in the well; droughts may decrease the portion of bank filtrate and thus may cause water quality changes	– Construct wells closer to river – Adapt well operation
Increased flooding	– Pathogen breakthrough; Increasing dilution but higher input of pollutants from surface run-off	– Higher abstraction rates possible		– Flood-proofing of wells – Ensuring sufficient disinfection
Increased drought	– High mineralization and increase in contaminant concentrations due to lesser dilution	– Lower abstraction rates		– Construct wells closer to river – Intensify monitoring of well water quality
Variable precipitation patterns	– Fluctuating water quality	– May be variable		– Real-time water quality monitoring – Installing multiple wells at varying distances and switching operations of the wells as per the conditions
Emerging contaminants:				
Deteriorating source water quality (increasing pollution)	– Long-term deterioration will cause delayed deterioration of well water quality	– May not change	– Increasing removal rates but higher absolute concentrations, additional post-treatment measures may be required	– Increase travel time/distance of well to river – Additional post-treatment units according to the type of pollutant

The predicted population increase from 1.21 billion (2011) to 1.6 billion (2050) in India is likely to have severe effects on the already stressed water resources. The impacts of population growth on MAR could be increased sewage production, combined with probable groundwater over-exploitation, increased use of fertilizers etc. A total of 32% increase in water use is estimated for 2050 (Amarasinghe *et al.*, 2007). Higher total suspended solids (TSS) in source water from sewages may result in clogging of MAR systems. This may be addressed by installing sedimentation and sand filtration as additional pre-treatment. Higher salinity due to over-exploitation may be treated with reverse osmosis (RO). Increased use of fertilizers and improper sanitation facilities may result in elevated nitrogen in surface water. This can be treated by RO, ion exchange, and biological denitrification.

Table 12.5 Possible impacts of population growth and industries/urbanization on MAR.

Influencing Factors	Effect on Water Quality	Effect on Water Quantity	Impacts on MAR	Coping Strategies (Additional Pre- and Post-Treatment Required)
Population growth – Projected population in the year 2050:1.3 to 1.6 billion (PRB, 2007) – Increasing water demand (680 to 900[a] billion m^3) (Amarasinghe *et al.*, 2007; KPMG, 2010)	– Increasing sewage volume in Class I cities and Class II towns from 2003 to 2051: 26,254 to 83,300 MLD (Bhardwaj, 2005) – At the coastline groundwater over-exploitation and subsequent seawater intrusion – Inadequate sanitation systems cause increase in nutrients and pathogens in water – Algal growth due to nutrients	– Increasing pressure on water resources – Increasing water demand	– Higher sewage load makes surface water unfit for MAR – Higher sewage load may cause clogging and deterioration of recovered water's quality in MAR systems. Therefore pre-treatment becomes necessary – Anoxic condition through high organic carbon	– Reducing sewage load on water bodies by providing proper wastewater treatment systems – Sedimentation and sand filtration for total suspended solids (TSS) removal (pre-treatment) – Reverse Osmosis (RO) for salinity removal – Nitrate: RO, Ion exchange, biological denitrification etc. – Iron and manganese: Aeration and sand filtration
– Increasing industrialization,[b] urbanization[c] and intensification of agriculture: – Increasing pollution; deteriorating source water quality (emerging pollutants)	– Increased industrial effluents – Pollution from fertilizers and pesticides: (Pesticides levels of 13 μg/L against permissible limit of 1 μg/L were reported from the Ganga basin. Major threats were DDT and HCH (GRBMP, 2011), organochlorine pesticides higher than 1 μg/L observed in Delhi (Mutiyar *et al.*, 2011) – Higher CO_2 emission and acidic rainfall – Personal care products, pharmaceuticals, steroids and hormones and plasticizes levels will also increase in the future	– Stressed water resources	– Persistent pollutants (pesticides, PhACs, PCPs) may break through – Increased sulphur and nitrogen dioxides in the atmosphere may result in acidic rainfall. This lead to various hydrogeochemical reactions and subsequent source water contamination in the aquifer – Higher ammonium levels (>0.2 mg/L) in rain were reported from Ahmedabad (Rastogi and Sarin, 2005) – Source water rich in sodium (from industries) may trigger the release of geogenic contaminants such as fluoride and increase their concentration.	– Strict regulation on effluent disposal to maintain water quality of river and lakes – Along with the conventional treatment methods like activated carbon, oxidation-filtration or membrane filtration, process such as nanofiltration and reverse osmosis as post-treatment may be needed to remove the persistent compounds – Apart from first flush and metallic filters, activated carbon filters and biofilms may be implemented to remove ammonium. – pH regulation using Na_2CO_3, NaOH, $CaCO_3$ and $MgCO_3$ – Fluoride: electrocoagulation, ion exchange or membrane filtration as post-treatment

[a]forecasted to 2050; [b]Average industrial growth is reported as 8% per annum during 2007–2012 (Kaushal, 2012; PCI, 2012); [c]An average of 2% growth during past 3 decades (IUSSP, 2009).

The major impacts of urbanization and industrial growth were identified as increasing industrial effluents, higher sulphur dioxide and nitrogen dioxide emissions that may result in acid rain, increased use of pesticides and personal care products as well as an increase of other organic pollutants. For the emerging pollutants additional pre/post-treatment such as activated carbon, oxidation-filtration or membrane process such as nanofiltration (NF) and RO were suggested. For higher ammonium concentrations in rainwater, activated carbon filters may be used. In case of higher fluoride concentrations, electro-coagulation, ion exchange or membrane filtration may be adopted.

Different climate change scenarios were investigated based on scenarios of increasing average temperatures, floods and droughts. Table 12.6 summarizes the possible impacts of climate change scenarios on MAR systems.

Table 12.6 Possible impacts of climate change scenarios on MAR systems.

Influencing Factors	**Possible Impacts on Source Water**		**Impacts on MAR (Relies Mostly on SW)**	**Coping Strategies (Additional Pre- and Post-Treatment Required)**
Climate Change	**Surface Water (SW)**	**Groundwater**		
Temperature increase IPCC (2007) predicted 6 scenarios to 2090–2099 A1FI: 4°C A1T: 2.4°C A1B: 2.8°C A2: 3.4°C B1: 1.8°C B2: 2.4°C	– Increased evaporation – Decreased O_2 solubility in water – Increased algal and phytoplankton growth – Increased dissolved organic carbon (DOC) – Accelerated microbial regrowth in distribution systems (Zwolsman, 2008)	– Impact of temperature may not be so immediate in groundwater and surface water – Increased vegetation growth → CO_2 in the soil → groundwater may dissolve more calcium carbonate ($CaCO_3$) – Decreased viscosity and increased flow velocity	– Evaporation loss and concentration of salts – Higher temperature may result in anoxic conditions during underground passage which may result in the mobilization of redox sensitive species including Iron, Manganese and Arsenic	– Fluoride: Electro-coagulation, ion exchange or membrane filtration – Algal toxins: Activated carbon – Taste and odour: Oxidation, adsorption – Iron, manganese, arsenic: Aeration, Slow sand filtration – Salinity: Reverse Osmosis (RO) – Hardness: Ion Exchange
Flooding	– Surface run-off and inundation may mobilize point and non-point contaminants – Increase of total suspended solids (TSS) in flood water (Kale and Hire, 2004) – Increased river discharge and inundation	– Increased groundwater recharge – Possible introduction of contaminants by increased groundwater recharge	– Physical damage of the MAR structures – Frequent clogging of MAR structures by TSS and subsequent maintenance of CD, and CW	– TSS: Sedimentation, sand filtration – Heavy metals: Chemical precipitation, ion exchange, phytoremediation, biological treatment etc. – Pathogens: Chlorination, UV treatment or ozonation
Droughts	– Reduced/no discharge and reduced dilution potential – Algal blooms (TECHNEAU, 2009) – Increase in phosphate, pathogens and organic micropollutants (TECHNEAU, 2009; Hrdinka *et al.*, 2012) – Increasing concentration of salts due to reduced stream flow	– Reduced/no groundwater recharge Symbol Std declining water table – Lowering of freshwater table may cause intrusion of saltwater from the sea or inland salt lakes	– Complete/partial failure of the MAR due to lack of surface water – Increasing salinity	– Sulphate: Nanofiltration, ion exchange – Salinity: RO

Temperature has a gradual but continuous effect on water quality and quantity in terms of increased rates of algal growth, evaporation and concentration of salts, a change in the hydrological cycle and triggering of biogeochemical processes. For MAR, an increase in temperature may result in anoxic conditions during subsurface passage which may result in the mobilization of redox sensitive species like nitrate, manganese, iron oxide, hydroxide and sulphate. Loss of water by evaporation is an issue for MAR structures with large open surfaces (e.g. check dams and infiltration ponds). The pre-/post-treatment needs of water under increasing temperature are: (i) fluoride: with electro-coagulation, ion exchange or membrane filtration; (ii) algal toxins: with activated carbon, (iii) taste and odour: with oxidation and adsorption, (iv) iron, manganese and arsenic: with aeration + filtration, (v) salinity: with RO, and (vi) hardness: with lime softening or ion exchange.

If conditions are suitable flooding may increase groundwater recharge. However, uncontrolled flooding causes groundwater contamination through interaction with contaminant sources like agricultural fields, industrial and urban wastes. Increase of TSS loads in the groundwater is the most common problem anticipated. Higher TSS levels may cause clogging in NTS. In groundwater the flow length and/or travel times may be reduced and may affect the treatment efficiency. Physical damage of the MAR structures is also possible. TSS may also act as carriers for the heavy metals that potentially need treatment. Sedimentation tanks and Slow sand filters can be adopted to avoid higher TSS level.

Droughts reduce the discharge and dilution potential of the surface water which may cause more frequent algal blooms. Point source pollution and irrigation return flows are expected. Groundwater recharge will be reduced, decreasing freshwater flow which may result in saline intrusions. Lowering of water tables and subsequent atmospheric exposure may favour oxidation of sulphate minerals. Droughts may result in the failure of MAR structures. The potential coping strategies may be the treatment of sulphate with NF and ion exchange and salinity with RO.

MAR systems are generally robust, and flexible in regards to changing conditions. Failure to achieve required water quality objectives can be met by additional pre-or post-treatment.

12.4 CONCLUSIONS AND RECOMMENDATIONS

BF is being used in India for abstraction of water from rivers or lakes. However, traditionally these systems were designed mainly to improve the production of water from the quantitative perspective and did not aim to improve the water quality. In other words BF systems were not fully considered as a part of "water treatment systems". In India, chlorination is practiced at all the BF sites, whereas hardness, iron and manganese removal is also required at some sites. Nainital is the only place where hardness removal is practiced as a post-treatment of bank filtrate. At Mathura and some sites in Andhra Pradesh and Jharkhand, bank filtrate is aerated and filtered before chlorination. Limited data is available on the quality of bank filtrates and post-treatment being carried out at different BF sites in India.

In general, pathogens, hardness, iron and manganese, ammonium, bulk organic matter and OMPs (specifically in case of rivers with direct impact of wastewater and for future water quality considerations) are some of the critical water quality parameters of concern in India. There is a relatively high concentration of organic matter in some of the bank filtrates from wells with short travel times located at very polluted surface water bodies in India and chlorination is the only treatment applied. Because of this, formation of disinfection by-products is the main quality concern. Limited information is available on the concentrations of OMPs in the raw water and filtrates at the BF sites in India.

To date the majority of the MAR systems in India are designed and constructed with the aim of using rainwater or flood water for groundwater augmentation. Data available in the literature on pre- or post-treatment of MAR systems in India is scarce and covers systems that are mainly linked to rooftop RWH and few surface run-off recharge systems only. Pre-treatment is mostly limited to sedimentation basins and sand filters to avoid clogging and to maintain the infiltration rate. Pre-treatment, if any, often forms a part of the recharge structure.

The parameters that need treatment are high amounts of suspended materials and turbidity along with elevated fluoride and nitrate concentrations in certain locations. The water quality problems found in the literature on groundwater treatment in India (salinity, fluoride, nitrate, iron, manganese and pathogens) – which may indicate necessary post-treatment – are similar to those that have been encountered in the Saph Pani case study sites.

It was observed that in many of the RWH systems elimination of the first flush is used as pre-treatment. Pre-treatment is necessary during the monsoon season to remove TSS and turbidity in water collected as surface run-off. Sedimentation and sand filters are found to be the most suitable low cost treatment options for TSS and turbidity removal in MAR systems. Descriptions were found in the literature on using filters made up of metals and coir (coconut fibre) as pre-treatment for small scale systems. An alternative would be to remove the clogging mechanically at regular intervals. It is recommended to perform a cost analysis to select the viable one among the two options.

Analysis of the data obtained from the Saph Pani field sites showed that post-treatment is necessary to meet the guidelines for drinking water. Low salinity in all three MAR locations (except few wells in Chennai) suggests that groundwater is suitable for irrigation. The salinity in that region is mainly due to the seawater intrusion and it is expected to be pushed back after the implementation of MAR structures. Microbial quality of the groundwater has not been assessed in these cases. However, the most common disinfection method, chlorination, will probably be applicable here as well. The parameters that need treatment are salinity, magnesium hardness, iron, manganese, nitrate and fluoride.

It was found that BF systems in the northern part of India, specifically at Saph Pani project case study sites in Uttarakhand, where there are relatively clean rivers and lakes, treat water so effectively it nearly meets the quality requirements for drinking water supply. Chlorination is the only treatment necessary and applied to maintain residual chlorine in the distribution system. Some additional chlorination may be required for control of pathogenic organisms during flooding periods. However, BF systems along relatively polluted stretches of river like Yamuna (in Delhi and Mathura) will require extensive post-treatment to remove bulk organic matter as well as OMPs and some inorganic parameters. It is expected that post-treatment of BF with advanced treatment processes like ozonation, activated carbon filtration and membrane filtration will be required for such BF systems to meet the water quality guidelines. The post-treatment requirements for BF systems are likely to increase in the future unless comprehensive programmes are implemented to control of indiscriminate wastewater disposal to water bodies. Construction of wells at optimum distance from the river, increasing the number of wells as well as flood proofing the wells and event-adapted operation of well schemes are some of the coping strategies for the design of BF systems to meet future challenges with respect to quantity and quality of water.

Pre-treatment of MAR systems requirements will be more critical in the future if the quality of the rain or storm water changes significantly and if wastewater treatment plant effluents are used for MAR. Secondly, the direct and planned abstraction of recharged water after MAR for municipal and industrial uses is not practiced. Therefore, post-treatment requirements for MAR systems are not well known or documented. Post-treatment of "groundwater" in India is mainly limited to either disinfection to remove pathogens (in case of shallow and contaminated aquifers) or to removal of geogenic contaminants like iron, manganese, arsenic and fluoride.

The impacts of population growth on MAR could be increased sewage production, combined with probable groundwater over-exploitation, increased use of fertilizers and pesticides etc. Post-treatment methods like aeration followed by rapid sand filtration, coagulation or adsorption-based processes would be relevant for the removal of geogenic contaminants (iron, manganese, arsenic and fluoride) now and in the future due to several potential water quality impacts of global change pressures. Additional advanced post-treatment options would be required in the future to treat water contaminated with organics, nutrients and micropollutants from sewage pollution, fertilizers and pesticides. A potential increase in the incidences of floods and droughts in parts of India would further demand the increased use of MAR as an integrated water resources management option which will require suitable pre- and post-treatment systems.

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