Chapter 16

Application of a water quality guide to managed aquifer recharge in India

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16.1 INTRODUCTION

India is an international leader in the volume of enhanced recharge (4 km^3/year, CGWB, 2005) and the number of recharge structures employed in national, state and local level programs to help sustain groundwater storages and irrigation livelihoods. Potential recharge of 85 km^3/year of surplus run-off has been identified to augment groundwater recharge in the revised Master Plan for Artificial Recharge to Groundwater in India (CGWB, 2013).

While increasing the quantity of groundwater, artificial recharge also impacts the quality of groundwater. In many cases the recharge water is of comparable quality to water already in the aquifer. Enhancing recharge may improve the quality of groundwater, for example by freshening brackish groundwater. However, recharge may also introduce microbiological or chemical pollutants to aquifers, or mobilise minerals from the aquifer matrix, such as arsenic. Although these hazards are generally of relatively low concern for irrigation, they may potentially cause harm where groundwater is used as a drinking water supply. Hence when the same aquifer being recharged is also used as a drinking water source, it should be an obligation of those enhancing recharge to protect the health of those whose drinking water is affected by their operations.

Artificial recharge can be undertaken in such a way as to avoid these adverse effects on groundwater quality. When such control is done intentionally to protect human health and the environment this is called ‘managed aquifer recharge’ (MAR). In 2009, the Chairman of the Central Ground Water Board (CGWB) raised the opportunity to specifically account for groundwater quality protection in the Indian Guidelines for Artificial Recharge (CGWB, 2000) and Manual for Artificial Recharge of Groundwater (CGWB, 2007). This initiated a proposal to the Australian Department of Foreign Affairs and Trade (DFAT) to draw from Australia’s experience in developing risk-based guidelines for managed aquifer recharge (NRMMC-EPHC-NHMRC, 2009) and adapt this to India’s needs for groundwater protection. The revised Master Plan for Artificial Recharge to Groundwater in India (CGWB, 2013) also references the purposes and types of water quality monitoring necessary to protect groundwater quality.

The Australian MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) form part of the Australian National Water Quality Management Strategy and adopts a risk assessment and management framework consistent with World Health Organisation (WHO) Drinking Water Guidelines (WHO, 2011) and other Australian guideline documents including the Australian Drinking Water Guidelines (NHMRC-NRMMC, 2011) and Australian Guidelines for Water Recycling (NRMMC–EPHC–AHMC, 2006). However, in applying the Australian MAR Guidelines to assess risks in artificial recharge projects in India and several other countries in transition, it was found that water quality data, especially on the microbial pathogens, were not available to enable quantitative risk assessment (Dillon *et al*., 2010). Consequently, the DFAT funded project ‘A Water Quality Guide to Managed Aquifer Recharge in India’ (Dillon *et al*., 2014) combined elements of the ‘entry level assessment’ from the Australian MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) with the WHO sanitary survey approach (WHO, 2011, 2014) to produce a water safety plan commensurate with the WHO (2011) drinking water guidelines as applied to small scale systems (Davison *et al*., 2005; WHO, 2012). The guide relies only on visual observations and not on water quality sampling and analysis in order to be capable of application at village level throughout India by people with elementary training in water quality protection, without access to reliable laboratory resources.

The resulting guidance document (Dillon *et al*., 2014) aims to improve water safety based on visual observations and actions in response. It is intended to inform guidance at national level, for application and capacity building at state and local level. It aims to ensure that safety of drinking water is considered as an integral part of recharge enhancement planning and practice, and that this is integrated within water safety plans for drinking water wells accounting for natural and enhanced recharge. However, it currently has no formal status that requires compliance.

The purpose of this chapter is to document the application of the approach that was developed within the DFAT project to three recharge operations within Saph Pani;

- Bank filtration at Haridwar on the Ganga River, Uttarakhand
- Percolation tanks at Maheshwaram, Telangana, and
- Check dam near Chennai, Tamil Nadu.

For two of these sites where public drinking water supplies are potentially impacted by recharge enhancement this guidance is considered necessary to improve the safety of supplies but insufficient to assure safety. A recommended subsequent step would involve sampling and analysis of water quality for use in quantitative risk assessment for these sites.

16.1.1 Scope of the water quality guidance

Existing CGWB Guidelines for Artificial Recharge (CGWB, 2000) and Manual for Artificial Recharge of Groundwater (CGWB, 2007) provide advice on location, design and operation of groundwater replenishment projects with the current emphasis on the hydraulic performance of such systems. The current master plan for artificial recharge (CGWB, 2013) however references the need to account for water quality.

The water quality guidance for MAR (Dillon *et al*., 2014) refers to a number of existing specifications and guidelines, including the Bureau of Indian Standards (BIS) specifications for drinking water (BIS, 2012) and guidelines for the quality of irrigation water (BIS, 1986). Related guidance is available from Central Pollution Control Board (CPCB) on water quality monitoring protocols (CPCB, 2007) and on well head protection and from BIS on construction of drinking water wells. Ministry of Environment & Forests (1992) policy on pollution prevention has stimulated programs such as the CPCB's National River Conservation Plan largely focused on building sewage treatment plants, which is currently being strengthened and broadened by the Government of India. Plans to end open defecation in India on health and safety grounds are currently in development, and would also have benefits for run-off water quality.

For public drinking water supplies the WHO Guidelines (WHO, 2011) provide a comprehensive approach to managing risks to human health. This requires substantial effort for investigations, monitoring, analysis and evaluation. The Australian MAR Guidelines (NRRMC-EPHC-NHMRC, 2009) follow the same principles for risk management for public health for all types of uses of the water and a similar approach for managing environmental risks. They therefore also require substantial water quality data acquisition to support quantitative risk assessments. Based on experience reported earlier (Dillon *et al*., 2010) these approaches were unlikely to be adopted in India and many other countries in transition, due to the unavailability of the necessary data to support those assessments. In light of this, the current water quality guide for MAR in India (Dillon *et al*., 2014) provides a transitional pathway whereby basic information readily observable at an existing or proposed artificial recharge site is used to make water safer for its intended uses. In the absence of water quality data or further water treatment this approach cannot guarantee effective protection of groundwater used for drinking water supplies. However it highlights the need to consider water quality as standard practice for new and existing projects in India and other countries in transition. It may also serve as a screening tool to identify sites where more rigorous investigations are required, that would then support assessments that accord with WHO or Australian guidelines.

16.1.2 Sources of water, types of aquifers and purposes

The Indian guide to water quality in MAR is relevant to natural source waters in rural and peri-urban catchments. It is recommended not to apply this to other recharge sources, such as urban stormwater, sewage effluent, and industrial effluents that are expected to contain significantly higher contaminant loads. The current guidelines are considered applicable in unconfined alluvial aquifers. They should not be relied on for application in aquifers used as public drinking water supplies, confined aquifers (where changed reduction-oxidation status is likely) and fractured rock aquifers (where there is less exposure to sorption or net attachment sites than in primary porosity media, and contaminants may migrate over longer distances).

Hence, the proposed Indian guidelines (Dillon *et al.*, 2014) cover a more limited range of source water types, aquifer types and existing groundwater uses than the WHO (WHO, 2011) and Australian MAR Guidelines (NRRMC-EPHC-NHMRC, 2009). With the possible exception of Haridwar bank filtration, insufficient data on microbial pathogens were available from any of these sites where these proposed guidelines were applied to provide confident advice, particularly on microbial risks to public health and on release of toxic metals from aquifers.

16.1.3 Water governance issues

The National Water Policy (Government of India, 2012) represents a comprehensive approach to integrated water management of surface water and groundwater and considers quantity and quality with objectives of equity, social justice and sustainability. It declares that whereas groundwater is currently "still perceived as an individual property and exploited inequitably and unsustainably in places", water needs to be "managed as a community resource, held by the state under public trust doctrine to achieve food security, livelihood, and equitable and sustainable development for all."

The water quality guide for MAR in India presumes the adoption of the National Water Policy, to assure that taking surface water for recharge does not impoverish communities downstream, and that enhanced recharge will in fact make groundwater more plentiful enabling equitable use for the highest valued uses, such as to satisfy basic human needs. With allocation plans in place, the government can then optimise water efficiency improvement and recharge enhancement programs, including activities supported by the National Rural Employment Guarantee Act.

16.2 METHODOLOGY

The Australian MAR Guidelines (NRMMC-EPHC-NHMRC, 2009) use a risk assessment and management framework to ensure protection of public health and the environment. They adopt a staged approach to risk assessment, beginning with an 'entry level risk assessment' based on existing knowledge of the recharge scheme, followed by a semi-quantitative risk assessment which may require additional information to be obtained through experiment or investigation (Figure 16.1).

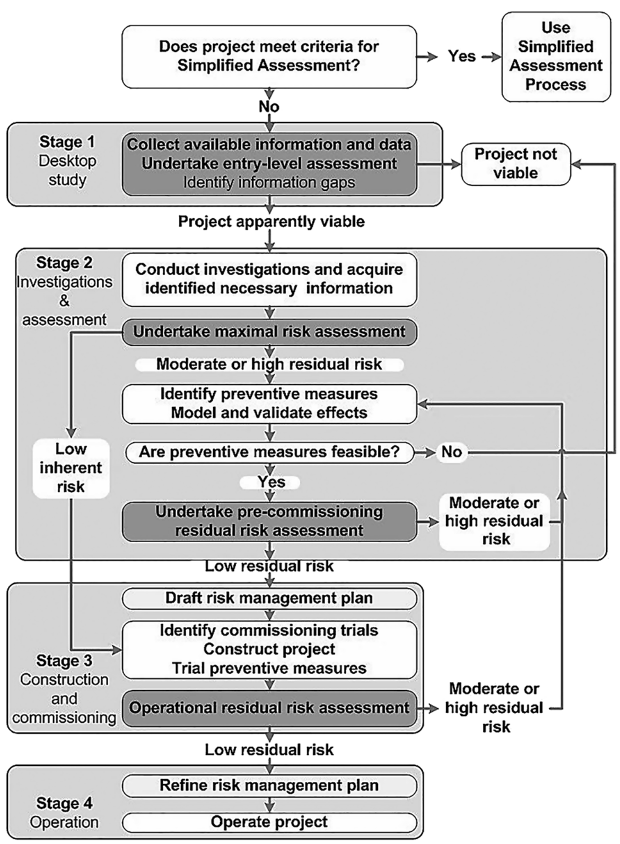

Figure 16.1 Australian MAR Guidelines risk assessment stages in managed aquifer recharge project development (NRMMC-EPHC-NHMRC, 2009).

Application of the Australian MAR Guidelines to assess risk in artificial recharge projects in India, China, Mexico, South Africa, and Jordan by experienced practitioners revealed that the initial entry level assessment was useful in providing a systematic pathway to identify any issues to be addressed (Dillon *et al*., 2010). However, the water quality analyses of pathogens (viruses, protozoa and bacteria) required to complete the subsequent quantitative pathogen risk assessment were not available at any site. However, at the bank filtration system in Haridwar (Uttarakhand), bacteriological indicators (thermotolerant coliforms) were measured enabling a microbial risk assessment to be inferred (Bartak *et al*., 2014). In the general absence of pathogen data 'A Water Quality Guide to Managed Aquifer Recharge in India' adapts elements of the Australian entry level assessment and incorporates the WHO sanitary survey approach (WHO, 2011). Together these identify hazards and hazardous events that are then addressed in a water safety plan.

A summary of the steps in the proposed Indian Guidelines, 'A Water Quality Guide to Managed Aquifer Recharge in India' is presented in Figure 16.2. This firstly eliminates from further consideration sites where risk to human health is inherently low (simple assessment). Then it addresses the viability of a project new project. It then assesses whether the nature of the project is within the constrained scope of applicability of the guidelines. Then it advances to a sanitary survey and aquifer assessment before compiling a water safety plan. An example of a water safety plan derived from this process is given in Table 16.1.

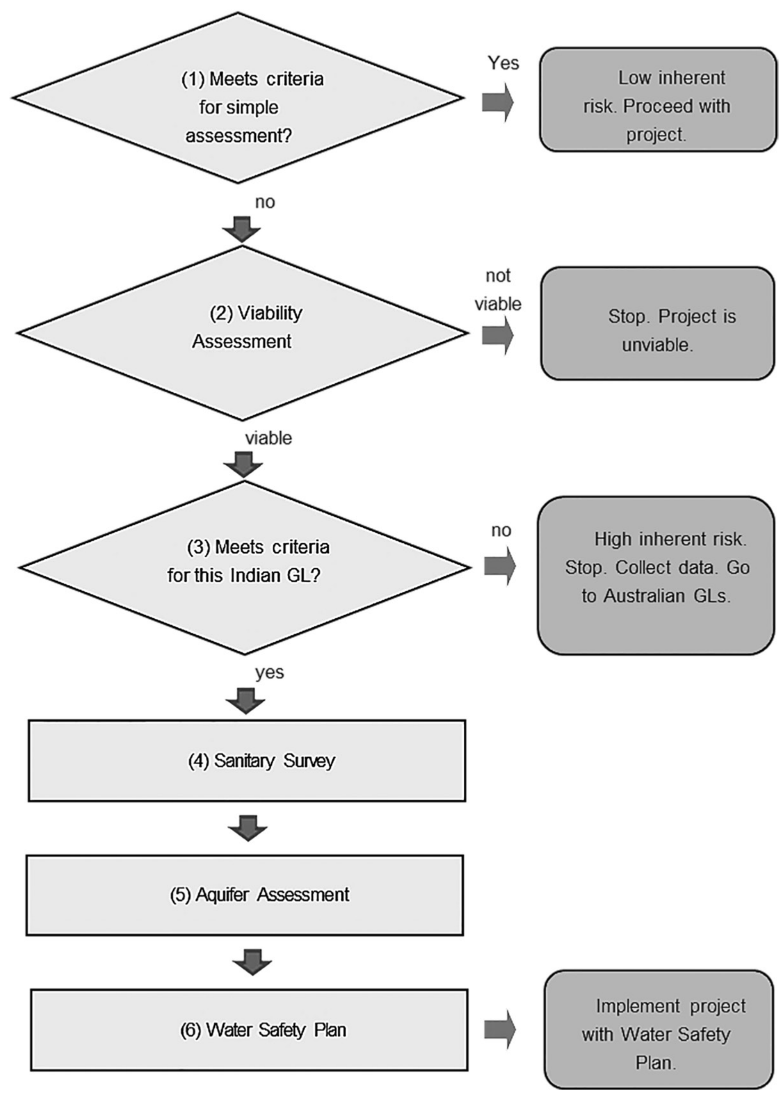

Figure 16.2 Outline of the steps involved in applying the Indian Guideline for managed aquifer recharge including implementation of a water safety plan (from Dillon *et al*., 2014).

Table 16.1 Example of a managed aquifer recharge water safety plan (from Dillon *et al.*, 2014).

Hazardous Event	Cause	Control Measure	Critical Limits		Monitoring			Corrective Action	Verification
			Targets	Action	What	When	Who		
1. Human sewage entrainment in source water	Latrine leakage, open sewers, sewer pipe leaks, open defecation in catchment, and close to recharge facilities and recovery wells	More latrines with improved design, install separate sewage system from stormwater drains, or only harvest high wet weather flows, improve sewer capacity and response to chokes and leaks	Control sewage leaks, regulate sewage discharge points in catchment	Identify sewage leaks sewage discharge points. Repair, rebuild, or implement overflow diversion. Boil drinking water.	Sanitary inspection	Monthly	Op*	Remove pollutant sources, improve sanitation design, reduce sewer leakage or sewage discharge	Microbiological examination of water
2. Animal faecal matter entrainment in source water	Animal manure accumulation or cess pits in the catchment and close to recharge area and recovery well	Exclude livestock from water harvesting and recovery structures, collect animal faeces and store in dry areas with setback distance from water infrastructure	No overstocking in catchment, set back distances honoured, dry storage of animal manures	Controls on animal husbandry in catchment. Repair fences, exclusion zones. Boil drinking water.	Sanitary inspection	Monthly	Op	Removing livestock out of catchment, repair or erect fencing, arrange collection and removal of faeces.	Microbiological examination of water
3. Leaching of microbial contaminants into aquifer	Infiltration of water that has been in contact with human and animal wastes	Provide adequate setback distances to drinking water wells or springs	No sources of faecal material within setback distance	Close any latrines, and enclose or seal open sewers within setback distance. Boil drinking water.	Sanitary inspection	Monthly	Op	Remove sources of faecal material within setback distance, repair or erect fencing, improve sewerage.	Microbiological examination of water
4. Entrainment of chemicals in source water for recharge	Industry, transport and agricultural activities generating stockpiles, wastes, spills, and emissions reaching the catchment surface	Regulate industrial and agricultural activities in the catchment	No unauthorised sources of chemical contamination in catchment. All pollutants in wise use and management. Minimise spills through industry standards.	Remove wastes from catchment. Install bunding around industrial sites to prevent run-off to recharge system. Traffic loading regulations enforced.	Sanitary inspection	Monthly	Op	Move or bund polluting industries, regulate industrial discharge and agricultural use of chemicals	Sanitary inspection Analysis of source water and groundwater quality for pollutants.

(*Continued*)

Table 16.1 Example of a managed aquifer recharge water safety plan (from Dillon *et al.*, 2014) (*Continued*).

Hazardous Eevent	Cause	Control Measure	Critical Limits		Monitoring			Corrective Action	Verification
			Targets	Action	What	When	Who		
5. Leaching of chemicals into groundwater	Leaching from landfill, waste dumps and industrial discharge	Provide adequate set back distance, regulate industrial discharge	No source of chemicals within the set-back distance	Prevent pollutant discharge within set-back distance	Sanitary inspection	Monthly	Op	Improve containment and move or control pollution sources	Sanitary inspection Analysis of groundwater quality for pollutants.
6. Bypassing or failure of pre-treatment in recharge facility	Short-circuit of recharge flow. Clogging of filters, power and mechanical failures, treatment chemicals run out.	Design treatment to avoid admitting untreated water into the well for each of these hazardous events	No recharge of untreated water	Maintain treatment system regularly. Install system to shut-down recharge when alarm activated Boil drinking water.	Sanitary inspection	Monthly	Op	Maintain filter and any other treatment. Check alarm system operates correctly.	Sanitary inspection Analysis of source water and groundwater quality for pollutants.
7. Bypassing or failure of post treatment at recovery well	Clogging of filters, power and mechanical failures, treatment chemicals run out	Design treatment to avoid admitting untreated water into the water supply for each of these hazardous events	No distribution of untreated recovered water	Maintain treatment system regularly. Install system to shut-down recovery when alarm activated. Boil drinking water.	Sanitary inspection	Monthly	Op	Maintain filter and any other treatment. Check alarm system operates correctly.	Sanitary inspection Analysis of groundwater and recovered water for pollutants.

*Op = MAR scheme operator.

16.3 RESULTS AND DISCUSSION

'A Water Quality Guide to Managed Aquifer Recharge in India' was applied to three Saph Pani case study sites to determine the applicability and usefulness of a simplified approach to reduce health risk in the absence of data on pathogens of concern:

1) Bank filtration at Haridwar on Ganga River, Uttarakhand (see Chapters 2 and 12)
2) Percolation tanks in crystalline aquifers at Maheshwaram, Telangana, (see Chapter 7) and
3) Check dam near Chennai, Tamil Nadu (see Chapter 6).

A brief summary of each site is provided in sections 16.3.1–16.3.3 and the short form assessment in Table 16.2.

16.3.1 Bank filtration at Haridwar on Ganga River, Uttarakhand

Bank filtration has been used in Haridwar mainly since the 1980s as an alternative to surface water abstraction and to supplement groundwater resources (Sandhu *et al*., 2011; Bartak *et al*., 2014). The alluvium is comprised of unconsolidated to semi-consolidated, coarse to fine sand, silt and clay. The Haridwar district aquifer system consists of four water bearing layers, separated by confining clay layers in the western part of the district. The hydraulic conductivity of the aquifer is typically 16 to 50 m/d and the aquifer is hydraulically connected to the adjacent Ganga River (Dash *et al*., 2010). Average discharge in the Ganga River at Haridwar is 200 m^3/s in non-monsoon months, rising to an average of 1,500 m^3/s during the monsoon (Das Gupta, 1975), with observed extreme peak flows up to 12,400 m^3/s in September 2010 (Saph Pani D1.2, 2013). During non-monsoon months, the average depth to the water table is 6.3 (2.8–9.4) m below ground level, while during the monsoon the depth to the water table rises by an average of 1.3 m (Saph Pani D1.2, 2013).

The source water for the BF system in Haridwar is the Ganga River and Upper Ganga Canal (UGC) that originate primarily from rural run-off. The presence of faecal indicators in groundwater wells was linked to areas where unsealed, temporary pit latrines are commonly used, social land use practices such as public bathing/washing at the well heads, presence of cattle in and around the RBF wells and unsanitary defecation practices (Bartak *et al*., 2014). Haridwar is one of the most important Hindu pilgrimage sites in the world. As a result, ~50,000 visitors come to Haridwar daily with up to 8.2 million people during specific religious days such as Kumbh (Gangwar & Joshi, 2004) to wash themselves in the Ganga in close proximity (<50 m) to the bank filtration wells. The source water for recharge can be turbid, especially in high flows (monsoon). Filtration through the river bed provides water quality improvement, shown as a reduction in turbidity and coliform bacteria (Bartak *et al*., 2014).

Faecal contamination sources are also present close to the extraction wells. Groundwater is used for drinking water supply; extraction is adjacent to the river (Figure 2.3; Figure 16.3). As of 2013, 59,000 to 67,000 m^3/d is sourced from 22 large diameter, bottom entry caisson wells (Figure 16.3), receiving a mixture of bank filtrate from the Ganga River, UGC and groundwater from the upper unconfined aquifer and around 50 tube wells, which target deeper confined aquifers. Average minimum travel times between the Ganga River and the production wells range from 30 to >88 d corresponding to flow distances of 4 to >490 m. During the monsoon the travel time to production wells can be as low as 2 d (Bartak *et al*., 2014). Drinking water is treated by chlorination at the well using sodium hypochlorite (NaClO), but this can be interrupted by power failures or defective disinfectant dosage pumps. Recovery wells are housed to exclude livestock, but anthropogenic activities take place near/around the well houses. Flood water can directly enter wells during high flow. Private wells are located further from the recharge site.

16.3.2 Percolation tanks in crystalline aquifers at Maheshwaram, Telangana

Investigations have been carried out at the Tummulur tank in the Maheshwaram watershed, which is located 35 km south of Hyderabad (Telangana State, India). This watershed covers an area of 53 km^2 and due to the rapid growth in urbanisation this watershed is now in transition from a rural to suburban area. The area has a relatively flat topography ranging from 590 to 670 m above mean sea level with no perennial streams.

The region has a semi-arid climate with annual monsoon rains (rainy or "Kharif" season from June to October), producing more than 90% of the mean annual precipitation of about 750 mm. The mean annual temperature is approximately 26°C although during summer ("Rabi" season from October to May), the maximum temperature can reach 45°C (Maréchal *et al*., 2006). The resulting potential evaporation from soil plus transpiration by plants is 1,800 mm/year. The watershed is overexploited with more than 700 boreholes used for agriculture dominated by rice paddy fields. As a result, the water table is currently 15 to 25 m below ground level and has become hydraulically disconnected from surface water.

The geology of the watershed is relatively homogeneous and is composed of the weathered Archean granite. Dewandel *et al*. (2006) describe a typical weathering profile from top to bottom:

- Saprolite (also called regolith or alterite) which, when saturated, constitutes a large part of the storage capacity of the aquifer.
- The fissured layer, which mainly assumes the transmissive function of the aquifer and is tapped by most of the wells drilled in the watershed. Hydraulic conductivity is found to range from 1.9×10^{-7} to 3.9×10^{-5} m/s (0.02 to 3.4 m/d). The effective porosity of the fissured layer is relatively low and is mainly ensured by small fissures affecting the blocks (Maréchal *et al*., 2004).
- Impermeable basement, except where tectonic fractures are present.

Figure 16.3 Example of a large diameter caisson well adjacent to Ganga River (Photo: HTWD, 2011).

The monitored Tummulur tank is located in the downstream part of the watershed and has been used for more than 10 years for water storage. An earth bund in its northern part dams the natural stream outlet, and consequently, run-off water is stored over an estimated maximum area of 130,000 m^2 and a maximum water depth of 4 m. Before the first significant rainfall events, the soil is withered due to the dry period which creates important shrinkage cracks observable in the entire tank area. The soils specificities of the tank are the clayey zone, mainly in the lower northern part of the tank (flooded in Figure 16.4b). Most of the rest of the tank area is covered by silt loam soil on the surface underlain by sandy loam at a depth of 40 to 80 cm. Inflow to the tank can be highly variable (Figure 16.4). Monitoring wells were installed to measure piezometric levels and one staff gauge records the surface water level within the tank.

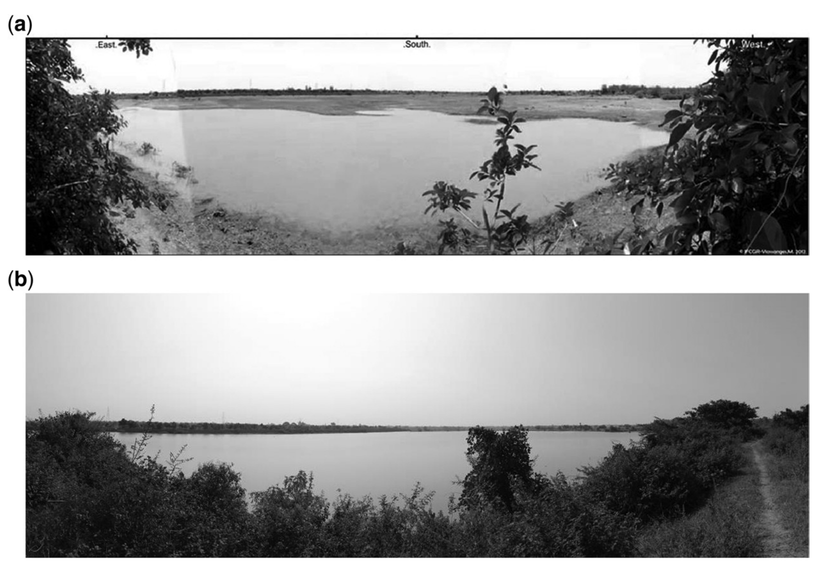

Figure 16.4 Views of the Tummulur tank from the dam, (a) 01/05/2012 and (b) 28/08/2013 (Photo: M.Viossanges, BRGM, 2012, 2013).

The water stored in the tank is used by the surrounding farmers (15) through individual borehole pumping. Irrigation duration and times are controlled by the availability of electricity (7 h per day). The percolation tank constitutes a drinking water supply source for livestock (goats and buffaloes in limited number) as well as for buffalo washing and hence may induce microbial contamination. The area is also known to be prone to geogenic fluoride contamination (Pettenati *et al*., 2013, 2014) with concentration up to 5 mg/L. Tank functioning has been described in detail in Boisson *et al.* (2014).

16.3.3 Check dam at Chennai, Tamil Nadu

Check dams are constructed across the two non-perennial rivers flowing just north of Chennai, to improve the groundwater recharge and mitigate seawater intrusion. As a part of Saph Pani a detailed investigation was carried out in a check dam constructed across Arani River at Paleshwaram village, which is located 35 km from the Bay of Bengal. This check dam is 260 m long and 3.5 m height with the storage capacity of 0.8 Million m^3 (Figure 16.5).

Figure 16.5 Paleshwaram check dam across Arani River, north of Chennai, Tamil Nadu, India (Photo: S. Parimala Renganayaki, Anna University, Chennai).

The atmospheric temperature of this area ranges from 38^o C to 42^o C during May-June and from 18^o C to 36^o C during December-January. The average annual rainfall is around 1,200 mm of which 35% falls during the southwest monsoon (June-September) and 60% falls during the northeast monsoon (October-December). Rainfall is the major source of groundwater recharge in this area. This check dam receives water during monsoon rains (October to December) in the catchment and release of water from Pichature reservoir located at a distance of about 40 km on the upstream side of this check dam (Parimala Renganayaki & Elango, 2015).

Intensive agricultural activity takes place throughout the year, which mainly depends on groundwater. The major crops cultivated in this area are paddy, watermelon, spinach and cucumber. Flowers like jasmine and rose are also grown. The Tamil Nadu Water Supply and Drainage Board tap groundwater to supply water to the houses in nearby villages (Parimala Renganayaki & Elango, 2014).

This region comprises of alluvial deposits overlying the Gondwana clay and functions as an unconfined aquifer. As the clay lenses present in the alluvial formation of this area are only localised and do not extend over a large region, the groundwater occurs under unconfined conditions. Groundwater level measurements made during the study indicate that the water table occurs at a depth from 3 m to 12 m below the ground level (Parimala Renganayaki & Elango, 2015).

The quality of water in the check dam is generally very good with regard to the major ion composition and the total dissolved solids value, which was generally less than 720 mg/L. The groundwater was found suitable for domestic and irrigation purposes based on ionic concentrations in wells located 1.5 km from the dam due to the recharge from good quality water from the check dam (Parimala Renganayaki & Elango, 2014). *Escherichia spp*., *Salmonella spp*., *Shigella spp.* and *Clostridium spp.* were present in the water collected from the check dam and wells. Hence, the groundwater is not suitable for drinking purposes (Parimala Renganayaki *et al*., 2015). As there were no spore producing organisms, the water from check dam and groundwater could be used for domestic purposes after boiling the water at house hold level, whereas municipal water supply requires the proper level of chlorination (Parimala Renganayaki, 2014).

Table 16.2 Application of 'A Water Quality Guide to Managed Aquifer Recharge in India' to three Saph Pani case study sites.

Case Study	**Bank Filtration at Haridwar on Ganga River, Uttarakhand**	**Percolation Tanks at Maheshwaram, Andhra Pradesh**	**Check Dam near Chennai, Tamil Nadu**
Source water and treatment	Mainly rural run-off, Filtration by recharge through river bed alluvium	Peri-urban run-off, infiltration through weathered sediments	River flow from rural run-off, infiltration through river bed
Aquifer type	alluvium	hard rock	alluvium
1. Simple Assessment	**Yes/No**	**Yes/No**	**Yes/No**
1. Is the aquifer being recharged used as a drinking water supply?	Y	Unknown	Y
2. Is the scale of recharge larger than domestic rainwater harvesting?	Y	Y	Y
3. Does the water being recharged contain sewage effluent, industrial wastewater, or urban stormwater?	Y	Y Animal excreta	Y Domestic solid waste disposal, pilgrim activity
4. Is the area around the recharge area ever waterlogged?	Y occasionally when river in flood	Y during monsoon	Y only during excess rains
Simple assessment is satisfied if all answers are No. No need to continue assessment. However if any answer is Yes proceed to Viability assessment.	*Proceed to Viability assessment*	*Proceed to Viability assessment*	*Proceed to Viability assessment*
2. Viability Assessment	**Yes/No**	**Yes/No**	**Yes/No**
1. Is there a sufficient demand for water?	Y	Y	Y
2. Is there an adequate source of water available for allocation to recharge?	Y	Y	Y but volume depends on rainfall in the upper catchment
3. Is there a suitable aquifer for storage and recovery of the required volume?	Y	Y Limited capacity	Y
4. Is there sufficient space available for capture and treatment of the water?	Y	Y	Y
If the answer to any question is No, then the project is not viable or has a major constraint. If answers are Yes, proceed to Guidelines applicability assessment.	*Viable, proceed to Guidelines applicability assessment*	*Viable, proceed to Guidelines applicability assessment*	*Viable, proceed to Guidelines applicability assessment*
3. Guideline Applicability Assessment	**Yes/No**	**Yes/No**	**Yes/No**
1. Is the source of water for recharge from a rooftop or a natural catchment? (i.e. not sewage effluent, industrial wastewater, or urban stormwater)	Y River is mostly rural run-off, but affected by towns and bathing	Y Rural run-off	Y Rural run-off, but some domestic solid waste disposal, pilgrim activity
2. Is the aquifer unconfined and not polluted?	Y Unconfined	Y Unconfined Some water quality issues (fluoride, pesticides)	Y Unconfined Some salinity issues, leading to use of check dams to freshen aquifer

3. Is the proposed recharge area remote from public drinking water supply systems?	N This is for public water supply.	Y There is not a public drinking water supply in the direct area.	N There are 2 public drinking water production wells, and many irrigation wells sometimes used for drinking.
These Guidelines are applicable if all answers above are Yes. Otherwise not applicable use alternate Guidelines e.g. Australian MAR Guidelines	*Not Applicable***	*Proceed to Viability assessment*	*Not Applicable***
4. Sanitary Survey	**Yes/No**	**Yes/No**	**Yes/No**
1. Is there a latrine, open sewer or leaky sewer or human or animal faeces within the catchment area of the recharge facility?	Y Unsealed & temporary pit latrines, public bathing/washing at the well heads, presence of cattle in and around the RBF wells, unsanitary defecation practices	Y Animals wash in percolation tanks	Y Latrines, animal waste, domestic waste and sewer
2. Is there a latrine, open sewer, leaky sewer or animal faeces in close proximity to the recharge structure or to the wells from which water will be recovered?	Y As above	Y Recovery is via farm wells.	Y Latrines, animal waste, domestic waste and sewer
3. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions reaching the surface of the catchment area of the recharge facility?	Y Some use of agricultural chemicals and fertilisers and transport of fuels through the catchment	Y Agricultural activities	Y only agricultural stockpiles for short time periods in a year
4. Are there industrial, transport or agricultural activities generating stockpiles, wastes, spills, or emissions in close proximity to the recharge structure or the wells from which water will be recovered?	Y As above	Y Agricultural activities	Y only agricultural stockpiles for short time periods in a year
5. Is there pre-treatment or means of preventing contaminated water to be recharged? If so describe its design and resilience to power and mechanical failure, and any alarm systems.	Y Natural treatment by passage through aquifer before recovery	N	N
6. Is there post-treatment of water to be recovered? If so describe its design and resilience to power and mechanical failure, and any alarm systems.	Y Chlorination. Pumps shut down when power fails.	N	Y Chlorination of both public drinking water supply wells. No alarm system.
7. Does the existence and condition of any barriers around of the recharge structure and recovery wells prevent short circuit of contaminated water?	Y Concrete base around wells of limited effectiveness (see Chap. 2)	N	N

(*Continued*)

Table 16.2 Application of 'A Water Quality Guide to Managed Aquifer Recharge in India' to three Saph Pani case study sites (*Continued*).

Case study	**Bank filtration at Haridwar on Ganga River, Uttarakhand**	**Percolation tanks at Maheshwaram, Andhra Pradesh**	**Check dam near Chennai, Tamil Nadu**
Any question answered by ***Yes*** *needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account.* Proceed to Aquifer assessment	*Account for these in MAR water safety plan*	*Account for these in MAR water safety plan*	*Account for these in MAR water safety plan*
5. Aquifer Assessment	**Yes/No**	**Yes/No**	**Yes/No**
1. Does source water have low quality; is water turbid, coloured, contains algae, has a surface slick or does it smell?	Y Turbid especially in high flows	Y Turbid	N
2. Does the unconfined aquifer have a shallow water table, say <8m in urban area and say <4m in rural area?	Y Shallow water table. Increase in groundwater levels in monsoon due to elevated surface water levels (Ganga River and UGC)	Y Water table before monsoon ~25 m below ground level (bgl), water table after monsoon ~1 m bgl	Y Water table before monsoon ~15 m bgl after monsoon ~4 m bgl
3. Are there other groundwater users, groundwater-connected ecosystems or a property boundary within 100m of the recharge site?	Y Private wells located further from river than the bank filtration well	Y No management plan, other groundwater users are within 100m	Y Private wells for irrigation purposes and a few wells for domestic use
4. Is the aquifer known to contain reactive minerals (e.g. pyrite) or is groundwater in this area known to contain arsenic? Does the aquifer contain soluble minerals such as calcite and dolomite?	N Alluvial aquifer sourced by natural recharge of same source. No new geochemical reactions expected	Y Fluoride	N Alluvium comprising of sand, silt and clay.
5. Is the aquifer composed of fractured rock or karstic (fissured or cavernous) limestone or dolomite?	N	Y Fractured rock	N
6. Is the proposed project of such a scale that it requires development approval? Is it in a built up area; built on public, flood-prone or steep land; or close to a property boundary? Does it contain open water storages or engineering structures; or is it likely to cause public health or safety issues (e.g. falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g. from waste products of treatment processes)?	Y Existing project primarily since 1980 (Bartak *et al.*, 2014). Built on flood prone land.	Y Existing project	Y Existing project. In rural area and water is stored within the river. No issues during construction or operation regarding noise, dust, insects. No known adverse environmental impact. Prevents saline intrusion.

(In these three cases the projects already exist, and answered as though approaching the project prior to construction.)			
Any question answered by ***Yes*** *needs to be taken into specific account in the Water Safety Plan below. Even if not observed, the possibility of these hazards occurring or barriers being breached also needs to be taken into account.*	*Account for possibility of these in MAR water safety plan*	*Account for possibility of these in MAR water safety plan*	*Account for possibility of these in MAR water safety plan*
Proceed to Water Safety Plan			
6. Managed Aquifer Recharge Water Safety Plan	**Yes/No**	**Yes/No**	**Yes/No**
Human sewage entrainment in source water			
1. Do latrine leakage, open sewers, sewer pipe leaks, open defecation occur in the catchment or close to recharge facilities or recovery wells?	Y Latrines, leaky sewers, open defecation	Y Open defecation	Y Latrines, animal waste, domestic waste and sewer
Animal faecal matter entrainment in source water			
2. Are there any animal manure accumulations or cess pits in the catchment or close to the recharge area or recovery well?	Y Stockpiles of animal manure, fresh animal faecal material close to extraction wells	Y	Y Animal waste from nearby pilgrim centre, domestic waste and sewer draining into the river
Leaching of microbial contaminants into aquifer			
3. Can water infiltrate that has been in contact with human and animal wastes?	Y Floodplain and ambient ground-water are likely to contribute more contaminants to drinking water than bank-filtered river water	Y Animals have access to percolation tank	Y Bathing of humans and animals in the dam
Entrainment of chemicals in source water for recharge			
4. Are there industry, transport and agricultural activities generating stockpiles, wastes, spills, or emissions reaching the catchment surface?	Y Manures and agricultural chemicals	Y	Y but only agricultural stockpiles for short time periods in a year
Leaching of chemicals into groundwater			
5. Can water infiltrate from landfills, waste dumps or industrial discharge?	Y from manure stockpiles, possible spills of transport fuels, pesticides	N	N

(*Continued*)

Table 16.2 Application of ‘A Water Quality Guide to Managed Aquifer Recharge in India’ to three Saph Pani case study sites (*Continued*).

Case study	Bank filtration at Haridwar on Ganga River, Uttarakhand	Percolation tanks at Maheshwaram, Andhra Pradesh	Check dam near Chennai, Tamil Nadu
Bypassing or failure of pre-treatment in recharge facility			
6. Can recharging water short-circuit existing barriers to protect groundwater quality? (for example caused by clogging of filters, power or mechanical failures, or treatment chemicals running out)	Y Bank filtration is robust, but anthropogenic activities near/around well head houses may defeat their protective purpose	N Infiltration	N
Bypassing or failure of post treatment at recovery well			
7. Can water used for drinking bypass existing barriers or treatments (for example caused by clogging of filters, power or mechanical failures, lack of fuel for boiling water, or treatment chemicals running out)?	Y Chlorination, pumps shut down when power fails, but leaky mains allow ingress of contaminated shallow groundwater when pipes are not pressurised. Plan should include verifying chlorination level, procedures during floods and repairing leaky pipes	N No treatment	Y Treatment by chlorination of public water supply wells, but no alarm system in event of chlorination failure.
See Table 16.1 to identify suitable control measures, critical limits, monitoring, corrective actions and verification. Insert site-specific measures in consultation with stakeholders and agree on whom to take each action is required.	*Stakeholders capable of implementation to complete the MAR Water Safety Plan*	*Stakeholders capable of implementation to complete the MAR Water Safety Plan*	*Stakeholders capable of implementation to complete the MAR Water Safety Plan*
Extra work is warranted to monitor at these sites (**) with higher risks to better assess risks to public water supplies and implement remedies.	**		**

**Two of these aquifer recharge sites directly contribute to public drinking water supplies. Therefore this approach alone is considered unable to confidently protect human health (i.e. not applicable because of the high potential risk to drinking water supplies). However, the guidelines were followed through regardless to help form a water safety plan to encourage immediate actions to improve water quality and to identify issues needing to be considered in a more rigorous assessment.

16.4 CONCLUSION

For many years India has been the international leader in the volume of water intentionally recharged and the number of recharge structures employed to sustain groundwater resources. In many cases the source of water for recharge is the same source that recharges the aquifer naturally, and little change in groundwater quality is expected. However, enhancing recharge can shorten the residence time of water in the unsaturated zone or accelerate the movement of water from streams to wells, potentially diminishing the opportunity for contaminant removal. Recharge enhancement can result in groundwater quality improvement for agricultural irrigation supplies while at the same time deteriorating the quality for drinking water supplies. Where groundwater is used as a drinking water source, it should be an obligation of those enhancing recharge to protect the health of those whose drinking water is affected by their operations.

Application of 'A Water Guide to Managed Aquifer Recharge in India' (Dillon *et al.*, 2014), to three Indian case studies within Saph Pani identified practical protective measures that can be applied to improve the protection of groundwater from contamination arising from recharge operations. It was found that the example form of a water safety plan in Table 16.2 was relevant to the three sites evaluated. The next step would be to identify local stakeholders who would take responsibility to undertake and implement the water safety plan.

The Haridwar and Chennai case studies involve public drinking water supplies. These are outside of the recommended scope of application of this approach as it is not feasible to confidently protect human health in public water supplies in the absence of water quality data, particularly for microbial pathogens. However, the approach was followed to help identify the issues needing to be considered in a water safety plan to improve the safety of supplies and to also to inform on the types of data that would support a more rigorous assessment.

For the Haridwar bank filtration system, based on monitored water quality data for the period 2005–2013, a comprehensive staged approach to assess the risks from 12 hazards to human health and the environment was undertaken by Bartak *et al.* (2014). Accordingly, it was determined that the risks from inorganic chemicals, salinity, nutrients and turbidity were acceptable. A quantitative microbial risk assessment (QMRA) indicated that the risks to human health from bacterial pathogens (Escherichia coli O157:H7) were below the reference risk used in the study (Bartak *et al.*, 2014). This QMRA was limited by inadequate characterization of viral and protozoan pathogen numbers in source water. Pathogen removal capabilities for bank filtration at several sites reported in literature indicate high removal capabilities even for viral and protozoan pathogens. Given the potential for high pathogen numbers in source waters at Haridwar, the site-specific pathogen risks warrant better characterization.

In the absence of water quality data it cannot be claimed that the approach was validated, and that its application will assure safety. It can however be confidently claimed that the application of this approach, which requires only basic information that is readily observable, will make recharge enhancement safer. The next stage would be to apply, test and refine this document for artificial recharge in rural and urban conditions, for a wider range of waters, aquifer types, recharge methods, end uses of recovered water, and capabilities of implementing institutions, to facilitate adoption by state and federal authorities. Sites where a water safety plan is developed and implemented can then be claimed to have progressed from artificial recharge to managed aquifer recharge.

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