Chapter 13

General framework and methodology for selection of pre- and post-treatment for soil aquifer-based natural treatment systems

Saroj Kumar Sharma, Richard Missa, Maria Kennedy, Cornelius Sandhu,
Thomas Grischek and Anders Nättorp

13.1 INTRODUCTION

Soil aquifer-based natural treatment systems (NTSs) namely bank filtration (BF), artificial recharge and recovery (ARR) and soil aquifer treatment (SAT) have been employed for water and wastewater treatment and reuse in different parts of the world. BF (river or lake) has been practiced as a method of "abstraction" of water from surface water sources for more than 100 years (Eckert & Irmscher, 2006). ARR has been employed using many techniques (infiltration ponds, dug wells, trenches, vadose zone wells and direct injection wells) mainly for replenishment of groundwater resources. Sometimes they are also used as a "natural method of water treatment" for surface water sources when the source water quality and/or hydrogeological conditions are not suitable to employ BF. SAT is a specific term designated for methods employed to recharge wastewater treatment plant (WWTP) effluents aiming at subsequent reuse (Sharma & Amy, 2010).

In general, soil-based NTSs or managed aquifer recharge (MAR) systems will be feasible where the following three key areas are adequately addressed (Martin & Dillion, 2002):

i) hydrogeological and technical system design and operation to achieve benefits that exceed costs
ii) system compliance with regulations, within a progressive regulatory regime
iii) establishment of suitable consultative mechanisms to allow satisfactory stakeholder negotiations

Several factors influence the feasibility of a soil-based NTS at a particular site. These include among others, (i) source water quality, (ii) variation in available quantity, (iii) hydrogeological conditions at the site (soil type and permeability, depth of groundwater table, type of the aquifer available, storage capacity of the aquifer, mineralogy of the aquifer material) as well as (iv) treated water quality requirements for intended use.

Pre- and post-treatment systems are integral components of natural systems employed for water and wastewater treatment. These systems not only enhance the performance of NTSs but also help to meet the water quality requirements for different applications. Pre-treatment is relevant for MAR (ARR and SAT) systems. Sedimentation (using detention tanks, reservoirs, settling basin) and filtration (roughing or rapid sand) are common pre-treatments applied to ARR systems (CGWB, 2007; Holländer *et al.* 2009). Sometimes coagulation, adsorption, membrane filtration, advanced oxidation, disinfection and their combinations have been applied as pre-treatment in some NTSs (van der Hoek, 2000; van Houtte & Verbauwhede, 2005; Tielemans, 2007; Sharma *et al.* 2011) to reduce clogging and contamination of the aquifers.

Post-treatment is often required after NTSs to meet the local water quality standards and guidelines for subsequent (re) use. Commonly used post-treatment methods for NTSs include (i) disinfection/chlorination to ensure microbial safety and disinfectant residual in the water distribution system, (ii) aeration/chemical oxidation-rapid sand filtration to remove common groundwater contaminants like iron, manganese and ammonium, (iii) ozonation for oxidation of bulk organics and organic micropollutants (OMPs), (iv) activated carbon filtration (with or without pre-ozonation) to remove the OMPs and colour/taste and odour present in the water, (v) softening and pH correction to remove the hardness and to ensure that there is no scaling or corrosion of water distribution system.

Disinfection (by chlorination) is the most common post-treatment applied to bank filtrates mainly in northern India such as in Uttarakhand, where the critical surface water quality parameters are mainly pathogens and very high turbidity in monsoon. Other systems also use aeration followed by rapid sand filtration before chlorination (e.g. Mathura, Ahmedabad and various BF sites in Jharkhand and Andhra Pradesh; Saph Pani D1.1, 2012; D1.4, 2014). Suspended solids removal by sedimentation in settling basins, detention tanks/chambers or ponds followed by sand filtration is the most common pre-treatment applied to rainwater or stormwater or river water used for MAR in India. Sometimes both of these two pre-treatment processes (sedimentation and filtration) are achieved in a combined unit which forms a part of recharge structure (Saph Pani D4.1, 2013).

13.2 TYPICAL POLLUTANTS AND PRE- AND POST-TREATMENT FOR SOIL/AQUIFER-BASED NTSS

13.2.1 Removal of pollutants by NTSs and pre- and post-treatment systems

Soil-based NTSs are capable of removing several pollutants from water sources. Their removal efficiencies are highly dependent on source water quality and the hydrogeological conditions on site. The type of pre- and post-treatment systems required depend on the type of NTS employed, source water type and quality (rainwater, urban runoff, river or lake water, WWTP effluent), local hydrogeological conditions, process conditions (hydraulic loading rate or HLR, travel time/distance, abstraction rate) applied and intended use of the water after the NTSs (Figure 13.1). Furthermore, required pre- and post-treatment is influenced by national and local regulations regarding groundwater recharge, wastewater reuse and water quality standards and guidelines in place (Sharma & Amy, 2010). Inadequate pre-treatment may clog the NTSs, reduce their runtime and removal capability and consequently make additional post-treatment necessary. On the other hand, a well-designed NTS with proper pre-treatment will require minimal post-treatment. Sometimes, pre- or post-treatment is required to ensure that there is no detrimental effect on aquifers or other receiving water bodies.

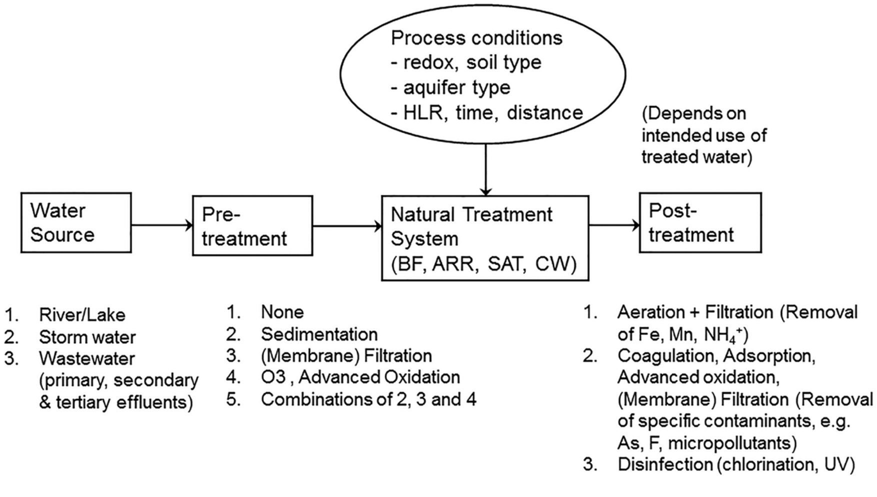

Figure 13.1 Natural treatment system components.

It is to be noted that the pollutant removal efficiencies of NTSs and conventional above-the-ground-treatment processes (pre- and post-treatment) are highly dependent on the raw water quality as well as process conditions applied locally. Some indicative values of the efficiencies of three different NTSs in removing different selected pollutants as collected from various literature sources are shown in Table 13.1. Additionally, based on the data collected from literature sources, lists of common pollutants to be removed by different possible pre- and post-treatment processes for BF, ARR and SAT and their typical removal efficiencies were compiled. These data are presented in detail in Missa (2014) and summarised in Tables 13.7, 13.8 and 13.9 which provide matrices for the selection of pre- and post-treatment for BF, ARR and SAT systems respectively.

Table 13.1 Indicative removal efficiency of typical pollutants by different NTSs.

Pollutant	BF	ARR	SAT*		References
Heavy metals	>90%	>90%	PE	100%	Idelovitch (2003)
			SE	100%	
			TE	100%	
Total Suspended Solids (TSS)	90–100%	90–100%	PE	86–100%	Goldschneider *et al.* (2007), Akber *et al.* (2003), Idelovitch (2003), Abel *et al.* (2014)
			SE	>90–100%	
			TE	>90–100%	
Turbidity	≤1 NTU (50–100%)	≤1 NTU (50–100%)	PE	≤1 NTU (50–100%)	Sharma (2013), BF[1]: Dash *et al.* (2008; 2010); see also Chapter 3
			SE	50–100%	
			TE	50–100%	
Colour	50–100%	50–100%	PE	50–100%	Saph Pani D4.2 (2013); BF[1]: Singh *et al.* (2010); Kumar *et al.* (2012)
			SE	50–100%	
			TE	50–100%	
Pathogens					
• Bacteria including indicators	2–6 Log	2–6 Log	PE	1.2–6.9 Log	WHO (2011); see specific references for BF site-investigations in India [2]
			SE	3–6.5 Log	
			TE	2.4–3 Log	
• Viruses	2.1–8.3 Log	2.1–8.3 Log	PE	4 Log	WHO (2011)
			SE	0≥4 Log	
			TE	0.4–4 Log	
• *Giardia*	1≥2 Log	1≥2 Log	PE	1≥2 Log	WHO (2011)
			SE	1≥2 Log	
			TE	1≥2 Log	
• *Cryptosporidium*	1≥2 Log	1≥2 Log	PE	1≥2 Log	WHO (2011)
			SE	1≥2 Log	
			TE	1≥2 Log	
Iron	0% Sometimes increase	0% Sometimes increase	PE	0%	Sharma (2013)
			SE	0%	
			TE	0%	
Manganese	0% Sometimes increase	0% Sometimes increase	PE	0%	Sharma (2013); de Vet *et al.* (2010)
			SE	0%	
			TE	0%	
Nitrate	50–100%	50–100%	PE	57–100%	Sharma (2013), Saph Pani D4.2 (2013), Essandoh *et al.* (2013), Akber *et al.* (2003), Idelovitch (2003), Al-Kubati (2013)
			SE	3≥90%	
			TE	0–22%	
Ammonium	53–90%	53–90%	PE	17–100%	Saph Pani D4.2 (2013), Sharma *et al.* (2012b), Essandoh *et al.* (2011), Akber *et al.* (2003), Abel *et al.* (2014)
			SE	0–99.2%	
			TE	17≥85%	
Phosphate	≥64%	≥64%	PE	4–100%	Cha *et al.* (2006), Akber *et al.* (2003)
			SE	30≥99%	
			TE	37≥80%	
Organic micropollutants (OMPs)**	≥50%	≥50%	PE	75–100%	Sharma (2013), BF[1]: Saph Pani D1.4 (2014)
			SE	20–100%	
			TE	10–100%	

(*Continued*)

Table 13.1 Indicative removal efficiency of typical pollutants by different NTSs (*Continued*).

Pollutant	BF	ARR	SAT*		References
Dissolved organic carbon (DOC)/ Total organic carbon (TOC)	>25%–≥50%	≥50%	PE SE TE	10–91% 10≥90 20≥80	Sharma (2013), Miehe *et al.* (2010), Quanrud *et al.* (2003), Abel *et al.* (2014); BF[3]
Salinity	Not removed	Not removed	Not removed		
Hardness	Not removed	Not removed	Not removed		

*SAT: PE = primary effluent; SE = secondary effluent; TE = tertiary effluent.
**Removal of OMPs is highly dependent on type of pollutant and redox conditions.
[1] specific reference for BF site-investigations in India.
[2] Dash *et al.* (2008, 2010); Sprenger *et al.* (2008, 2012); Singh *et al.* (2010); Sandhu and Grischek (2012); Saph Pani D1.2 (2013); Bartak *et al.* (2015); see also Chapter 3.
[3] Singh *et al.* (2010); Sandhu *et al.* (2011a, 2011b); Kumar *et al.* (2012); Saph Pani D1.4 (2014); see also Chapter 3.

The conventional physico-chemical treatment processes as pre- or post-treatment for NTS are capable of removing several main pollutants with varying removal efficiencies. This is obvious from the removal efficiencies data collected from different literature sources (Maeng, 2010; Abel, 2014; Missa, 2014) presented in Tables 13.7, 13.8 and 13.9 These tables also show that there is a wide range of options available for selecting conventional treatment processes for pre- and post-treatment of NTS depending on quality of water to be treated and final water quality requirements and costs. It is also to be noted that one treatment method may be able to remove several contaminants and often a combination of different treatment methods are employed to ensure that all pollutants are removed up to the desired level and to provide multiple barriers in the treatment system.

13.3 TYPICAL COSTS OF NTS AND PRE- AND POST-TREATMENT SYSTEMS

Estimation of total costs of treatment (capital costs as well as operation and maintenance (O&M) costs) is critical for assessing whether NTS (together with associated pre- and post-treatment) are competitive in terms of water quality and costs with the conventional surface water treatment options. Cost of water treatment depends on the size of the plant (treatment capacity) and varies from place to place depending upon the capital costs for installation of the facility (land costs, equipments and treatment units) and O&M costs (chemical, energy, manpower and routine maintenance).

Limited data are available on the costs of NTS in developing countries (some examples for India are Essl *et al*. 2014; Saph Pani D1.4; and D6.1) and most of the NTS in developed countries (where some cost data is available) are often of relatively large treatment capacities. These data often include the cost of pre-treatment as well as transmission and water distribution systems, and thus it is difficult to separate the cost of the NTS only. It has been estimated that the cost of the artificial recharge schemes varies from 7–100 USD/m^3 of daily infiltration capacity. The capital costs of artificial recharge schemes are comparable with those of treatment works for surface water for drinking water supply, but costs of operation and maintenance in recharge schemes are likely to be less. Estimates of operation and maintenance costs for artificial recharge schemes vary from of 0.05–0.30 USD/m^3 of water throughput (Hofkes & Visscher, 1986).

The following sub-sections present some estimated total costs (sum of capital and O&M costs) obtained from literature sources for NTS and conventional treatment systems per m^3 of water produced. These cost tables are indicative and can be used to make a relative comparison of costs of different pre- and post-treatment options with NTS combinations obtained from the matrices for feasibility study and preliminary decision making. Local capital and O&M costs should be calculated for each option at each site to obtain a realistic comparison with the alternatives.

13.3.1 Typical costs of NTS

Table 13.2 shows an example of the costs for NTS (BF, ARR, and SAT) based on literature review. The NTS costs vary from place to place and include construction costs, equipment costs (capital/investment costs). It also includes energy costs, chemical costs as well as other O&M costs.

Typical structures used for artificial recharge in India include percolation tanks (with or without recharge shafts), check dams, nala bunds, gabion structures, dug wells, injection wells, sub-surface dykes or underground bandhars, and roof top rainwater harvesting with recharge system. The sizes and costs of these recharge systems varies from state to state. Typical costs of different types of artificial recharge structures applicable in different states of India are presented in detail in "Master Plan for Artificial Recharge Ground Water in India" (MWR, 2013). Ranges of costs of recharge structures are summarized in Table 13.3.

Table 13.2 Indicative costs of soil-based NTS.

NTS	**Costs**		**References**
	Total Costs [INR/m^3]	**Relative Cost Class***	
BF	2.43–13.77	Low	Bosuben (2007), Sharma *et al.* (2012a), Saph Pani D1.4 (2014)
ARR	7.29–17.22	Low	Kumar and Aiyagari (2007), Osborn *et al.* (1997), Gale *et al.* (2002)
SAT	26.73–40.5	Low–Medium	Aharoni *et al.* (2011), Sharma *et al.* (2012b)

*Low = <0.40 EUR/m^3, Medium = 0.40–.00 EUR/m^3, High = 1.00–2.00 EUR/m^3

Table 13.3 Typical investment costs of different artificial recharge systems in India.

Artificial Recharge Structure	**Typical Cost Range [Million INR]**
Percolation tank	0.5–6
Check dam	0.4–2
Nala bund	0.2–0.3
Recharge shaft/bore hole	0.2–0.35
Rooftop rainwater harvesting system	0.1–0.5

Source: Adapted from MWR, 2013.

Nema *et al.* (2001) based on the detailed cost analysis of a 55 MLD SAT system, revealed the cost competitiveness of the SAT system with the conventional aerobic and anaerobic wastewater treatment systems (Table 13.4). The SAT system was found to be economical, specifically in terms of recurring O&M costs. The capital costs of a SAT system mainly consist of land costs and the overall cost of a SAT system is lower if the land is available at a reasonable cost.

Table 13.4 Cost comparison of SAT system with other conventional wastewater treatment systems (system capacity: 55 MLD).

Treatment System	**Capital Cost [Million INR]**	**Annualized Investment Cost [Million INR]**	**O&M Cost [Million INR]**	**Total Annualized Cost [Million INR]**	**Specific Treatment Cost [INR/m^3]**	**Cost Ratio (Specific Treatment Cost Basis)**
Activated sludge plant (conventional)	145.0	20.4	29.0	49.4	2.45	1.55
Activated sludge plant (extended aeration)	129.0	18.0	34.0	52.0	2.60	1.65
Trickling filter	139.7	19.3	35.0	54.3	2.70	1.70
Anaerobic filter	130.0	16.9	26.0	42.9	2.13	1.35
Up-flow anaerobic sludge blanket	110.0	17.5	20.0	37.5	1.86	1.17
SAT	90.0	12.6	19.2	31.8	1.58	1.00

Source: Nema *et al.* (2001).

13.3.2 Typical costs of surface water treatment

The surface water treatment costs vary considerably due to the type and size of treatment plant and location of the plant, construction costs, equipment costs and additional costs like licenses, taxes (capital/investment costs). Table 13.5 shows some examples of typical costs of conventional surface water treatment processes based on the literature review. These are the total costs per m^3 of water treated which include installation costs as well as O&M costs (including energy and chemical costs, but excluding the costs of waste/sludge disposal).

Table 13.5 Typical costs of conventional water treatment processes.

Treatment Process	Total Costs [INR/m^3]	Relative Cost Class*	References
Coagulation	8.1–20.25	Low	de Moel *et al.* (2006)
Sedimentation	4.05–20.25	Low	de Moel *et al.* (2006)
Aeration	8.1–44.55	Low–Medium	de Moel *et al.* (2006)
Rapid sand filtration	24.3–44.55	Low–Medium	de Moel *et al.* (2006)
Slow sand filtration	56.7–121.5	Medium–High	de Moel *et al.* (2006)
Cl_2	0.57–8.91	Low	Dore *et al.* (2014)
O_3	1.22–12.15	Low	Dore *et al.* (2014)
UV	0.89–3.65	Low	Dore *et al.* (2014)
AOP	6.48–365.31	High	Goi (2005)
GAC	40.50–72.90	Medium–High	de Moel *et al.* (2006)
Activated Alumina	36.45–59.13	Medium	USEPA (2000)
Lime softening	28.35–48.60	Low–Medium	de Moel *et al.* (2006)
Ion Exchange	4.86–12.96	Low	Kratochvil *et al.* (2009)
MF	4.05–16.20	Low	Kennedy *et al.* (2013)
UF	4.05–16.20	Low	Kennedy *et al.* (2013)
NF	12.15–162.00	Low–High	Kennedy *et al.* (2013), de Moel *et al.* (2006)
RO	20.25–162.00	Low–High	Kennedy *et al.* (2013), de Moel *et al.* (2006)

*Low = <0.40 EUR/m^3, Medium = 0.40–1.00 EUR/m^3, High = 1.00–2.00 EUR/m^3.

Costs of water treatment in India

The capital cost of conventional surface water treatment (with relatively clean source water except in Delhi and Agra where it is significantly polluted) in India currently ranges from 2 to 2.2 million INR/MLD with minimal operation costs of 0.01–0.10 INR/m^3. The most expensive water treatment plant in India is in Agra with capital costs of 10 million INR/MLD and O&M costs of 4–5 INR/m^3 (WG-UIWSS, 2011). This is attributed to the extreme pollution of the Yamuna river that is currently used as a raw water source. The new water treatment plant under construction in Agra (located in Sikandra), will source its raw water through a 130 km long pipeline from an irrigation canal that carries relatively clean water as it originates from the Ganga river. Table 13.6 presents the costs of some modern water treatment plants in India.

13.4 MATRICES FOR SELECTION OF PRE- AND POST-TREATMENT FOR NTS

This section presents the matrices to be used for selection of the appropriate pre- and post-treatment for NTSs (BF, ARR and SAT). The selection matrices are in the form of tables. Each matrix includes a list of pollutants to be removed, pre-treatment/ and post-treatment system to be selected for a NTS with their indicative removal efficiencies and guidelines for drinking water quality. Where available, WHO (2011) and Indian Standard (BIS, 10500, 2012) guideline values for drinking water quality have been included in the matrices as water quality requirements to be met. These guideline values vary for some parameters in India because they have been prepared based on the exposure, magnitude of concentration and occurrence or prevalence (spatial distribution) of a specific parameter of concern and consequent risk to human health (e.g. widespread, relatively high hardness and fluoride concentrations in ambient groundwater in India). Thus according to BIS 10500 (2012), if the required concentration of a certain parameter is exceeded, it may still be tolerated up to the specified tolerance limit in the absence of an alternative source.

Table 13.6 Cost of water treatment with modern plants in India.

Treatment Plant	Technology	Capacity [MLD]	Capital Cost [Million INR]	Capital Cost [Million INR/MLD]	O&M Costs [INR/m³]	Power Costs [INR/m³]	Total O&M Costs [INR/m³]
Sonia Vihar, Delhi	Pre-settler-Pulsator + Aquazur (Degremont)	635	1,890	3	0.38	1.04	1.43
Chemba-rambakkam	Pulsator + Aquazur (Degremont)	530	1,350	2.5	0.39	0.82	1.21
TK-Halli-1	Pulsator + Aquazur (Degremont)	300	450	1.5	0.22	0.10	0.32
Nagpur	Pulsator + Aquazur (Degremont)	120	150	1.3	0.39	1.04	1.43
TK Halli-II	Aquadaf + Aquazur (Degremont)	550	1,900	3.4	0.32	0.10	0.42
Agra (Sikandra)	Conventional + MBBR	144	1,560	10.8	3–4	n.a.	4–5
Minjur, Chennai	Desalination	100	4,730	47.3	48.66	10–12	59–61
Nemmeli	Desalination	100	10,340	100	n.a.	n.a.	21

n.a.: not available.
Source: WG-UIWSS, 2011.

13.4.1 Matrix for selection of appropriate post-treatment for BF systems

Table 13.7 shows a matrix for the selection of post-treatment options for BF. The selection matrix of BF is different compared to the selection matrices of ARR and SAT because it includes only post-treatment and no pre-treatment. Post-treatment is required for BF systems when some water quality parameters of concern in bank filtrate or extracted water do not meet the drinking water guidelines and standards.

As shown in the above matrix developed for selection of post-treatment for BF, depending upon on the water quality and site conditions, typical examples of post-treatment combinations for the removal of key contaminants in bank filtrate could be:

- BF only (when there are no water quality problems with bank filtrate and water distribution systems are in very good conditions and well-maintained)
- BF + Disinfection (for removal of pathogens, and presence of low concentration of ammonium)
- BF + Aeration + Rapid Sand Filtration (RSF) + Disinfection (for removal of pathogens, ammonium, nitrate, iron and manganese)
- BF + Microfiltration (MF)/Nanofiltration (NF) + Reverse Osmosis (RO) (for pathogens, ammonium, nitrate, micropollutants, hardness and fluoride)
- BF + Aeration + RSF + Ozonation + Activated carbon filtration + Disinfection (for removal of pathogens, iron, manganese and OMPs)

13.4.2 Matrix for selection of appropriate pre- and post-treatment for ARR systems

The selection matrix for ARR (with their different possible pre- and post-treatment options together with their removal efficiencies) is presented in Table 13.8. From this table, possible combinations for ARR system can be: (i) pre-treatment + ARR, (ii) ARR + post-treatment or (iii) pre-treatment + ARR + post-treatment. ARR systems generally include pre-treatment because clogging is the critical problem in soil-based NTSs. Additionally, post-treatment may be necessary to meet the water quality standards and guidelines as some pollutants may not be removed adequately during the soil passage or because some other contaminants may be introduced into the water during the soil passage (depending on local hydrogeology/mineralogy and redox conditions).

Table 13.7 Matrix for selection of appropriate post-treatment options for BF.

Parameter	Removal Efficiency of BF	Post-treatment		Guideline Values (WHO, 2011; BIS 10500, 2012)
		Type*	Removal Efficiency	
Pathogens	1≤8.3 Log	Chlorination	1–4 Log	No pathogen in 100 mL sample
		UV	1–4 Log	
		MF/NF	3–7 Log	
		Ozonation	1–4 Log	
Hardness	–	Lime softening	60%	500 mg/L (WHO, 2011); 200 mg/L (required) & 600 mg/L in the absence of an alternate source (BIS, 10500, 2012)
		Ion exchange	35%	
		NF	85–99%	
		RO	>99%	
		Ion exchange + RO	35≥99%	
Iron/ Manganese	–	Aeration + RSF	Fe 92–97%	0.3 mg/L Fe Recommended value for aesthetic reason
			Mn 17–79%	
		Aeration + RSF + Aeration + RSF	Fe 92≥99%	
			Mn 17–96%	
		Aeration + Coagulation + RSF	Fe 92–99%	
			Mn 17–92%	
		Aeration + Coagulation + Sedimentation + RSF	Fe 95≥99%	<0.1 mg/L Mn Recommended value for aesthetic reason; 0.3 mg/L in the absence of an alternate source (BIS, 10500, 2012)
			Mn 38–87%	
		Aeration + Coagulation + RSF + MF/UF	Fe >60–100%	
			Mn <20–90%	
		Aeration + Coagulation + RSF + Ion exchange	Fe >60–100%	
			Mn <20–92%	
Fluoride	–	NF/RO	92%	1.0 mg/L (required by BIS 10500, 2012) and 1.5 mg/L (WHO, 2011; in the absence of an alternate source by BIS 10500, 2012)
		Activated Alumina	75%	
		Coagulation + NF/RO	20–97%	
		Coagulation+ Activated Alumina	20–90%	
		Ion exchange	95%	
Nitrate	50–100%	Ion exchange	90%	50 mg/L (WHO, 2011); 45 mg/L (BIS, 10500, 2012)
		NF/RO	65≥95%	
		Ion exchange + NF/RO	90–100%	
Ammonium	53–90%	Chlorination	100%	1.5 mg/L as threshold odour concentration (WHO, 2011); 0.5 mg/L (as total ammonia-N; BIS 10500, 2012)
		NF	90–98%	
		Aeration + RSF	40–50%	
		Aeration + RSF + RSF	50–75%	
		Ion exchange	97%	
OMPs**	≥50%	NF	>99%	For pesticides 0.01 (Alpha HCH) to 190 μg/L (Malathion) depending upon type (BIS, 10500, 2012)
		GAC	0–70%	
		AOP	20–99.9%	
		Ion exchange	40–100%	
		Ion exchange + NF	82–100%	
Salinity	–	NF	40–99%	50 mg/L
		RO	≥98.5%	
		NF + RO	>99%	

*Type: UV = Ultraviolet; MF = Microfiltration, NF = Nanofiltration, UF = Ultrafiltration, RO = Reverse Osmosis, RSF = Rapid sand filtration, GAC = Granular activate d carbon, AOP = Advanced oxidation process.

**Removal of OMPs is highly dependent on type of pollutant and redox conditions.

Table 13.8 Matrix for selection of appropriate pre- and post-treatment options for ARR.

Pollutants to be Removed	**Pre-treatment**		**Removal Efficiency of ARR**	**Post-treatment**		**Guideline Values (WHO, 2011)**
	Type*	**Removal Efficiency**		**Type***	**Removal Efficiency**	
Pathogens	Ozonation	1–4 Log	1≤8.3 Log	Chlorination	1–4 Log	No pathogens in 100 mL sample
	UV	1–4 Log		Ozonation	1–4 Log	
	Chlorination	1–4 Log		UV	1–4 Log	
				NF	3–6 Log	
Hardness	Lime softening	60%	–	–	–	500 mg/L
	NF	85–99%				
Turbidity	Sedimentation + Aeration + RSF/SSF	>95–100%	50–100%	MF/UF	>98%	<5 NTU
				NF	70–86%	
	MF/UF	>98%				
TSS	Sedimentation + Aeration + RSF/SSF	100%	90–100%	–	–	<1,000 mg/L
	Coagulation/ Sedimentation	50 ≥ 85%				
	UF	85–99.9%				
Iron/ Manganese	Aeration + RSF	Fe 92–97%	–	Coagulation + Sedimentation	Fe 95–96%	0.3 mg/L Fe**
		Mn 17–79%			Mn 37–38%	
	Aeration + RSF + Aeration + RSF	Fe >99%		Aeration + RSF	Fe 92–97%	<0.1 mg/L Mn**
					Mn 17–79%	
		Mn 31–96%		(Coagulation + Sedimentation) + Aeration + RSF	Fe 95≥99%	
					Mn 34–84%	
				MF/UF	Fe 95–97%	
					Mn 37–43%	
Fluoride	–	–	–	Activated alumina	75%	1.5 mg/L
				Coagulation	71%	
				NF	92%	
				RO	92%	
				Ion exchange	95%	

(*Continued*)

Table 13.8 Matrix for selection of appropriate pre- and post-treatment options for ARR (*Continued*).

Pollutants to be Removed	Pre-treatment		Removal Efficiency of ARR	Post-treatment		Guideline Values (WHO, 2011)
	Type*	Removal Efficiency		Type*	Removal Efficiency	
Arsenic	–	–	90%	Coagulation and filtration	>20%	0.01 mg/L
				Activated alumina	96%	
				NF/RO	93%	
				Ion exchange	99.43%	
				Lime softening	91%	
Nitrate	Ion exchange	90%	50–100%	Ion exchange	90%	50 mg/L
				RO	65≥95%	
Ammonium	Chlorination	100%	53–90%	NF	90–98%	
	Aeration + RSF	40–50%		Chlorination	100%	–
				Aeration + RSF	40–50%	
OMPs***	Ozonation	50≥90%	≥50%	Ozonation	50≥90%	–
				AOP	20–99.9%	
	GAC	0–70%		GAC	0–70%	
				Ion exchange	40–100%	
				NF	>99%	
Colour	Aeration + Coagulation + RSF	>60–64%	50–100%	AOP	<48%	50 mg/L
	GAC	<55%		Coagulation + Sedimentation	>60%	
				NF	70–94%	
Salinity	–	–	–	NF	40–99%	50 mg/L
				RO	≥98.5%	

*UV = Ultraviolet Radiation; MF = Microfiltration, NF = Nanofiltration, UF = Ultrafiltration, RO = Reverse Osmosis, RSF = Rapid sand filtration, SSF = Slow Sand filtration, GAC = Granular activated carbon, AOP = Advanced oxidation process.

**Recommended Fe and Mn values for aesthetic reasons.

***Removal of OMPs is highly dependent on type of pollutant and redox conditions.

Based on the water quality and site conditions, the following are typical examples of key contaminants and relevant pre- and/or post-treatment systems for the ARR to handle these key contaminants:

- Pathogens and stabilization of temperature: ARR only
- Pathogens, bulk organic matter and OMPs: Ozonation + ARR
- Pathogens: ARR + Disinfection only
- Pathogens and arsenic or other metals at low concentrations: ARR + Lime softening or Coagulation + RSF
- Pathogens, TSS and turbidity: Sedimentation + RSF + ARR
- Pathogens, TSS, turbidity, ammonium, iron and manganese: Sedimentation + RSF + ARR + Aeration + RSF + Chlorination

13.4.3 Matrix for selection of appropriate pre- and post-treatment for SAT systems

Table 13.9 shows a matrix which can be used to select the pre-and post-treatment for SAT. It also includes the pollutants to be removed by each pre- and post-treatment together with SAT. Moreover the table contains the removal efficiencies for each treatment step and guidelines values.

Depending upon source of water, quality and site conditions, the following are typical examples of the key contaminants and pre- and/or post-treatment system for SAT to handle them:

- TSS, turbidity at low concentrations: Sedimentation + SAT
- TSS, turbidity at higher concentrations: Sedimentation + Coagulation + SAT
- TSS, turbidity: UF + SAT
- Pathogens, TSS, turbidity and ammonium: MF/UF + SAT + Chlorination
- Pathogens, ammonium, nitrate and salinity: SAT + NF/RO
- Pathogens, TSS, turbidity, iron and manganese: Coagulation + Sedimentation + RSF + SAT + Aeration + RSF + Chlorination
- Pathogens, salinity, iron, manganese, ammonium, bulk organic matter and OMPs: Ozonation + SAT + Aeration + RSF + NF

13.4.4 Use of the matrices for selection of pre- and post-treatment options

The stepwise procedure to use the matrix tables for selection of pre- and post-treatment for different NTS is as follows (Figure 13.2). However, under certain circumstances NTS can also cause risks to ambient groundwater (environment) and human health. Thus, the implementation of NTS should be undertaken using a structured management approach to assess the risks. In this context and in addition to the use of the following matrix tables, approaches presented in well-established MAR Guidelines (NRMMC–EPHC–NHMRC, 2009; Page *et al.* 2010) and a risk-based assessment and management approach to BF in India under local conditions (Bartak *et al.* 2014), should be considered:

- Collect raw water quality and hydrological/hydrogeological data for the given site intended for NTS.
- Select the type of NTS to be used based on the water quality and hydrological/hydrogeological data.
- Check in the appropriate matrix table which contaminants require pre-treatment or post-treatment or both to meet the water quality guidelines.
- Make all possible combinations of pre- and post-treatment options for those contaminants from the matrix table.
- Estimate the final water quality with different combinations of pre- and post-treatment options. In order to assess the final quality, first calculate the removal of a given contaminant in pre-treatment, NTS and post-treatment. Also consider the effects of dilution if some natural groundwater is also abstracted together with the infiltrated or recharged water (Sharma et al., 2012a). When the dilution effect is taken into consideration separately, the final concentration of a pollutant can be computed using the following relation:

  $$C_{\text{final}} = C_{\text{source}} * (1-R_{\text{PRE}}) * (1-R_{\text{NTS}}) * (1-R_{\text{POST}}) \tag{13.1}$$

  where C_{source} = concentration of a pollutant in source water, C_{final} = final concentration of a pollutant after post-treatment, R_{PRE}, R_{NTS}, R_{POST} = removal efficiency of a pollutant in pre-treatment system, NTS and post-treatment system respectively.
- If there is more than one treatment step in pre-treatment or post-treatment, then R_{PRE} and R_{POST} refers to overall removal efficiencies of all the steps involved.
- Assess the final results by comparing them with the guidelines or standards.
- Select the options that meet the water quality requirements.
- For each alternative (that meet water quality requirements) estimate the total costs by adding the costs of pre-treatment, NTS and post-treatment.

Table 13.9 Matrix for selection of appropriate pre- and post-treatment options for SAT.

Pollutants to be Removed	Pre-treatment		Removal Efficiency of SAT**		Post-treatment			Guideline Values (WHO, 2011)
	Type*	**Removal Efficiency**			**Type***	**Removal Efficiency**		
Pathogens	Chlorination	1–4 Log	PE	>1–6.9 Log	Chlorination	1–4 Log		No pathogens in 100 mL sample
	UV	1–4 Log	SE	0–6.5 Log	Aeration + RSF	0.4–4 Log		
	Ozonation	1–4 Log	TE	0.4–4.0 Log	Ozonation	1–4 Log		
	MF/UF	0–7 Log			UV	1–4 Log		
					NF/RO	3–7 Log		
Hardness	–	–	PE	–	NF	85–99%		500 mg/L
			SE	–	Ion exchange + NF	90–99%		
			TE	–	RO	>99%		
Turbidity	UF	>98%	PE	50–100%	–	–		<5 NTU
			SE	50–100%				
	Coagulation + Sedimentation	>95%	TE	50–100%				
TSS	UF	85–99.9%	PE	86–100%	–	–		<1,000 mg/L
	Coagulation + Sedimentation	60≥85%	SE	>90–100%	–	–		
	Aeration + RSF	70–80%	TE	>90–100%	–	–		
Iron/ Manganese	–	–			Coagulation + Sedimentation	Fe	95–96%	0.3 mg/L Fe***
						Mn	37–38%	
			PE	–	Aeration + RSF	Fe	92–97%	<0.1mg/L Mn***
						Mn	17–79%	
			SE	–	(Coagulation + Sedimentation)+ (Aeration + RSF)	Fe	95≥99%	
			TE	–		Mn	48–87%	
					Aeration + RSF + MF/UF	Fe	>99%	
						Mn	48–88%	

Nitrate	Ion exchange	90%	PE	57–100%	Ion exchange	90%	50 mg/L
	RO	65≥95%	SE	3≥90%	RO	65≥95%	
			TE	0–22%			
Ammonium	NF/RO	90–98%	PE	25–99%	Ion exchange	98%	–
			SE	0–99%	NF/RO	90–98%	
					Chlorination	100%	
			TE	17–100%	Aeration + RSF	40–50%	
OMPs****	UF	>90%	PE	75–100%	Ion exchange	40–100%	–
	RO	70–99.9%			Ozonation	50≥90%	
			SE	20–100%	AOP	20–99.9%	
					GAC + AOP	20–100%	
					Ion exchange	40–100%	
			TE	10–100%	NF	>99%	
					RO	70–99.9%	
Salinity	–	–	PE	–	NF	40–99%	50 mg/L
			SE	–	RO	≥98.5%	
			TE	–	NF + RO	>99%	

*Type: UV = Ultraviolet Radiation; MF = Microfiltration, NF = Nanofiltration, UF = Ultrafiltration, RO = Reverse Osmosis, RSF = Rapid sand filtration, GAC = Granular activated carbon, AOP = Advanced oxidation process.

**SAT: PE = primary effluent, SE = secondary effluent, TE = tertiary effluent.

***Recommended Fe and Mn values for aesthetic reasons.

****Removal of OMPs is highly dependent on type of pollutant and redox conditions.

- Rank different possible combinations of pre- and post-treatment for a given NTS based on the removal efficiencies and cost effectiveness for decision making.

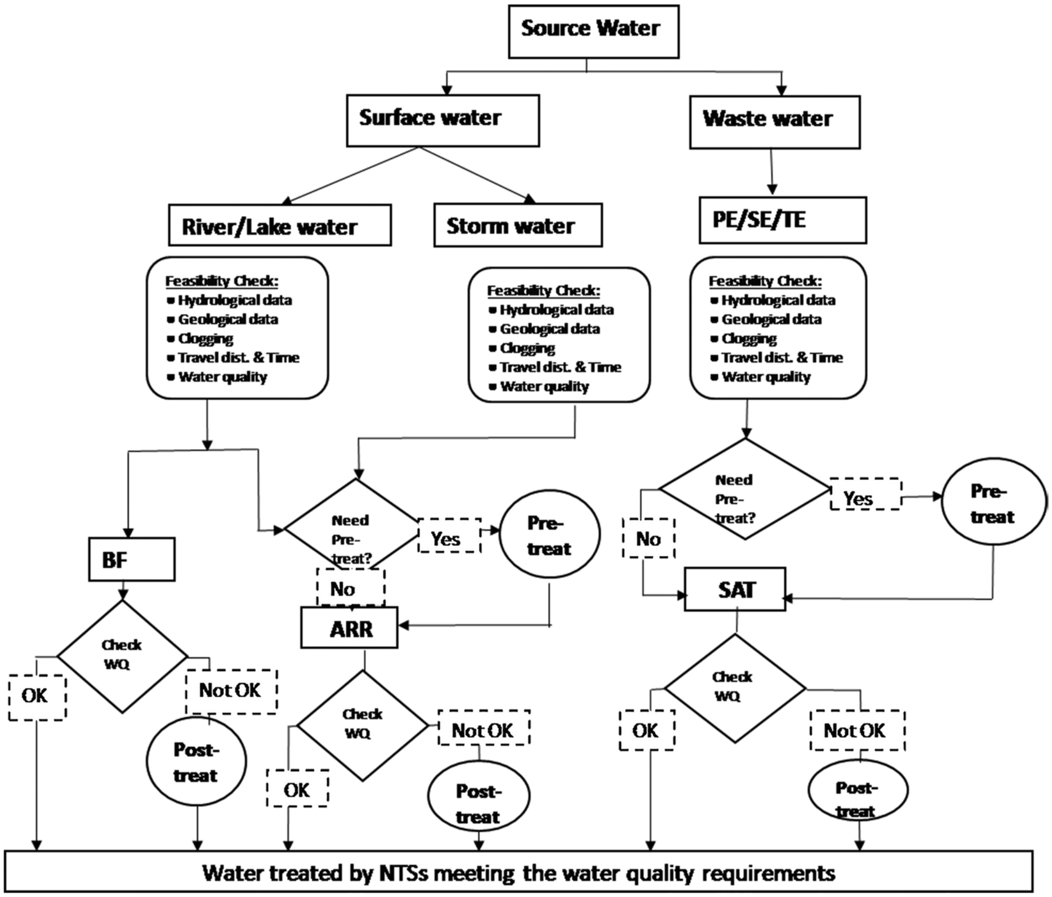

Figure 13.2 Framework for selection of pre- and/or post-treatment (PE = primary effluent, SE = secondary effluent, TE = tertiary effluent, WQ = Water quality).

Two examples of the use of the matrices developed for the selection of pre- and post-treatment of NTS under given conditions (BF and ARR respectively) are presented in the Annex of this chapter.

It is to be noted that engineering judgment in the selection of a proper treatment combination (pre-treatment + NTS + post-treatment) is required. For the correct selection of a treatment system availability of energy, chemicals and skilled manpower as well as cost of land play an important role.

13.5 CONCLUSION

Soil-based NTSs, namely BF, ARR and SAT, have been used in different parts of the world for water and wastewater treatment and reuse. While assessing the feasibility of NTSs at a given site, all the components of the NTS (including pre- and post-treatment) as well as local regulations, water quality guidelines and institutional capacities should be taken into consideration. Source water quality and local hydrological/hydrogeological conditions determine the type of NTS which is most favorable and feasible under given conditions. Furthermore, treated water quality requirements (local guidelines and standards) as well hydrogeological conditions at the intended site determine the pre- and post-treatment requirements.

Comprehensive literature data on cost of NTS as well as some common conventional treatment processes (used as pre- and post-treatment) were compiled. In general, when the source water quality and local hydrogeological conditions are favorable, BF is the cheapest and most effective method of water treatment for developing countries requiring no or minimal post-treatment. ARR is attractive when relatively cheap land is available nearby and BF is not feasible due to local hydrogeological conditions. SAT is an attractive option for polishing wastewater effluents with the aim of water reuse provided the local regulation permits such technology and if the clogging of the aquifer can be minimized by proper pre-treatment and operation of the system.

Also, a comprehensive compilation of removal efficiencies of NTS was made as well as of common conventional treatment processes for different pollutants generally present in water. They were presented in the form of matrices/tables to facilitate selection of appropriate treatment process to remove a particular pollutant. In addition, stepwise procedures for the selection of the most suitable pre- and post-treatment systems for any given NTS were developed.

Several combinations of pre- and post-treatment together with a NTS can meet the water quality guideline values and standards for the intended use. Determination of capital and O&M costs of each of the feasible options is required to rank them in terms of cost effectiveness. It is expected that the matrices and the developed selection procedure can be used by designers and planners to make a preliminary selection of NTS and associated pre- and post-treatment systems.

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13.7 APPENDIX

Example of application of matrices developed for selection of pre- and post-treatment options

A.1 Example of selecting post-treatment for a BF system

River water is proposed to be used as a source; there is an alluvial aquifer of 60 m depth at site and travel distance and travel time are expected to be 150 m and 4 months respectively. Critical pollutants to be treated after BF are iron and manganese (due to local hydro-geological conditions) with estimated concentrations of 5 mg/L and 1 mg/L respectively in the bank filtrate. It is required to find the appropriate treatment train with or without post-treatment processes.

The selection of post-treatment alternatives for iron and manganese removal, calculations of removal efficiencies of each alternative and comparison of the costs of selected alternatives are presented in the following tables.

Table 13A.1 Treatment alternatives to remove iron and manganese (from the BF matrix table 13.7).

Water Type	NTS	Post-treatment	Output
River water	BF	Aeration + RSF Aeration + RSF + Aeration + RSF* Aeration + Coagulation + RSF Aeration + Coagulation + Sedimentation + RSF	Treated water meeting guideline values

*Applied when iron and manganese concentrations are high or when iron, manganese and ammonium are present.

From the above selection table it is clear that both options meet the guidelines although option 2 is more efficient than option 1. In terms of costs, option 1 is cheaper than option 2. Consequently, option 1 is selected because it meets the guidelines and is cheaper than option 2. Furthermore, the water is generally chlorinated before supply to maintain disinfectant residual in the distribution system. Then, a schematic diagram of the proposed treatment system for given condition would be:

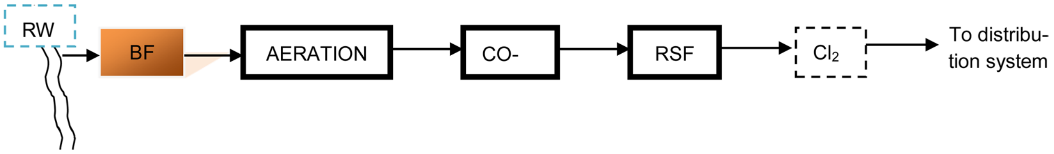

Table 13A.2 Calculation of removal efficiencies and comparison with guidelines.

River Water		BF		Post-treatment			Comparison	
Pollutant	**C_{source}** mg/L	**Eff_0 %**	**Conc. rem_{i+1}** mg/L	**Process**	**Eff_1** %	**Conc. rem_{i+2} mg/L**	**Guideline Values mg/L**	**Remarks**
Fe	–	–	5	Aeration + RSF	92–97	0.15–0.3	0.3	Yes
Mn	–	–	1		17–79	0.21–0.83	<0.1	No
Fe	–	–	5	**Aeration + RSF + Aeration + RSF**	92≥99	**<0.05–0.4**	**0.3**	**Yes**
Mn	–	–	1		17–96	**0.04–0.83**	**<0.1**	**Yes**
Fe	–	–	5	**Aeration + Coagulation + RSF**	92–99	**0.05–0.4**	**0.3**	**Yes**
Mn	–	–	1		17–92	**0.08–0.83**	**<0.1**	**Yes**
Fe	–	–	5	Aeration + Coagulation + Sedimentation + RSF	95≥99	>0.05–0.25	0.3	Yes
Mn	–	–	1		38–87	0.13–0.62	<0.1	No
Fe	–	–	5	Aeration + Coagulation + RSF + MF/UF	>60–100	0.00–2.00	0.3	Yes
Mn	–	–	1		<20–90	0.1≥0.8	<0.1	No

NB: Conc. rem. $_{i+(n+1)}$ = (100–eff_n/100) Conc.$_{i+n}$.

Yes: Means pollutant can be removed either with minimum removal efficiency or maximum removal efficiency.

No: Means pollutant cannot be removed at up to the required level with the proposed treatment process.

Table 13A.3 Cost comparison of selected alternatives.

NTS		Post-treatment		Comparison	
Type	**$Costs_1$ (Euro/m^3)**	**Process**	**$Costs_2$ (Euro/m^3)**	**Total $Costs_{1+2}$ (Euro/m^3)**	**Rank**
BF	0.03–0.17	**Aeration + Coagulation + RSF**	**0.20–1.35**	**0.23–1.52**	**1**
		Aeration + RSF + Aeration + RSF	0.80–2.20	0.83–2.37	2

A.2 Example of selecting pre-and post-treatment options for an ARR system

Stormwater is available as the source of the water; the soil-aquifer system which can be used for NTS is made up of a phreatic aquifer; travel distance and travel time are expected to be 150 m and 4 months respectively. The depth of vadose zone was estimated to be 5.0 m. The major pollutants to be removed are iron, manganese and hardness with estimated concentrations of 3 mg/L, 0.8 mg/L and 240 mg/L respectively in the source water. It is required to determine the appropriate pre-and/ post-treatment processes for ARR system.

The selection of pre- and post-treatment alternatives for iron, manganese and hardness removal, calculations of removal efficiencies of each treatment alternative and comparison of the costs of selected alternatives are presented in the following tables.

Table 13A.4 Treatment alternatives to remove iron and manganese (from the ARR matrix table 13.8).

Water Type	Pre-treatment	NTS	Post-treatment	Output
Storm water	Aeration + RSF	ARR	ARR Aeration + RSF	Treated water meeting guideline values
			Aeration + RSF + RSF	
			Aeration + Coagulation + RSF	
			Aeration + Coagulation + Sedimentation + RSF	
			Aeration+ Coagulation + RSF + MF/UF	

Table 13A.5 Treatment alternatives to hardness (from the ARR matrix table 13.8).

Water Type	Pre-treatment	NTS	Post-treatment	Outcome
Storm water	–	ARR	–	Treated water meeting guideline values
	Lime softening	ARR	–	
	FN	ARR	–	

Table 13A.6 Calculation of removal efficiencies for iron and manganese and comparisons with guidelines.

River Water		Pre-treatment			ARR		Post-treatment			Comparison	
Pollutant	**C$_{source}$** mg/L	**Process**	**Eff$_1$ (%)**	**Conc. rem$_{i+2}$ mg/L**	**Eff$_0$ (%)**	**Conc. rem$_{i+1}$ mg/L**	**Process**	**Eff$_1$ (%)**	**Conc. rem$_{i+2}$ mg/L**	**Guideline Values mg/L**	**Remarks**
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	Aeration + RSF	92–97	0.003–0.020	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		17–79	0.04–0.55	<0.1	Yes
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	Aeration + RSF + Aeration + RSF	92≥99	0.001–0.02	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		17–96	0.007–0.55	<0.1	Yes
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	Aeration + Coagulation + Aeration + RSF	92–99	<0.001–0.02	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		17–92	0.01–0.55	<0.1	Yes
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	Aeration + Coagulation + Sedimentation + RSF	95≥99	0.001–0.012	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		38–87	0.02–0.41	<0.1	Yes
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	Aeration + Coagulation + RSF + MF/UF	>60–100	0≥0.096	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		<20–90	0.02–0.53	<0.1	Yes
Fe	3	Aeration + RSF	92–97	0.09–0.24	–	0.09–0.24	–	–	0.09–0.24	0.3	Yes
Mn	0.8		17–79	0.17–0.66	–	0.17–0.66		–	0.17–0.66	<0.1	No
Fe	3	–	–	3	–	3	Aeration + RSF	92–97	0.09–0.24	0.3	Yes
Mn	0.8		–	0.8	–	0.8		17–79	0.17–0.66	<0.1	No
Fe	3	–	–	3	–	3	Aeration + RSF + Aeration + RSF	92≥99	0.03–0.24	0.3	Yes
Mn	0.8		–	0.8	–	0.8		17–96	0.03–0.66	<0.1	Yes
Fe	3	–	–	3	–	3	Aeration + Coagulation + RSF	92–99	0.03–0.24	0.3	Yes
Mn	0.8		–	0.8	–	0.8		17–92	0.06–0.66	<0.1	Yes
Fe	3	–	–	3	–	3	Aeration + Coagulation + Sedimentation + RSF	95≥99	0.03–0.15	0.3	Yes
Mn	0.8		–	0.8	–	0.8		38–87	0.10–0.5	<0.1	No
Fe	3	–	–	3	–	3	Aeration + Coagulation + RSF + MF/UF	>60–100	0–1.2	0.3	Yes
Mn	0.8		–	0.8	–	0.8		<20–90	0.08–0.64	<0.1	Yes

Table 13A.7 Calculation of removal efficiencies for hardness and comparisons with guidelines.

River Water		Pre-treatment			ARR		Post-treatment			Comparison	
Pollutant	**C$_{source}$** mg/L	**Process**	**Eff$_0$ (%)**	**Conc. rem$_{i+1}$ mg/L**	**Eff$_1$**	**Conc. rem$_{i+2}$ mg/L**	**Process**	**Eff$_2$**	**Conc. rem$_{i+3}$ mg/L**	**Guideline mg/L**	**Remarks**
Hardness	240	–	–	240	–	240	–	–	240	500	Yes
Hardness	240	Lime softening	60	96	–	96	–	–	96	500	Yes
Hardness	240	**NF**	**85–99**	**2.4–36**	**–**	**2.4–36**	**–**	**–**	**2.4–36**	**500**	**Yes**

NB: Conc. rem. $_{i+(n+1)}$ = (100-eff$_n$/100) Conc$_{i+n}$.
Yes: Means pollutant can be removed either from minimum removal efficiency or/to maximum removal efficiency.

Table 13A.8 Cost comparison of selected alternatives for iron and manganese removal.

Pre-treatment		NTS		Post-treatment		Comparison	
Process	**Costs$_2$ (Euro/m^3)**	**Type**	**Costs$_1$ (Euro/m^3)**	**Processes**	**Costs$_2$ (Euro/m^3)**	**Total Costs$_{1+2}$ (Euro/m^3)**	**Rank**
Aeration + RSF	0.40–1.10	ARR	0.093–0.206	Aeration + RSF	0.40–1.10	0.893–2.406	3
Aeration + RSF	0.40–1.10			Aeration + RSF + Aeration + RSF	0.80–2.20	1.293–3.506	7
Aeration + RSF	0.40–1.10			Aeration + Coagulation + RSF	0.50–1.35	0.993–2.656	4
Aeration + RSF	0.40–1.10			Aeration + Coagulation + Sedimentation + RSF	0.55–1.60	0.943–2.906	6
Aeration + RSF	0.40–1.10			Aeration + Coagulation + RSF + MF/UF	0.55–1.55	1.043–2.856	5
–	–			Aeration + RSF + Aeration + RSF	0.80–2.20	0.893–2.406	3
–	–			**Aeration + Coagulation + RSF**	**0.50–1.35**	**0.593–1.556**	**1**
–	–			Aeration + Coagulation + RSF + MF/UF	0.55–1.55	0.643–1.756	2

Table 13A.9 Cost comparison of selected alternatives for hardness removal.

Pre-treatment		NTS		Post-treatment		Comparison	
Process	**Costs$_2$ (Euro/m^3)**	**Type**	**Costs$_1$ (Euro/m^3)**	**Process**	**Costs$_2$ (Euro/m^3)**	**Total Costs$_{1+2}$ (Euro/m^3)**	**Rank**
–	**–**	ARR	0.093–0.206	–	–	0.093–0.206	1
Lime softening	0.35–0.60			–	–	0.443–0.806	2
NF	0.15–2.00			–	–	0.243–2.166	3

It is clear from the above table 13A.9 that option 1 is the cheapest and it will be selected for hardness removal. Table 13A.8 shows that, for iron and manganese removal, option 1 is the cheapest and will be selected. The two options will be combined to form the post-treatment system. Although ARR may not be effective for removal of iron, manganese and hardness but it will be used for removal of some turbidity and TSS and some pathogens that may exist in the source water. Iron and manganese in abstracted water will be removed by the post-treatment system. Furthermore, the water is generally chlorinated before supply to maintain disinfectant residual in the distribution system. The following is the schematic diagram of the treatment system proposed for removal of iron, manganese and hardness: