Saph Pani

Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India

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Matrix for Feasibility Assessment of Natural Treatment Systems and Selection of Post-treatment

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AOP	Advanced Oxidation Process
ARR	Artificial Recharge and Recovery
BAC	Biological Activated Carbon
BF	Bank Filtration
CWs	Constructed Wetlands
DOC	Dissolved Organic Carbon
FC	Faecal Coliform
GAC	Granular Activated Carbon
HLR	Hydraulic Loading Rate
KLD	Kilolitres per Day
MAR	Managed Aquifer Recharge
MBBR	Moving Bed Biofilm Reactor
MF	Microfiltration
MLD	Millions Liters per Day
NF	Nanofiltration
NTS	Natural Treatment System
NTU	Nephelometric Turbidity Units
OMP	Organic Micropollutant
O&M	Operation and Maintenance
PE	Primary Effluent
RSF	Rapid Sand Filter
RCW	Radial Collector Wells
RO	Reverse Osmosis
RWH	Rainwater Harvesting
SAT	Soil Aquifer Treatment
SE	Secondary Effluent
SS	Suspended Solids
SSF	Slow Sand Filter
TC	Total Coliform
TE	Tertiary Effluent
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
UF	Ultrafiltration
UV	Ultraviolet

1. Introduction

1.1 Background and scope of the report

Work package 4 of EU Saph Pani Project deals with the post-treatment aspects of natural treatment systems (namely bank filtration BF, managed aquifer recharge MAR, constructed wetlands CWs and other natural systems for wastewater treatment). One of the objectives under this work package is to develop matrices for the feasibility assessment and selection of post-treatment options for different types of natural treatment systems (NTSs) for water and wastewater treatment and reuse. These decision support matrices are expected to help planners and designers in assessing different options and selecting the appropriate NTSs and subsequent post-treatment systems based on source water quality, hydrogeological conditions at site, treated water quality requirements and costs.

This deliverable focuses on three main soil-based NTSs namely BF, artificial recharge and recovery ARR and soil aquifer treatment SAT whereas feasibility assessment and post-treatment requirements of CW and other NTSs for wastewater treatment and reuse are presented in D3.4. It outlines the conditions favorable for these soil-based NTSs, lists different pre- and post-treatment options available and finally elaborates the stepwise methodology for selection of appropriate pre- and post-treatment options for given NTSs. Additionally, it also presents typical costs of different NTSs and post-treatment options based on literature review.

1.2 Feasibility assessment of different NTSs

Soil-based NTSs namely BF, ARR and SAT has been employed for water and wastewater treatment and reuse in different parts of the world. Bank filtration (river or lake) has been practiced as a method of "abstraction" of water from alluvial deposits in hydraulic contact with surface water sources for more than 100 years. 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 specific term designated for methods employed to recharge wastewater treatment plant effluents aiming at subsequent reuse (Sharma and Amy, 2010).

In general, soil-based NTSs or MAR systems will be feasible where the following three key areas are adequately addressed (DWLBC, 2002):

(i) hydrogeological and technical system design and operation to achieve benefits that exceed costs

(ii) system compliance with local policies and regulations, within a progressive regulatory regime (with adequate institutional capacity)

(iii) establishment of suitable consultative mechanisms to allow satisfactory stakeholder negotiations

Several technical factors influence the feasibility of a soil-based NTS at a particular site. These includes 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. Conditions favourable to different types of NTSs are presented in detail in the following sections.

1.2.1 Conditions favourable for BF

Bank filtration, as an "engineered natural system" for water treatment, has been employed dating back to the nineteenth century (Eckert and Irmscher, 2006). During BF, river or lake water is extracted indirectly by drawing it through the subsurface prior to use. Extraction is accomplished by an infiltration gallery, line of wells (horizontal, vertical or at an angle) or even single well (designed according to demand requirements) located at a short to intermediate distance from the bank of a river or lake. The water quality improvement performance of a BF system depends on a number of variables: (i) source water quality, (ii) characteristics and composition of alluvial aquifer materials, (iii) geochemistry, (iv) filtration velocity and distance of the well(s) from river/lake, (v) temperature of the water, (vi) pumping rate, (vii) soil/sediment characteristics at the river-aquifer interface, and (viii) groundwater dilution.

In general, the following conditions are favourable for BF systems:

(i) Hydrological condition

- Availability of alluvial aquifer (fluvial, marine, lacustrine) at a depth from 5 -120 m
- Low or gentle slope from river bed to ground water table
- Sediments profile arrangement should be from highly permeable to impermeable fine grained silt and mud (Doussan et al., 1997)

(ii) Geological condition

- Aquifer mineralogy which will enable natural removal or reaction without adding any other contaminants
- Temperature and oxygen concentration which will enable organism to biodegrade organic matter

- o Shape of materials of the sediments which will be easily facilitate the filtration of the pollutants, e.g. fine clay, silt and rounded sandy (Sahoo et al., 2005).
- o Travel distance and travel time >100 m and >3 months respectively (Sharma, 2013; Maeng et al., 2013). It is to be noted that in BF systems of Uttrakhand (India), where source water is relatively clean, significant water quality improvement has been observed even at shorter travel distances of 5 to 90 m (travel times of 3 to 15 days).

(iii) Water quality parameters

- o Concentration of suspended solids in the range of 11-152 mg/L is suitable to avoid clogging in BF (Laszio and Literathy, 2002).
- o If concentrations of pollutants are such that their removal by BF can meet the water quality guidelines, then BF only is sufficient as treatment option.
- o If the source water quality parameters are poor such that BF only cannot meet the guidelines, then post-treatment will be required. If NH_4^+>28 mg/L, NO_3^->300 mg/L or organic micropollutants are present in source water then BF only may not be sufficient. The alternative is to apply BF with post-treatment or to apply ARR (Buzek et al., 2006; Doussan et al., 1997; Jekel and Gruenheid, 2005).

1.2.2 Conditions favourable for ARR

Artificial Recharge and Recovery (ARR) systems are designed for intentional treatment, storage, and withdrawal of water in aquifers. ARR methods are employed when the local geological conditions and/or water quality in the river/lake are not suitable for BF, or when different source waters are available (e.g., stormwater). ARR can be employed without pre-treatment of the source or the source water can be treated to the required level prior to recharge. Artificial recharge is also practiced to control seawater intrusion into coastal aquifers, control land subsidence caused by declining groundwater levels, maintain base flow in some streams, and raise water levels to reduce the cost of groundwater pumping.

Depending upon the local hydrogeological conditions as well as quantity and quality of water available for recharge, different types of ARR systems are employed. Some of the common ARR methods include infiltration ponds, trenches, check dams, dug wells, vadose zone wells and direct injection wells. Surface infiltration systems can be used to recharge unconfined aquifers only. Confined aquifers can be recharged with wells that penetrate the aquifer. Well recharge is also used for unconfined aquifers if suitable land for infiltration systems is not available.

Table 1 compares the engineering factors for three major ARR systems and Table 2 summarizes the advantages and disadvantages of vadose zone and direct injection wells.

Table 1 Comparison of engineering factors for three major artificial recharge and Recovery (ARR) systems (Source: USEPA, 2004)

	Recharge Basins	Vadose zone injection wells	Direct injection wells
Aquifer Type	Unconfined	Unconfined	Unconfined or confined
Pre-treatment Requirements	Low technology	Removal of solids	High technology
Estimated Major Capital Costs (US $)	Land and distribution system	25,000 – 75,000 per well	500,000 – 1,500,000 per well
Capacity	100-20,000 m^3/ha-d	1,000-3,000 m^3/d per well	2,000-6,000 m^3/d per well
Maintenance Requirements	Drying and scraping	Drying and disinfection	Disinfection and flow reversal
Estimated Life Cycle	> 100 years	5-20 years	25-30 years
Soil Aquifer Treatment	Vadose zone and saturated zone	Vadose zone and saturated zone	Saturated zone

Table 2 Comparison of vadose zone and direct injection recharge wells (USEPA, 2012)

Recharge method	Main advantages	Main disadvantages
Vadose zone wells	Suitable for unconfined aquifers	Inability to rehabilitate clogged wells
	Bypass low permeability layers	Decreased certainty of migration pathways
	Decrease travel time to aquifers versus surface spreading	Requires operation to avoid air entrainment
	Lower cost	Deeper wells needed to penetrate deep clay layers
	SAT benefits to water quality	New wells required periodically
	May allow smaller setback from extraction wells	Greater risk of water loss
Groundwater injection wells	Can target specific aquifers and locations	Wells can be costly to install and maintain
	Benefits groundwater levels immediately	Periodic pumping required to maintain capacity
	Wells can be cleaned and redeveloped	Foot valves may be required to minimize air entrainment
	Can be maintained for a longer life	

In general, the availability of (i) suitable aquifer (sites for creating sub-surface reservoir in suitable hydrogeological environment through cost effective artificial recharge techniques) and (ii) sufficient quantity of water of reasonable quality, are two main prerequisite for ARR system.

The followings are the conditions favourable for ARR systems:

(i) Hydrological conditions

- Availability of phreatic type of aquifer with high hydraulic conductivity (10^{-2} m/s to 10^{-4} m/s) to provide sufficient well yield
- Availability of monsoon run off with a rainfall of <1000 mm/annum.
- Availability of appropriate hydrological environments of about 40-100 hectares which will support sub-surface reservoir.
- Low water level fluctuation (CGWB, 2000)

(ii) Geological conditions

- Slope in the range of 1:10 to 1:500 from river source to groundwater table to allow infiltration of water
- Vadose zone should be at least 3 m high to enable the filtration process from the surface to the ground water table
- Aquifer thickness should be more than 10 m to provide sufficient storage volume. It should be able to absorb a large amount of water and to release it slowly (CGWB, 2000)
- Preferable travel time is > 50 days (Maeng et al., 2013).

(iii) Water quality parameters

- Concentration of suspended solids of <12 mg/L and infiltration rate of <0.1 m/h for avoiding clogging in ARR (CGWB, 2000).
- If water quality parameters are not so severe but seem to affect performance of ARR, then pre-treatment can be applied.
- If the parameters are not so severe to affect performance of ARR but the "filtrate" from ARR may not meet the water quality guidelines then post-treatment must be applied.

ARR is not favourable under the following conditions:

(i) High concentration of suspended solids (> 12 mg/L) which needs extensive pre-treatment

(ii) Only confining type of aquifer with impermeable characteristics is available

(iii) If the water table can rise up to less than 3 m below the ground (CGWB, 2000).

(iv) Clay/silt or black-cotton soil.

(v) A slope of more than 1:10 (CGWB, 2000)

1.2.3 Conditions favourable for SAT

SAT is conceptually similar to ARR and has been practiced in different parts of the world for further polishing and groundwater recharge of primary, secondary and tertiary effluents from wastewater treatment plants. The important factors in site evaluation and selection are (i) soil depth, (ii) soil permeability, (iii) depth to groundwater (depth of vadose zone), (iv) aquifer thickness (depth from water table to bedrock/confining layer), and (v) groundwater flow direction and velocity (Sharma et al., 2012b). Depending upon the quality of recharge water available and local hydrogeological conditions, infiltration ponds or vadose zone wells have been employed for improving the effluent quality by SAT.

In general, the followings are the conditions favourable for SAT systems:

(i) Hydrological/Geological conditions

- o Availability of land and high permeable soil vadose zone with unconfined aquifer below is favourable for SAT using infiltration basins
- o If land is unavailable (or costly) and the top layer soil is soft and unable to withstand the infiltration basin, then vadose infiltration SAT is applicable.
- o Water table is deeper and aquifer is at higher depth (> 46 m), then vadose zone infiltration is not suitable. The alternative is to employ direct injection well (USEPA, 2012; Metcalf and Eddy, 2007).
- o Travel distance >30 m and travel time >10 days

(ii) Clogging conditions

- o Very low amount of inorganic (clay and silt) and organic (algae/sludge) suspended solids in raw water
- o Absence or low rate of formation of iron and manganese oxide/hydroxides precipitation and low formation of $CaCO_3$ precipitation.
- o Low or no biofilm formation on soil particles and low production of gases (like nitrogen, methane and carbon dioxide) from bacteria/microorganisms (Bouwer, 1999; Bouwer, 2002)

(iii) Water quality parameters

- o Concentration of suspended solids is <45 mg/L.

SAT is not favourable under following conditions

(i) Weak top layer soil and aquifer at a high depth (> 50 m).The vadose zone well cannot be applicable due to the difficulty in cleaning of wells and formation of several types of clogging. This situation needs extensive pre-treatment which can be very expensive.

(ii) There is a confined aquifer at a high depth (> 46 m) and the injection well is very expensive to apply. Then it is better to use conventional wastewater treatment systems (Metcalf and Eddy, 2007; USEPA, 2012).

(iii) Inorganic (clay and silt) and organic (algae/sludge) suspended solids in raw water are very high.

(iv) High rate of formation of iron and manganese oxide/hydroxides precipitates and $CaCO_3$ precipitates are sources of clogging to the SAT.

(v) High biofilm formation on soil particles and high production of gases (like nitrogen, methane and carbon dioxide) from bacteria/microorganisms then the SAT will clog (Bouwer, 1999; Bouwer, 2002).

2. Typical pollutants and pre- and post-treatment applied to different soil-based NTSs

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 hydrogeological conditions on site. 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. The type of pre- and post-treatment systems required depend on the type of NTS employed, source water and quality (rain water, urban runoff, river or lake water, wastewater treatment plant effluent), local hydrogeological conditions, process conditions (hydraulic loading rate, travel time/distance, abstraction rate) applied and intended use of the water after the NTSs (Figure 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 and 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 (NRMMC–EPHC–NHMRC, 2009).

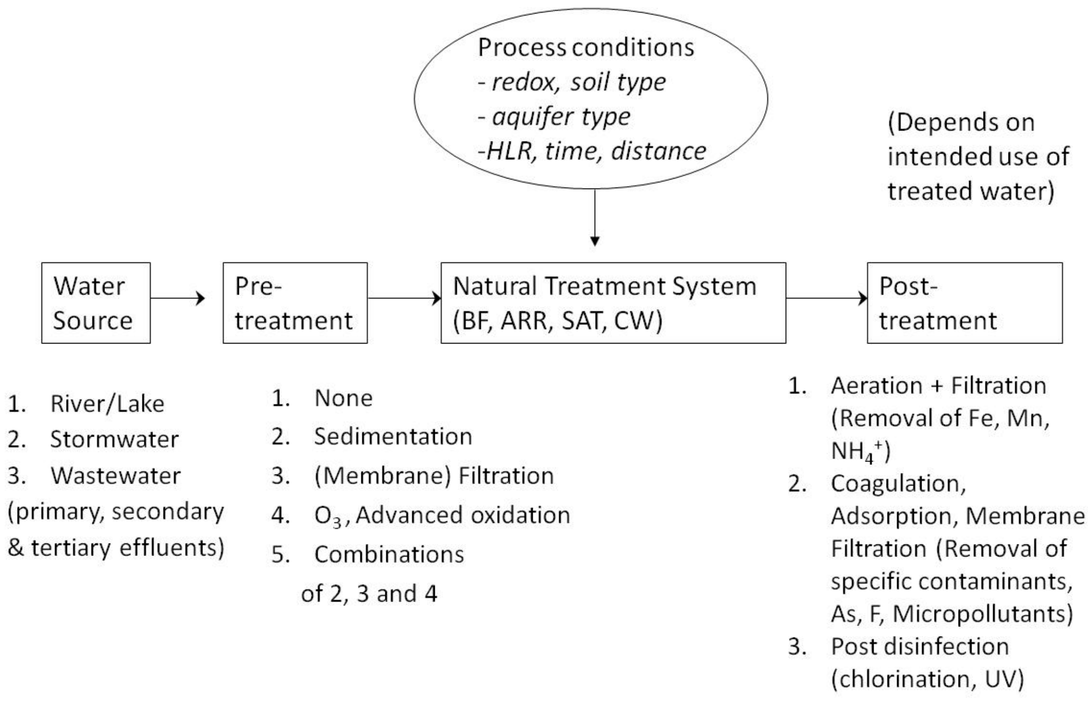

Figure 1 Natural treatment system components

It is to be noted that the pollutant removal efficiencies of NTSs and conventional above-the-ground-treatment processes (pre- and post-treatment) is highly dependent 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 3. 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 15, 16 and 17 which provide matrices for selection of pre- and post-treatment for BF, ARR and SAT systems respectively.

Table 3 Indicative removal efficiencies of typical pollutants by different NTSs

Pollutant	BF	ARR	SAT		References
Heavy metals	90%	90%	PE	100%	Idelovitch (2003)
			SE	100%	
			TE	100%	
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)
			SE	50-100%	
			TE	50-100%	
Colour	50-100%	50-100%	PE	50-100%	Saph Pani (2013)
			SE	50-100%	
			TE	50-100%	
Pathogens					
• Bacteria	2-6 Log	2-6 Log	PE	1.2-6.9 Log	WHO (2011)
			SE	3.0-6.5 Log	
			TE	2.4-3.0 Log	
• Viruses	2.1-8.3 Log	2.1-8.3 Log	PE	4.0 Log	WHO (2011)
			SE	0->4.0 Log	
			TE	0.4-4.0 Log	
• *Giardia*	1->2 Log	1->2 Log	PE	1->2 Log	WHO (2011)
			SE	1->2 Log	

Pollutant	BF	ARR	SAT		References
			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 (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 (2013), Sharma et al. (2012a), 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 (highly dependent on type of pollutant and redox conditions)	≥50%	≥50%	PE	75-100%	Sharma (2013)
			SE	20-100%	
			TE	10-100%	
DOC/TOC	>25% - ≥50%	≥50%	PE	10-91%	Sharma (2013), Miehe et al. (2010), Quanrud et al. (2003) Harun (2007), Abel et al. (2014)
			SE	10->90	
			TE	20->80	

Pollutant	BF	ARR	SAT	References
Salinity	Not removed	Not removed	Not removed	
Hardness	Not removed	Not removed	Not removed	

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 the tables 15, 16 and 17. These tables also show that there are 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/process may be able to remove several pollutants 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.

2.2 Examples of different possible post-treatments for NTSs

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, (ii) 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 in India while few systems also use aeration followed by rapid sand filtration before chlorination (e.g. Mathura, Ahmedabad). 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 storm water 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.

Examples of post-treatment applied to BF, ARR and SAT systems at different sites in the world are presented in tables 4, 5 and 6 respectively.

Table 4 Examples of Post-treatment for BF

SN	Site	Water type	Post-treatment	Reference
1.	Mathura (India)	Yamuna river	Aeration + Filtration + Chlorination	Singh et al. (2010)
2.	Ahmedabad (India)	Sabarmati river	• (i) Monsoon season: Chlorination + Filtration + Chlorination • (ii) Non-monsoon season: Chlorination only	Saph Pani D4.1 (2013)
3.	Patna, Bihar (India)	Ganga river water	Chlorination	Sandhu et al. (2011)
4.	Nainital (India)	Nainital lake	Ion exchange + Chlorination	Saph Pani D4.1 (2013)
5.	Several RBF sites in Germany	River water	• Activated carbon filters + Disinfection • Ozonation + Filtration+ Activated carbon filters	Schmidt (2003)
6.	Torgau-water works (Germany)	Elbe river water	Aeration + Deacidification + Sedimentation + RSF + Chlorination	Krueger and Nitzsche (2003)
7.	Water works Dusseldorf (Germany)	Rhine rive	Ozonation + Double Activated Carbon Filtration + Chlorination	Sharma (2013)
8.	RBF site of Oasen (Netherlands)	Lek Canal/Rhine	Aeration + Filtration	de Vet et al. (2010)
9.	Engleese werk, Zwolle (The Netherlands)	IJssel river water	• Aeration +RSF + Aeration + 2 RSF + GAC + Aeration • Catridge filtration+ NF + RSF + GAC + Aeration	Hiemstra et al. (2003)
10.	Roosteren (The Netherlands)	Meuse river water	Aeration + RBF + Activated carbon + UV	Stuyfzand and Doomen (2004)
11.	Louisville, Kentucky (USA)	Ohio river water	Coagulation + Sedimentation + RSF + Disinfection	Sharma and Amy (2010)
12.	Aswan city (Egypt)	Nile river	Chlorination	Hamdan et al. (2012)

Table 5 Examples of Post-treatment for ARR

SN	Site	Water type	Post-treatment	Reference
1.	Mulheim Styrum (Germany)	Ruhr river water	Ozonation + BAC filtration + UV + Deacidification	Miehe et al. (2010)
2.	Prairie, Aurora water (colorado-USA)	South platte river water	Precipitation/softening + AOP (UV/H_2O_2) + Sand filtration + GAC and blending	Miehe et al. (2010)
3.	Bi'eau process at Flins-Auberqeiville/Suez (France)	Seine river water	GAC + disinfection (ozone and chlorine)	Miehe et al. (2010)

SN	Site	Water type	Post-treatment	Reference
4.	Mulheim Dohne (Germany)	Ruhr river water	Double layer filter + BAC filtration	Miehe et al. (2010)
5.	Pecq-Croissy (France)	Seine river water	Nitrification + AOP + GAC filtration	Miehe et al. (2010)
6.	Waternet-Amsterdam Water Supply Company -Leidun (Netherlands)	Rhine river water	Sand filtration + Ozonation + Pellet softening + BAC1 + BAC2 + SSF	Sharma (2013)
7.	Heemskerk, PWN (Netherlands)	IJssel lake water	Aeration + RSF + Softening + RSF	Sharma (2013)
8.	Lange Erlen Plant-Basel (Switzerland)	Rhine river water	Activated carbon filtration + UV	Sharma (2013)
9.	RBF Maribor (Slovenia)	Drava river water	Sedimentation + Aeration + RSF + Ozonation + Coagulation + PAC	Sharma and Amy (2010)

Table 6 Examples of Post-treatment for SAT

SN	Site	Water type	Post-treatment	Reference
1.	Shafdan, Greater Tel Aviv (Israel)	Secondary effluent	NF	Cikurel (2006)
2.	Tula valley (Mexico)	Primary effluent	Chlorination	Le Corre et al (2012)
3.	Atlantis (South Africa)	Secondary effluent	Ion exchange + Chlorination	Le Corre et al (2012)
4.	Wulpen/ Torreele (Belgium)	Tertiary effluent	Chlorination + Aeration + RSF + UV	Le Corre et al (2012)
5.	Sabadell (Spain)	Secondary effluent	UV + Chlorination	Le Corre et al (2012)

2.3 Typical costs of NTSs and pre-and post-treatment systems

Estimation of total costs of treatment (capital costs as well as O&M costs) is critical for assessing whether NTSs (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 NTSs in developing countries and most of the NTSs 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 separate the cost of the NTSs only. It has been estimated that the cost of the artificial recharge schemes varies from US$ 7 to 100 per 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 US$ 0.05 to 0.30 per m^3 of water throughput (Hofkes and Visscher, 1986). Table 7 and 8 compare the relative levels of capital and O&M costs for artificial recharge and conventional surface water treatment systems.

Table 7 Comparison of the relative level of capital costs for equivalent artificial recharge schemes and treatment works (Source: Hofkes and Visscher, 1986)

Cost item	Artificial Recharge Scheme	Conventional Water Treatment Works
Land acquisition	High	Low
Excavation	High	Low
Pumping system	Medium	Low
Civil works	Low	High
Mechanical Equipment	Low	High
Power supply	Low	Medium

Table 8 Comparison of relative operation and maintenance costs for artificial recharge schemes and equivalent water treatment works (Source: Hofkes and Visscher, 1986)

Cost item	Artificial Recharge Scheme	Conventional Water Treatment Works
Skilled operators	Low	High
Unskilled labour	High	Medium
Power	Low	Medium
Chemicals	Low to none	High
Maintenance operations	Low	High

The following sub-sections present some estimated total costs (sum of capital and O&M costs) obtained from literature sources for NTSs and conventional treatment systems per m^3 of water produced. These cost tables are indicative and can be used to make relative comparison of costs of different pre- and post-treatment options with NTSs 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 of the alternatives.

2.3.1 Typical costs of NTSs

Table 9 shows an example of the costs for NTSs (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.

Table 9 Indicative costs of soil-based NTSs

NTS	Total costs		References
	(Euro/m^3)	Relative cost class*	
BF	0.03 - 0.17	Low	Bosuben (2007), Missa (2014), Sharma et al. (2012a)
ARR	0.09 - 0.21	Low	Kumar and Aiyagari (2007), Osborn et al. (1997), Gale et al. (2002)
SAT	0.33 - 0.50	Low-Medium	Aharoni et al. (2011), Sharma et al. (2012b)

* Low = 0.00 - 0.40 Euro/m^3, Medium = 0.40 - 1.00 Euro/m^3, High = 1.00 - 2.00 Euro/m^3

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, roof top rainwater harvesting and recharge system. The sizes and costs of these recharge systems varies from state to state. Typical costs of different type 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 10.

Table 10 Typical costs of different artificial recharge systems in India (Adapted from MWR, 2013)

Artificial recharge structure	Typical cost range in INR (x 100,000)
Percolation tank	5 - 60
Check dam	4 - 20
Nala bund	2 - 3
Recharge shaft/bore hole	2 - 3.5
Rooftop rainwater harvesting system	1 - 5

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 11). The SAT system was found to be economical specifically in terms of recurring operation and maintenance costs. The capital costs of a SAT system is mainly influenced by the land costs and the overall cost of a SAT system is lower if the land required is available at reasonable costs.

Table 11 Cost analysis of SAT system with other conventional wastewater treatment systems (system capacity: 55 MLD) (Source: Nema et al., 2001)

Treatment system	Capital cost (Million INR)	Annualized investment cost (Million INR)	O&M cost (Million INR)	Total annualized cost TAC (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
Upflow anerobic sludge blanket (UASB)	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

2.3.2 Typical costs of surface water treatment processes

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 licences, taxes (capital/investment costs). Table 12 shows some examples 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 operational & maintenance costs (including energy and chemical costs, but excluding the costs of waste/sludge disposal).

Table 12 Costs of Conventional Water Treatment Processes

Treatment Process	Total costs (Euro/m^3)	Relative cost class	References
Coagulation	0.10-0.25	Low	de Moel et al. (2002)
Sedimentation	0.05-0.25	Low	de Moel et al. (2002)
Aeration	0.10-0.55	Low-Medium	de Moel et al. (2002)
Rapid sand filtration	0.30-0.55	Low-Medium	de Moel et al. (2002)
Slow sand filtration	0.70-1.50	Medium-High	de Moel et al. (2002)
Cl_2	0.007-0.11	Low	Dore et al. (2014)
O_3	0.015-0.15	Low	Dore et al. (2014)
UV	0.011-0.045	Low	Dore et al. (2014)
AOP	0.08-4.51	High	Goi (2005)
GAC	0.50-0.90	Medium-High	de Moel et al. (2002)
Activated Alumina	0.45-0.73	Medium	USEPA (2000)
Lime softening	0.35-0.60	Low-Medium	de Moel et al. (2002)
Ion Exchange	0.06-0.16	Low	Kratochvil et al. (2009)
MF	0.05-0.20	Low	Kennedy et al. (2013)
UF	0.05-0.20	Low	Kennedy et al. (2013)
NF	0.15-2.00	Low-High	Kennedy et al. (2013), de Moel et al. (2002)
RO	0.25-2.00	Low-High	Kennedy et al. (2013), de Moel et al. (2002)

Low = 0.00-0.40 Euro/m^3; Medium = 0.40-1.00 Euro/m^3; High = 1.00-2.00 Euro/m^3

Costs of water treatment in India

The capital cost of conventional surface water treatment (with relatively clean source water) in India ranges from 2 - 2.2 million INR/MLD currently with the minimal operation costs of INR 0.01-0.10/m^3. The most expensive water treatment plant in India is in Agra with capital costs of INR 10 million/MLD and O&M costs of INR 4-5/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 presents the costs of some modern water treatment plants in India. Table 14 presents an example of the costs of industrial wastewater treatment in India aiming at water reuse.

Table 13 Cost of water treatment with modern plants in India (Source: WG-UIWSS, 2011)

Treatment plant	Technology	Capacity (MLD)	Capital cost (Million INR)	Capital cost (Million INR /MLD)	O&M costs (INR/m^3)	Power costs (INR/m^3)	Total O&M costs (INR/m^3)
Sonia Vihar, Delhi	Presettler-Pulsator + Aquazur (Degremont)	635	1890	3	0.38	1.04	1.43
Chembarambakkam	Pulsator + Aquazur (Degremont)	530	1350	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	1900	3.4	0.32	0.10	0.42
Agra (Sikandra)	Conventional + MBBR[a]	144	1560	10.8	3 - 4		4 -5
Minjur, Chennai	Desalination	100	4730	47.3	48.66	10-12	59 - 61
Nemmeli	Desalination	100	10340	100			21

[a] UPJN (2007 – 2017)

Table 14 Typical cost of wastewater treatment for recovery of water (Source: CPCB, 2007)

Particulars	Primary Treatment System[1]	Primary Treatment + Ultrafiltration	Primary Treatment + Ultrafiltration + Reverse osmosis
Capital cost (Million INR) (Total capacity 575 m^3/day)	3.0	9.06	14.5
Annualized capital cost (@15% p.a. interest & depreciation; Thousand INR/annum)	579	1806	2969
Operation and maintenance cost (Thousand INR/annum)	588	704	1263
Annual burden (Annualized cost + O&M cost; Thousand INR/annum)	1185	2710	4250
Treatment cost INR/m^3 (without interest & depreciation)	34.1	52.4	73.2

1. Conventional treatment like oil and grease removal, coagulation, settling, neutralization, filtration etc.

3. Matrices for selection of pre- and post-treatment for NTSs

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 removal efficiencies and guidelines for drinking water quality. Where available, WHO guideline values for drinking water have been included in the matrices as water quality requirements to be met.

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

Table 15 shows the matrix for selection of post-treatment options for BF. The selection matrix of BF is different compared to the section matrices of ARR and SAT because it includes only post-treatment and no pre-treatment. Post-treatment is required for BF systems when some pollutants are generated or passed through soil treatment in bank filtrate or extracted water do not meet the drinking water guidelines and standards.

Table 15 Matrix for selection of appropriate post-treatment options for BF

Pollutants to be removed	Removal Efficiency of BF	Post Treatment			Guideline values
		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
		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 +	Fe	95->99%	<0.1 mg/L Mn Recommended value for
			Mn	38-87%	

		RSF			aesthetic reason
		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%		1.5 mg/L
		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
		NF/RO	65->95%		
		Ion Exchange + NF/RO	90-100%		
Ammonium	53-90%	Chlorination	100%		-
		NF	90-98%		
		Aeration + RSF	40-50%		
		Aeration + RSF + RSF	50-75%		
		Ion Exchange	97%		
Organic micropollutants (* highly dependent on type of pollutant)	≥50%	NF	>99%		-
		RO	70-99.9%		
		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%		

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

- BF only (When there are no water quality problems with bank filtrate and where the water distribution system are in good conditions and well-maintained)
- BF + Disinfection (For removal of pathogens, and presence of low concentration of ammonium)
- BF + Aeration + RSF (For removal of pathogens, ammonium, nitrate, iron and manganese, at relatively lower concentrations)

- BF + Aeration + RSF + Disinfection (For removal of pathogens, ammonium, nitrate, iron and manganese)
- BF + MF/NF + RO (For removal of pathogens, ammonium, nitrate, micropollutants, hardness and fluoride)
- BF + Aeration + RSF + Ozonation + ACF + Disinfection (For removal of pathogens, iron, manganese and organic micropollutants)

3.2 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 16. From this table, several possible combinations for ARR system can be (i) pre-treatment + ARR, (ii) ARR + post-treatment or (iii) pre-treatment + ARR + post-treatment. The ARR generally includes pre-treatment because clogging is the critical problem in soil-based NTS. Additionally post-treatment may be necessary as some pollutants may not be removed adequately during the soil passage to the meet the water quality standards and guidelines or some other contaminants may be introduced into the water during the soil passage depending upon the local hydrogeology/mineralogy and redox conditions.

Table 16 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 pathogen 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
	MF/UF	>98%		NF	70-86%	
TSS	Sedimentation + Aeration + RSF/SSF	100%	90-100%	-	-	<1000 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 Recommended value for aesthetic reason
		Mn	17-79%			Mn	37-38%	
	Aeration + RSF + Aeration + RSF	Fe	>99%		Aeration + RSF	Fe	92-97%	
		Mn	31-96%			Mn	17-79%	<0.1 mg/L Mn Recommended value for aesthetic reason
					(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%		
Arsenic	-	-		90%	Coagulation and filtration	>20%		0.01 mg/L
					Act. Alumina	96%		
					NF/RO	93%		
					Ion exchange	99%		
					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%		
Organic micropollutant (*highly dependent on type of pollutant)	Ozonation	50->90%		≥50%	Ozonation	50->90%		-
	GAC	0-70%			AOP	20-99.9%		
					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%		

Based on the water quality and site conditions, the followings are typical examples of the key contaminants and pre- and/or post-treatment system for ARR to handle them:

- pathogens and stabilization of temperature: ARR only

- pathogens, bulk organic matter and organic micropollutants: 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

3.3 Matrix for selection of appropriate post-treatment for SAT systems

Table 17 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.

Table 17 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	Chlorination	1-4 Log	No pathogen in 100 mL sample
	UV	1-4 Log			Aeration + RSF	0.4.4 Log	
	Ozonation	1-4 Log			Ozonation	1-4 Log	
	MF/UF	0-7 Log	SE	0-6.5	UV	1-4 Log	
					NF/RO	3-7 Log	
			TE	0.4-4.0			
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%	-	-	<1000 mg/L
	Coagulation + Sedimentation	60->85%	SE	>90-100%	-	-	
	Aeration + RSF	70-80%	TE	>90-100%	-	-	
Iron/ Manganese	-	-	PE	-	Coagulation + Sedimentation	Fe 95-96%	0.3 mg/L Fe Recommend
			SE	-		Mn 37-38%	

Pollutants to be removed	Pre-treatment Type	Pre-treatment Removal Efficiency	Removal Efficiency of SAT		Post-treatment Type	Post-treatment Removal Efficiency		Guideline values (WHO 2011)
			TE	-	Aeration + RSF	Fe	92-97%	ed value for aesthetic reason
						Mn	17-79%	
					(Coagulation + Sedimentation)+ (Aeration+ RSF)	Fe	95->99%	<0.1 mg/L Mn Recommend ed value for aesthetic reason
						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	25-99.5%	Ion Exchange	98%		-
			SE	0-99.2%	NF/RO	90-98%		
					Chlorination	100%		
			TE	17-100%	Aeration + RSF	40-50%		
Organic micropollutants (* highly dependent on type of pollutant)	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%		

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 organic micropollutants: Ozonation + SAT + Aeration + RSF + NF

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

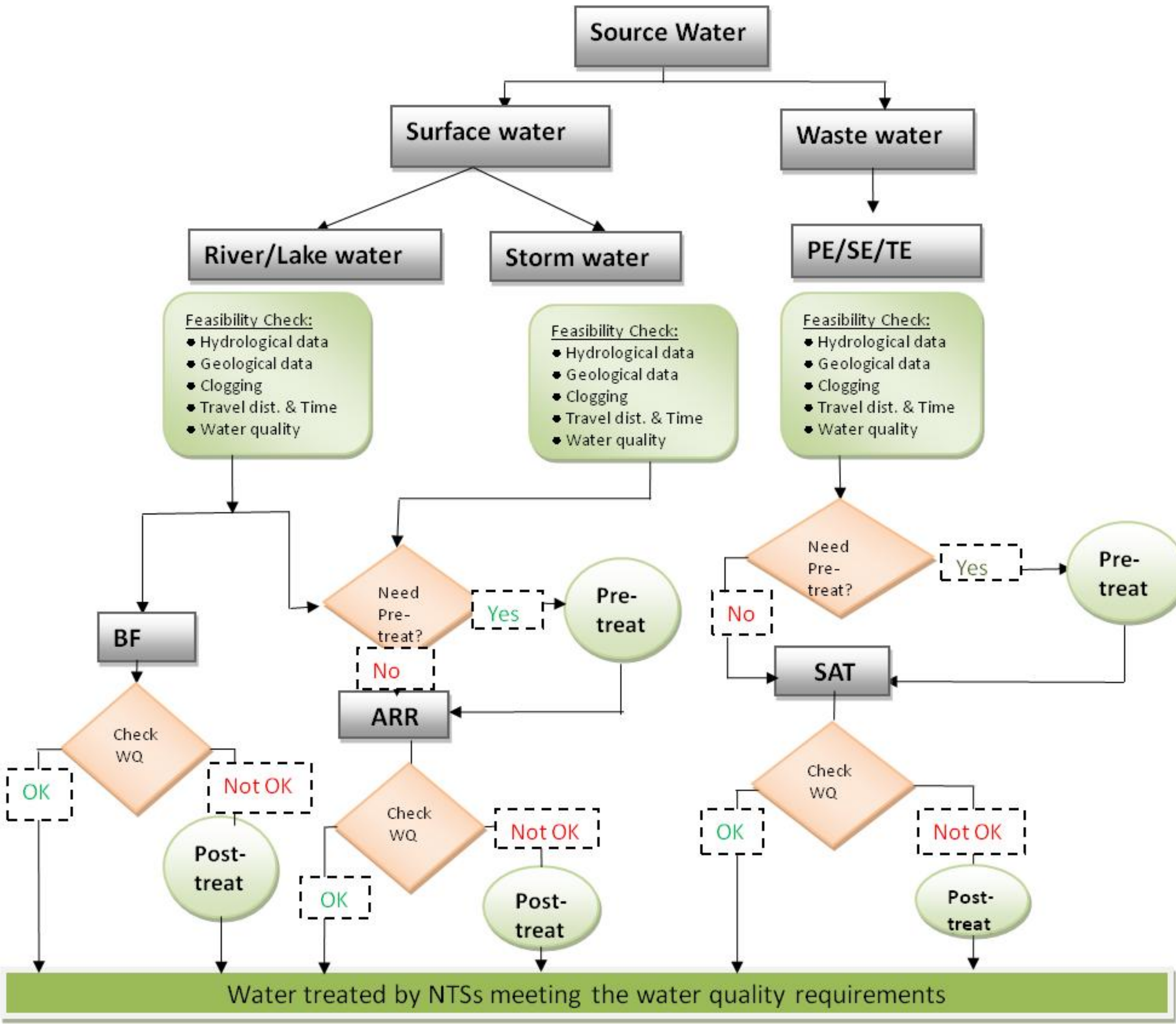

Figure 2 Flow chart to use framework for selection of pre- and/or post-treatment

Figure 2 summarises the pathways for selection of appropriate NTS and pre-and post-treatment alternatives depending upon the raw water type. The stepwise procedure to use the matrix tables for selection of pre- and post-treatment for different NTSs is as follows:

- Collect raw water quality and hydrological/hydrogeological data for the given site to use 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 effect 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:

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

  where C_{source} = concentration a pollutants 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 are more than one treatment steps 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 with the guidelines or standards.
  - Select the options that meet 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.
- Rank different possible combinations of pre- and post-treatment for given NTS based on removal efficiencies and cost effectiveness for decision making.

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

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

4. Summary and Conclusions

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 a particular NTS at a given site, all the components of the NTSs (including pre- and post treatment) as well as local policies and regulations, water quality guidelines and standards, 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 site determine the pre- and post-treatment requirements.

Based on literature data, conditions favorable for BF, ARR and SAT were outlined. Additionally, comprehensive literature data on cost of NTSs 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 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 aiming at water reuse if 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 was made of removal efficiencies of NTSs as well as 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. Additionally, stepwise procedures for the selection of most suitable pre- and post-treatment systems for given NTS was developed and 2 examples of using the selection matrices were presented.

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

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Annex: 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 A1 Treatment alternatives to remove iron and manganese (from the BF matrix table 15)

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

Table A2 Calculation of removal efficiencies and comparisons 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	Guide lines 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.$_{i+n}$

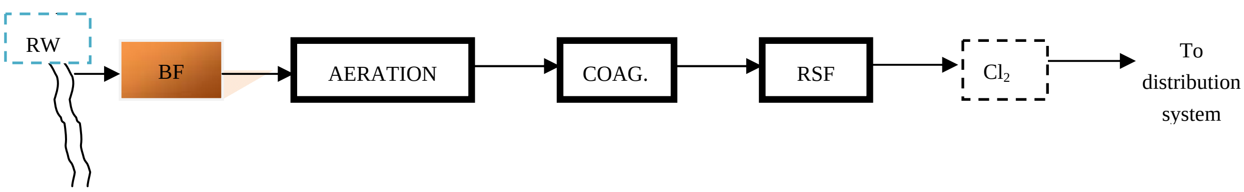
Yes means pollutant can be removed either with minimum removal efficiency or maximum removal efficiency.

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

Table A3 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 + RSF + Aeration + RSF	0.80 - 2.20	0.83 - 2.37	2
		Aeration + Coagulation + RSF	**0.20 - 1.35**	**0.23 - 1.52**	**1**

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, the schematic diagram of the proposed treatment system for given condition would be as shown below:



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

Stormwater is available as the source of the water; the soil type which can be used for NTS is made up phreatic aquifer; the 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 A4 Treatment alternatives to remove iron and manganese (from the ARR matrix table 16)

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

Table A5 Treatment alternatives to hardness (from the ARR matrix table 16)

Water type	Pre-treatment	NTS	Post-treatment	Outcome
Storm water	-	ARR	-	Treated water meeting guideline values
	Lime softening	ARR	-	
	NF	ARR	-	

Table A6 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	Guidelines 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 +	92-99	<0.001-0.02	0.3	Yes
Mn	0.8		17-79	0.17-0.66	-	0.17-0.66		17-92	0.014-0.55	<0.1	Yes

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**	**Guidelines mg/L**	**Remarks**
							RSF				
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	0.168-0.66	<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	0.032-0.66	<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	0.064-0.66	<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	0.104-0.5	<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 A7 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**	**Proc.**	**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.

No means: pollutant cannot be removed with the proposed combination of treatment processes up to the desired level

Table A8 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)	Processess	Costs$_2$ (Euro/m^3)	Total Costs$_{1+2}$ (Euro/m^3)	Rank
Aeration + RSF	0.40-1.10	ARR	0.09-0.21	Aeration + RSF	0.40-1.10	0.89-2.41	3
Aeration + RSF	0.40-1.10			Aeration + RSF + Aeration + RSF	0.80-2.20	1.29-3.51	7
Aeration+RSF	0.40-1.10			Aeration + Coagulation + RSF	0.50-1.35	0.99-2.66	4
Aeration+RSF	0.40-1.10			Aeration + Coagulation +Sedimentation + RSF	0.55-1.60	0.94-2.91	6
Aeration+RSF	0.40-1.10			Aeration + Coagulation + RSF + MF/UF	0.55-1.55	1.04-2.86	5
-	-			Aeration + RSF + Aeration + RSF	0.80-2.20	0.89-2.41	3
-	-			**Aeration + Coagulation + RSF**	**0.50-1.35**	**0.59-1.56**	**1**
-	-			Aeration + Coagulation + RSF + MF/UF	0.55-1.55	0.64-1.76	2

Table A9 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	0.09-0.21	**-**	**-**	**0.09-0.21**	**1**
Lime softening	0.35-0.60			-	-	0.44-0.81	2
NF	0.15-2.00			-	-	0.24-2.21	3

Table A8 shows that option 1 is the cheapest for iron and manganese removal and Table A9 shows that option1 is the cheapest option for hardness removal. The two options will be combined to form the post-treatment system. Although ARR may not be effective in removal of iron, manganese and hardness, but it will be used for removal of turbidity and TSS and some pathogens that may be present 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.