Saph Pani

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

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AOX	Adsorbable Organically Bound Halogens
AP	Anaerobic Pond
ARR	Artificial Recharge and Recovery
ASP	Activated Sludge Process
ASR	Artificial Storage and Recovery
ASTR	Artificial Storage Transfer and Recovery
BF	Bank Filtration
BIS	Bureau of Indian Standards
BOD	Biological Oxygen Demand
CGWB	Central Ground Water Board
CPCB	Central Pollution Control Board
COD	Chemical Oxygen Demand
CWs	Constructed Wetlands
DP	Duckweed Pond
DBP	Disinfection Byproduct
DOC	Dissolved Organic Carbon
E. Coli	Escherichia Coli
FC	Fecal Coliform
FP	Facultative Pond
FS	Fecal Streptococci
GAC	Granular Activated Carbon
IS	Indian Standards
KT	Karnal Technology
KI	Kelly's Index
MF	Microfiltration (MF)
MAR	Managed Aquifer Recharge
MR	Magnesium Ratio
MH	Magnesium Hazard
MLD	Millions liters per day
MoWR	Ministry of Water Resources
MP	Maturation Pond
MPN	Most Probable Number

NTS	Natural Treatment System
OP	Oxidation Pond
PI	Permeability Index
PP	Polishing Pond
RSBC	Residual Sodium Bicarbonate
RCW	Radial Collector Wells
RWH	Rainwater Harvesting
SAR	Sodium Absorption Ratio
SAT	Soil Aquifer Treatment
SF	Sub-surface Flow
SFA	Sewage Feed Aquaculture
SGT	Subsurface Groundwater Treatment
SS	Suspended Solids
STP	Sewage treatment plant
TDS	Total Dissolved Solids
THM	Trihalomethane
TN	Total Nitrogen
TP	Total Phosphorus
WHO	World Health Organization
WHP	Water Hyacinth Pond
WSP	Waste Stabilization Pond
UASB	Up-flow Anaerobic Sludge Blanket
UJS	Uttaranchal Jal Sansthan

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, managed aquifer recharge, constructed wetlands and other natural systems for wastewater treatment). One of the main objectives under this work package is to assess the state of the art in India with respect to pre- and post-treatment methods applied to the "recovered water" or "effluents" from different natural treatment systems. This will help to analyze the critical water quality parameters of concern for each type of natural systems and establish the treatment targets in terms of product water quality requirements for different uses (potable or non-potable) in line with national legislation and international guidelines.

This deliverable provides a general overview of the need for pre- and post treatment and different types of pre- and post-treatment applied to various natural treatment systems. Furthermore, based on the literature review and field data collection and sampling, it provides the state of the art review of the pre- and post-treatment applied to riverbank filtration, managed aquifer recharge and constructed wetlands and other natural systems in India and critical water quality parameters of concern for different uses.

1.2 Natural treatment systems and need for pre- and post-treatment

Terrestrial (soil/aquifer-based) and aquatic (vegetation/pond-based) natural treatment systems are commonly used for water and wastewater treatment worldwide. Soil/aquifer-based natural treatment systems namely bank filtration (BF), artificial recharge and recovery (ARR) and soil aquifer treatment (SAT) are managed aquifer recharge (MAR) systems that are robust, reliable, capable of removing multiple contaminants and are sustainable (Dillon, 2005; Amy and Drewes, 2007; Ray, 2008). In addition to replenishing groundwater aquifers, depending upon the quality of the water source used for recharge (river or lake water, stormwater, wastewater treatment plant effluents) and local hydrogeological conditions, these MAR systems can serve at least as a pre-treatment or sometimes even as a total treatment system (Sharma and Amy, 2010; Sharma *et al*., 2012). Comprehensive analysis of the source water quality as well as the quality of water currently present in the aquifer to be recharged must be done prior to design of these MAR systems.

Vegetation and pond-based systems namely constructed wetlands (CWs) and waste stabilization ponds are equally attractive for wastewater treatment and reuse (specifically in the developing countries) as they are low cost, capable of removing multiple contaminants and minimize the use of chemicals and energy (Crites *et al*., 2006). CWs are attractive for wastewater treatment at a household or community level and at a larger scale also for the recovery of nutrients to minimize the eutrophication potential of the receiving water bodies. They are an established technology in many water reuse schemes, and in addition also offer ancillary benefits such as biomass production, habitat provision and landscape improvement (Kaldec and Wallace, 2008).

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

Need for pre-treatment and post-treatment

The following are some of the main reasons to employ pre-treatment and post-treatment in natural treatment systems aiming at water and wastewater treatment and reuse:

- Some contaminants present in source water may seriously affect the performance of a natural treatment system (e.g. clogging or contamination of the soil layer and aquifer) and reduce its efficiency for removal of certain contaminants
- Some contaminants in source water are not removed or only partially removed by natural treatment systems (e.g. bulk organics, nutrients and organic micropollutants)
- Some new contaminants may be introduced during the treatment due to local hydrogeological conditions and leaching (e.g. iron, manganese, ammonium, arsenic, fluoride, colour, nitrate, natural organic matter etc.)
- Some treatment may be needed to meet local water quality guidelines and standards for artificial recharge and intended reuse of the reclaimed water
- Additional treatment may be required to ensure “multiple barrier treatment system” in the context of deteriorating quality of source waters, increasing water demand, emerging contaminants and climatic change

1.3 Typical pre- and post-treatment applied to natural systems

1.3.1 Pre-treatment for natural systems

Pre-treatment refers to removing some of the critical contaminants in source water to enhance the performance of subsequent treatment systems. Pre-treatment may be required in natural systems to avoid clogging and contamination of the aquifers, to increase the run time, to enhance the removal efficiency of different contaminants. Sedimentation, filtration (roughing or rapid sand), and disinfection are some of the common pre-treatment applied for MAR systems. Some pre-treatment filters also incorporate additional layer of adsorbents for the removal of heavy metals or other specific contaminants from source water before recharge. Screens, grit chambers and primary sedimentation are applied as pre-treatment for constructed wetlands and pond-based systems.

In case of bank filtration, proper location of the extraction wells, their type (horizontal or vertical) and their design (number, spacing and pumping rates) are critical as no specific pre-treatment is applied. Where river or lake water of low turbidity is diverted to infiltration basins for enhancing irrigation supplies, no treatment may be necessary. Dillon *et al.* (2009) reported that CWs may be suitable as pre-treatment when urban stormwater is being used to recharge a brackish limestone aquifer with recovery of water for irrigation without any requirement for post-treatment. Furthermore, they mentioned that microfiltration (MF) and granular activated carbon (GAC) filtration were needed at an artificial storage and recovery (ASR) site with a very fine-grained aquifer to prevent clogging of the well. This requirement was more stringent than those to protect groundwater quality and for recovered water to be fit for use. On the other hand, when wastewater treatment plant effluent is used for recharge aiming at indirect potable reuse, there is need for high degree of pre-treatment before recharge. Again, the pre-treatment requirements may vary depending upon whether surface infiltration (basins), vadose zone wells or direct injection wells are employed for MAR. Table 1 summarizes the main water quality concerns and commonly used pre-treatment options for different types of source water used for MAR.

Often some type of pre-treatment is applied before the wastewater treatment plant effluent is applied for aquifer recharge or treatment using SAT. The objective of pre-treatment is to the improve removal efficiencies for different contaminants, increase run time and to reduce clogging (Sharma *et al*., 2011). Pre-treatment operations and processes can include fine screening, primary treatment, lagoons or ponds, constructed wetlands, biological treatment, membranes, and disinfection. Primary sedimentation or the equivalent is the minimum recommended pre-treatment for all SAT systems. This level of treatment reduces wear on the distribution system, prevents unmanageable soil clogging, reduces the potential for nuisance conditions, and allows the potential for maximum nitrogen removal. For small systems, a short-detention-time pond is recommended. Long-detention-time facultative or aerobic ponds are not recommended because of their propensity to produce high concentrations of algae. The algae produced in stabilization ponds will reduce infiltration rates significantly (NAP, 1994).

Table 1: Main water quality concerns and pre-treatment options for different types of water used for MAR

Source water	Main water quality concern	Pre-treatment options
Rainwater (from roofs)	Suspended solids, turbidity (fines)	Sedimentation, sand filtration
Urban runoff	Suspended solids, turbidity, nutrients, heavy metals	Sedimentation, sand filtration, adsorption, constructed wetlands
River water	Suspended solids, turbidity, bulk organic matter, colour, pathogens	Sedimentation, sand filtration, coagulation, adsorption, disinfection
Wastewater treatment plant effluents	Depends on the degree of wastewater treatment (pathogens, suspended solids, nutrients, bulk organic matter, colour, organic micropollutants)	Depends largely on the MAR method employed (Sedimentation, sand filtration, coagulation, adsorption, disinfection, constructed wetlands, membrane filtration, advanced oxidation and their combinations)

1.3.2 Post-treatment for natural systems

Post-treatment refers to further upgrading the quality of the "treated water" produced by different natural treatment systems so that it meets the water quality requirements for different applications. Requirements for post-treatment of "product water" from natural systems vary from simple disinfection to complete full-scale treatment depending upon on the quality of the source water used, type, design and operation of natural system employed, process conditions applied and applicable water quality guidelines or standards for intended use (Sharma and Amy, 2010). In general, two main water treatment requirements after natural systems include (i) removal of contaminants like bulk organics, nutrients and organic micropollutants that are not removed or only partially removed and (ii) removal of contaminants like iron, manganese, arsenic, fluoride, color, microorganisms and their biodegradation products that may be introduced into the water due to various physical, chemical and biological processes taking place in the natural treatment systems.

Generally, conventional water treatment (coagulation, rapid sand filtration, ozonation, activated carbon filtration and disinfection) or advanced treatment (membrane filtration, advanced oxidation) or their combinations are applied as post-treatment for water MAR system intended for municipal or industrial use. Very often designs of these post-treatment systems are site specific. Commonly, used post-treatment methods 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, (iv) activated carbon filtration (with or without pre-ozonation) to remove the organic micropollutants 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. Table 2 presents the main water quality concerns for water extracted from a MAR system and commonly applied post-treatment methods.

Table 2: Common water quality concerns for water from natural systems and post-treatment options

Water quality concern	Post-treatment options
Pathogens	Disinfection (Chlorination, ozonation, UV disinfection)
Iron, Manganese, Ammonium	Aeration/chemical oxidation - rapid sand filtration
Fluoride, Arsenic	Coagulation - sedimentation, rapid sand filtration, adsorption-based processes using specific adsorbents
Nitrate	Ion-exchange, biological-denitrification, membrane filtration
Hardness	Chemical softening, ion-exchange, membrane filtration
Organic micropollutants	Ozonation, activated carbon filtration, advanced oxidation, membrane filtration
Salinity (from brackish groundwaters)	Membrane filtration (reverse osmosis)

2. Post-treatment of Bank Filtrates in India

2.1 Status of bank filtration in India

Bank filtration (river or lake) has been utilized as a technology for water abstraction and treatment in many water supply systems in India. Very often wells are constructed on the riverbank as an intake to facilitate water collection from the rivers with varying water depth and quality. Short descriptions of some of the bank filtration systems in India are presented below:

Haridwar: The BF system in Haridwar consists of 22 caisson wells (~ 10 m diameter and 7 - 10 m deep) along Ganga River and Upper Ganga Canal. A study by Dash *et al*. (2010) for water-quality analysis of the river, canal and water from wells fetching bank filtrate during monsoon and post-monsoon period's exhibits a dominance of calcium and bicarbonate ions. Water samples from the river and canal were 50–100 times more turbid in monsoon than non-monsoonal months. The bacterial count increased by 10 times and electrical conductivity decreased by 0.6 times in the monsoon as compared to non monsoon. The water quality of production and monitoring well waters, however, was not found to vary much during monsoon and non-monsoon periods.

If one compares the results of bank filtrates from production wells and monitoring wells with Indian standards for drinking water (IS 10500: 1991), one can say that turbidity, dissolved solids and pH are within limits both during monsoon and non-monsoon periods. Ca, Mg, Na and K are also well within the limits. There is no problem with the concentration of Cl, SO_4 and CO_3 ions too. Total and fecal coliform are present in all the wells during monsoon and non-monsoon periods. In the filtrate value of total coliform and fecal coliform (both in MPN/100 mL) varied from 2 to 93 and 2 to 23 respectively (Dash *et al.*, 2010). The fecal coliform count in the filtrate abstracted by the nearby (to IW18) production well IW40 was in the range of 3 – 93 MPN/100 mL during the non-monsoon, and 4 – 17 MPN/100 mL during monsoon (Sandhu and Grischek 2012). Chlorination using mainly sodium hypochlorite (and sometimes bleaching powder) is the only post-treatment applied to the river bank filtrate at Haridwar (Dash *et al*., 2010). The water abstracted from the production wells was found to have very low (less than 1 mg/L) DOC content under aerobic conditions, an arsenic concentration of less than 0.01 mg/L, and other trace metals below the Indian Standard IS 10500 (1991) limit (Sandhu *et al*., 2011a). The Ganga River water also exhibited a low DOC concentration of less than 1.2 mg/L. Thus there is a very low risk of formation of disinfection by-products (DBPs).

Nainital: In Nainital city, UJS utilises water from the Naintal lake as a source of supply employing bank filtration technology. The proportion of lake water being pumped from seven vertical filter wells (installed in 1990 – 2007) located near the lake was estimated by isotopic tracer technique (Nachiappan *et al*., 2002). The results show that the proportion of the lake water in the water pumped from wells is lower in non-monsoon season (25–40%) as compared to that of monsoon season (80%). Water samples from production wells and Nainital lake were collected during non-monsoon and monsoon periods from 1997 to 2006 by Dash *et al*. (2008). The hardness of the production well water ranged from 370 to 434 mg/L (as $CaCO_3$). As per the Indian standards (IS 10500: 1991), desirable limit for hardness is 300 mg/L (as $CaCO_3$). However, in the absence of an alternate source, hardness is permissible up to 600 mg/L (as Ca CO_3). Nainital production well and lake waters were found to have an excess of magnesium hardness, particularly associated with bicarbonate and sulphate ions. This is apparently typical for surface water mainly originating from groundwater (and artesian springs), in the limestone regions (Krol Formation) of the Lower Himalayas (Malter, 2008). Temporary hardness (i.e. carbonate) was 3–5 times the permanent (i.e. non-carbonate) hardness in bank-filtered waters collected from different production wells. TDS, electrical conductivity, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate were found to be more in production well water than lake water. Ammonia, phosphorus, organic matter and total coliform were more in lake water than production well water. Total and fecal coliform were not detected in any of the production well water samples both during monsoon and non-monsoon seasons. It was concluded that lake water as such was not potable as it contained unacceptable levels of organics, coliforms and nutrients. Water softening (lime-soda process) and chlorination (using hypochlorite salt, calcium hypochlorite) are the only post-treatments given to the bank filtrate at Nainital. About 1 mg/L of chlorine is added in the storage reservoir to maintain a residual of about 0.2 mg/L in the distribution network and finally at the consumers tap.

Srinagar: The town of Srinagar (in Uttarakhand) is located on the south bank of the meandering Alaknanda River. The abstraction wells near the river bank have been used as a source of water supply for the city. The bacteriological contamination of the river, in terms of the most probable number of total and fecal coliform counts, ranges from 350 MPN/100 mL to 79 $\times$ 10^3 MPN/ 100 mL and from 1.6 $\times$ 10^3 MPN/100 mL to 17 $\times$ 10^3 MPN/100 mL, respectively (Sood *et al*., 2008; Sandhu *et al*., 2011a). Especially during the monsoon season the Alaknanda exhibits high turbidity which cannot be removed in the existing surface water treatment plant by conventional processes. Preliminary hydrogeological investigations in 2009 – 2010 have shown promising conditions for developing RBF in Srinagar (Sandhu *et al*., 2011a). A very low turbidity and no indication of bacteriological contamination in the water abstracted by two existing drinking water production wells located 39 m and 240 m from the river bank (constructed in Deen Dayal Park and Silk Farm in 2006) was reported. Subsequently, another production and one monitoring well were constructed in the south-west part of the town in May 2010, at a distance of 170 m from the river bank (Kimothi *et al*., 2012). The objective of these wells is to investigate the potential of RBF for improving the existing water quality and quantity of the drinking water supply to Srinagar and Pauri town located 29 km from

Srinagar (Ronghang *et al*., 2011; Kimothi *et al*., 2012). After abstraction and on-site disinfection by chlorination, the water is pumped into a storage reservoir and then supplied into the distribution network by gravity. Water quality investigations of the production well in operation since 2010 have shown that nitrate concentration is in the range of 53 – 123 mg/L in the abstracted water (Ronghang *et al*., 2011). Although the mean hardness concentration monitored since 2010 is 439 mg/L as $CaCO_3$, it however lies within the permissible limit of 600 mg/L in the absence of an alternative drinking water source. Thus the main parameters of concern for post-treatment are the occasional presence of coliforms in very low numbers (prior to disinfection), and high nitrate concentrations (>50 mg/L) in the abstracted water.

Mathura: In Mathura, subsurface water is collected from a radial well having 13 radials (total length of 522 m) laid at 15.5–18 m below the bed of river Yamuna. Filtrate is aerated, filtered, chlorinated and then supplied. Water samples were collected from 2006 to 2007 (Singh *et al*., 2010). TDS, hardness (324 to 396 mg/L as $CaCO_3$) alkalinity (312 to 349 mg/L as $CaCO_3$), sulfate (62 to 80 mg/L) and chloride (203 to 244 mg/L) were found to exceed desirable limits prescribed (IS 10500: 1991). However, values were well within permissible limits in the absence of an alternative source of raw water (IS 10500: 1991). RBF reduced colour, UV-absorbance and DOC by around 50%. Results show that colour of filtrate (18 to 25 CU) was much higher than the desired guideline value. Although RBF resulted in 2 log removal, total coliform (43 to 75 $\times$ 10^3 MPN per 100 mL) and fecal coliforms (43 to 93 $\times$ 10^2 MPN per 100 mL) were present in substantial numbers in river bank filtrate. Post-treatment resulted in no or marginal reductions in DOC, UV-absorbance and colour. Accordingly, it was termed as totally ineffective. However, results indicate that post-chlorination (on-site electrolytic generation of chlorine from brine) is quite effective if practiced continuously.

The distribution of THMs (chloroform, bromodichloromethane, dibromochloromethane, bromoform) was different in different water samples. River water, bank filtrate, and RBF post-treated waters were found to have very low values of total THMs (Kumar *et al*., 2012). Bank filtrate and RBF post-treated waters (with post-chlorination, using a dose of 1 mg/L chlorine) had total THMs < 1 µg/L. According to Kumar *et al*. (2012), AOX concentration was also low in the bank filtrate (17.5 µg/L). Both river water and bank filtrate contained ammonia concentrations in excess of 10 mg/L. Ammonia together with chlorination result in the formation of N-nitrosodimethylamine (NDMA), a potential human carcinogen. However, no investigations on NDMA in waters in India/at Mathura are known so far.

New Delhi: Investigations were done at two RBF sites in Delhi namely (i) Palla and (ii) Nizamuddin during EU TECHEAU Project (TECHNEAU, 2010). These are characterized with respect to hydrogeological, geochemical and hydrochemical settings. The Palla field site is an active well field abstracting bank filtrate located in the northern part of New Delhi, on the flood plain of western bank of Yamuna River, upstream of the urbanized parts of New Delhi. The area covers 18 km^2 with around 100 abstraction wells, which provide ~10% of the water supply in Delhi. Most of the parameters lie within the limits of Indian standards (IS 10500: 1991), no fecal contamination is found in the well waters at Palla. However, fluoride had average value of 1.7 mg/L and maximum value of 3 mg/L in tube well (30 – 60 % of bank filtrate). At Palla site, chlorination is the only post-treatment applied to bank filtrate.

Nizamuddin site is situated in the urban central part of the city, on the eastern bank of the Yamuna River, about 100 m upstream of Nizamuddin bridge. Through its flow in the city, the quality of the Yamuna River is significantly affected by untreated urban wastewater. The concentrations of Fe, Mn, As, F and ammonia increased during infiltration, all of which reached concentration levels critical for use as potable water. Therefore, post-treatment at this site needs to target these substances. Chemical and biological oxidation followed by membrane filtration is the recommended treatment option for this site (TECHNEAU, 2010).

Muzaffar Nagar: The River Kali, a tributary of River Hindon, is a highly polluted river. The RBF site was selected at a distance of around 68 m from River Kali and water samples of the surface and ground waters in the vicinity and filtrate from a production well were analysed by Thakur *et al*. (2009). Turbidity, pH (6.8 to 7.8), and alkalinity (238 to 250 mg/L) of filtrate were within limits (IS 10500: 1991). Total hardness varied from 146 to 212 mg/L, and dissolved solids were from 355 to 380 mg/L. Total coliform were 2 to 28 MPN/ 100 mL in the filtrate. Fecal coliform were 0 to 11 MPN/ 100 mL. Chlorination is the only post-treatment given to filtrate.

Patna: Patna city, with a population of 2.05 million (Census of India, 2011), is located along the River Ganga. Six wells of varying depths (150 to 200 m) below ground level are located 9 to 236 m away from the river. Analysis done by Sandhu *et al*. (2011b) on these wells showed that concentrations of Ca, Mg, Na, Cl and SO_4 are on higher side. Alkalinity (151 to 238 mg/L) and hardness (84 to 364 mg/L) were also on higher side. Total coliform in monsoon (8 – 300 MPN/100 mL) and pre-monsoon (8 – 170 MPN/ 100 mL) in the abstracted water from the wells were high. The presence of coliform bacteria in some wells is probably due to the contamination from land-side groundwater and infiltration of wastewater from open and unlined drains. Chlorination is the only post-treatment given to the filtrate at Patna (Sandhu *et al*., 2011b).

Ahmedabad: In 2007, the Ahmedabad Municipal Corporation (AMC) supplied around 750,000 m^3/day of drinking water to a population of more than 4.5 million. Treatment plants at Kotarpur, Dudheswar, and Jaspur supply around 650,000 m^3/day, 40,000

m^3/day, and 60,000 m^3/day of water respectively. According to Sandhu *et al*. (2011a), the treated water was made up of around 615,000 m^3/day of surface water (82%), 110,000 m^3/day of riverbed filtered water (14%), and 30,000 m^3/day of groundwater (4%). At Kotarpur treatment plant, raw surface water is chlorinated twice before filtration and after filtration but before entering the distribution network (Sandhu *et al*., 2011a). During the non-monsoon period, the bank filtrate requires only disinfection and is then supplied directly into the distribution network. During a flood event, however, the operation of the radial collector wells (RCWs) has to be discontinued because of the high turbidity and sand content.

Medinipur and Kharagpur: With populations of more than 150,000 and 273,000, respectively the towns of Medinipur and Kharagpur make up a municipality and a railway settlement in the state of West Bengal. They are located a short distance to the north and south, respectively, of the Kangsabati River. One RCW (3 m diameter) abstracts approximately 15,900 m^3/day of riverbed filtered water for Medinipur. The well is made up of 32 laterals, each of them having a diameter of 0.3 m, in two layers of 16 laterals per layer, at depths of 6 m and 11 m below the riverbed. Chlorination is the only post treatment given to river bank filtrate before distribution (Sandhu *et al*., 2011a).

2.2 Critical water quality parameters and post-treatment options

Table 3 summarizes the main water quality concerns and post-treatment applied at some selected sites in India (based on literature review and field data collection). Some of the important water quality parameters at various Indian bank filtration sites are summarized in Table 4 and Table 5.

Tables 3 to 5 clearly show that removal of pathogens, hardness and organic matter are the key elements of post-treatment systems for bank filtrates. Furthermore, as the rivers/lakes in India are often polluted with untreated or poorly treated sewage and industrial wastes, the presence of bulk organic matter and micropollutants could be one of the main requirements of post treatment systems. Limited information is available on the concentrations of organic micropollutants in the raw water and filtrates at the bank filtration sites in India. Another potential source of contamination is the dissolution of iron, manganese, calcium, magnesium, arsenic or fluoride from the aquifer due to low dissolved oxygen in river water and/or anoxic conditions created by the infiltrating river or lake water.

These quality concerns can be minimized in some cases by redesign or relocation of the wells while in most cases a comprehensive post treatment would be required. At majority of the bank filtration sites in India chlorination is the only treatment applied while a few have rapid sand filtration step before it. Due to relatively high concentrations of natural organic matter in (river) bank filtrates, formation of THMs or other DBPs is another major water quality concern. In summary, depending upon the raw water quality (of river or lake) and local hydrogeological conditions at site, the post-treatment of filtrates of the bank filtration sites in India would require improvement of one or more of the following group of parameters:

- Pathogens
- Hardness
- Iron, manganese, arsenic and fluoride
- Bulk organics and organic micropollutants

Table 3: Summary of the post-treatment applied in selected bank filtration systems in India

Bank filtration site	**Source of Water for BF**	**Main water quality concern after BF**	**Post-treatment applied**	**Reference**
Haridwar (Uttarakhand)	Ganga River and Upper Ganga Canal	Occasional presence of coliform indicators in very low concentrations	Chlorination only	Field survey by UJS & HTWD (2011-12); Sandhu *et al*. (2011a, 2012); Dash *et al*. (2010)
Nainital (Uttarakhand)	Nainital Lake	Hardness	Water Softening and Chlorination	Field survey by UJS & HTWD (2011-12); Dash *et al*. (2008)
Srinagar (Uttarakhand)	Alaknanda River	Nitrate (from ambient groundwater) > 50 mg/L in abstracted water probably currently due to low fraction of bank filtrate	Conventional surface water treatment (coagulation-sedimentation-filtration-chlorination) and chlorination only of bank filtrate	Field survey by UJS & HTWD (2011-12); Ronghang *et al*. (2011); Sandhu *et al*. (2011a)
Mathura (Uttar Pradesh)	Yamuna River	Organic matter (DOC), Hardness; Pathogens; Organic micropollutants	Aeration- filtration-chlorination	Singh *et al*. (2010); Kumar *et al*. (2012)
Patna (Bihar)	Ganga River	Pathogen indicators (Total coliforms 8 – 170 MPN/100 mL);	Chlorination only	Sandhu *et al*. (2011a & b)
Ahmedabad (Gujarat)	Sabarmati River	Pathogens; Organic matter	(i-a)SW abstraction in monsoon: Chlorination (2 times)-filtration-chlorination	Sandhu *et al*. (2011a)

			(i-b) Abstraction from RBF wells is discontinued when breakthrough of turbidity is high (ii)Non-monsoon: Chlorination (of bank filtrate) only	
Medinipur (West Bengal)	Kangsabati River		Chlorination only	Sandhu *et al*. (2011a)
Muzaffar Nagar (Uttar Pradesh)	Kali River	Pathogens	Chlorination only	Thakur *et al*. (2009)
Delhi - Palla (National Capital Territory)	Yamuna River	Iron, Manganese Fluoride (present in deeper aquifer) Pathogens during monsoon	Chlorination only	Sprenger *et al*. (2008) Lorenzen *et al*. (2010)

Table 4: Inorganic content in source water and filtrate at important Indian RBF sites [Dash *et al*. (2008, 2010), Kumar *et al*. (2012), Sandhu *et al*. (2011b), Singh *et al*. (2010), Thakur *et al*. (2009) & TECHNEAU (2010)]

Site	Conductivity (µS/cm)		TDS (mg/L)		Hardness (mg/L)		Na (mg/L)		Cl (mg/L)	
	River	Filtrate	River	Filtrate	River	Filtrate	River	Filtrate	River	Filtrate
Mathura	1170-1454	1356-1483	725-902	840-934	260-358	324-396	115-153	30-170	175-237	203-244
Nanital	640	655	407	501	328	387	9.5	22	7.3	13.5
Haridwar	218-262	415-466	108-172	194-334	100-112	190-200	6.3-10.6	12.4-20.5	1.5-3	7.5-17
Muzzafar nagar	424-599	477-550	293-350		196-252	N.A.	N.A.	N.A.	N.A.	N.A.
Patna	303-549	505-681	N.A.	N.A.	105-506	84-364	17-29	25-35	3-21	3-69
New Delhi										
Nizamudin	1277	1051					141	58	370	157
Palla	738	734					75	58	90	95

Table 5: Organic matter and coliform count in source water and filtrate at important Indian RBF sites [Dash *et al*. (2008, 2010), Kumar *et al*. (2012), Sandhu *et al*. (2011a, 2011b, 2012), Thakur *et al*. (2009) & TECHNEAU (2010)]

Site	UV absorbance (m^{-1} at 254 nm)		DOC (mg/L)		Total Coliform (MPN/ 100 mL)		Fecal Coliform (MPN/ 100 mL)	
	River	Filtrate	River	Filtrate	River	Filtrate	River	Filtrate
Mathura	11-28	7-13	4.04 - 29.1	1.65 - 6.3	2300 -15 $\times 10^5$	43 - 75×10^3	150 - 23×10^4	43 - 93 $\times 10^2$
Nanital	N.A.	N.A.	N.A.		14.3×10^4	<2	14.5×10^2	<2
Haridwar	N.A.	N.A.	<1.2	<1	4300 - 9300	2-93	2100-6400	3-93
Mazzafar nagar	N.A.	N.A.	N.A.	N.A.	100-1000	40	23-1500	0-11
Patna	N.A.	N.A.	1.9-2.1	0.2-2.8	24000 - 160000	8-170	N.A.	N.A.

3. Pre-treatment and Post-treatment for MAR Systems in India

3.1 Review of existing pre- and post-treatment systems for MAR in India

3.1.1 Investigated MAR schemes in India with pre-/ or post-treatment

India has a long tradition in water harvesting and the artificial recharge: for example, under the dug well recharge scheme of the Government of India 107,249 recharge structures were constructed till 2011 (Saph Pani D2.1). For this study an extensive review was conducted on pre-and post- treatment for various MAR structures.

Eight case studies were found in scientific publications describing the pre-treatment aspects of MAR of which 5 were rooftop rainwater harvesting and recharge systems and 3 were surface runoff recharge systems. Analysis of these studies yielded a variety of ARR structures either in connection with rooftop rainwater harvesting or with normal surface run-off. The structures used for MAR are recharge pits, open wells, ASR wells, injection wells, gravity wells, recharge shaft and tube wells (Shivkumar, 2006; Hollander *et al.*, 2009).

The suitability of the MAR structures for a particular area depends on the geographical location, hydrology and hydrogeology of the site. For the urban areas, less space consuming structures such as recharge pit, recharge trench, tube well and recharge well are suitable, while the rural areas can afford large structures such as percolation tanks, check dams, nala bunds, contour bunds etc. (Shivakumar, 2006). Similarly an injection well is more suitable than tube wells if a confined aquifer needs to be recharged (Bhattacharya, 2010). An overview of the structures used in MAR based on the analyzed case studies is shown in Figure 1. This results show that 3 out of 8 cases have a combination of one or more structures.

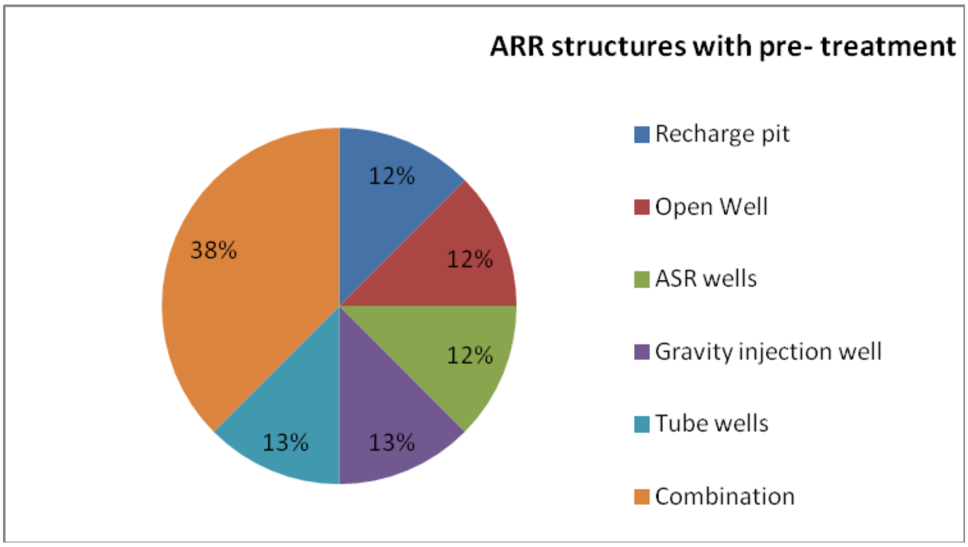

Figure 1: Overview of the eight ARR schemes investigated

3.1.2 Source water quality

The quality of water used for MAR primarily depends on the source. In the majority of the analysed cases *(n=5*) rain water collected from the roof top is used as source water. The chemical composition of rainwater varies from site to site and region to region due to influence of local sources. Normally the rainwater is considered as pure so that the quality aspects were hardly studied in projects dealing with MAR. However, the quality of rainwater and their regional variations in India have been reported by many researchers (Satgansi *et al*., 1998; Rastogi and Sarin, 2005; Salve *et al*., 2008). Kulshrestha *et al*. (2005) observed that the concentration of sulphate, sea salt (Na and Cl) and ammonium are present in a higher concentration in urban regions than the rural areas and nitrate does not have a definite trend.

In the remaining 3 cases surface runoff is used as source water. For surface runoff, literature suggests that suspended materials and turbidity are the common water quality problems which lead to clogging of the MAR system. Hardness of the source water and high TDS concentrations were observed at two locations (Dwarakanath, 2006; Jebamalar and Ravikumar, 2006). In addition, high fluoride and nitrate concentrations were also reported as a quality problem at certain sites (Gale, 2006; Dhiman and Gupta, 2011). Bacteriological parameters such as *E.Coli* and *Fecal Sterptococi*, COD and BOD of the source water from rooftop were found to be much higher than WHO standards for drinking water (Nema *et al*., 2001; Reed *et al*., 2005; Vasudevan and Tandon, 2006; Jamwal and Mittal, 2010).

Treated wastewater is emerging as viable source water for the MAR in megacities in India. The WHO has recommended standards for microbiological quality of treated wastewater for restricted and unrestricted irrigation are 105 FC/100 mL and 103 FC/100 mL, respectively. Jamwal and Mittal (2010) studied the effluent quality of the 16 wastewater treatment plants in Delhi for analyzing the reuse options such as SAT and irrigation. They reported that except 2 plants, the effluents from all others shall pose risk to public health. So, direct reuse is not possible before improving the quality of effluents. More or less same similar results observed by Nema *et al.* (2001) from a pilot SAT system at Ahmadabad.

3.1.3 Pre- and post-treatment techniques identified for MAR

The investigated case studies show that all the 8 cases have only pre-treatment. In the case of water collected from storm water (e.g. roads), pre-treatment is required due to the high sediment loads. In contrast, water from rooftop rainwater harvesting has lower loads of suspended materials.

Identified pre-treatment methods for surface runoff are sedimentation, sand filters, wrapped PVC pipes and metallic filters:

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

In the rainwater harvesting and recharging systems, elimination of first flush from the roof tops is a common practice to minimize negative impacts on source water quality (Vasudevan and Tandon, 2006; Shivkumar, 2006). The aim of this method is to remove the first rain with lots of impurities due to the interaction between atmosphere and also with the dirty roof tops. There is an inbuilt filter system in most of the rooftop harvesting systems practiced in India. This is fixed immediately after the first flush separator and acts as a primary treatment method. A schematic diagram showing the first flush separator and filter in a rooftop RWH system is shown in Figure 2.

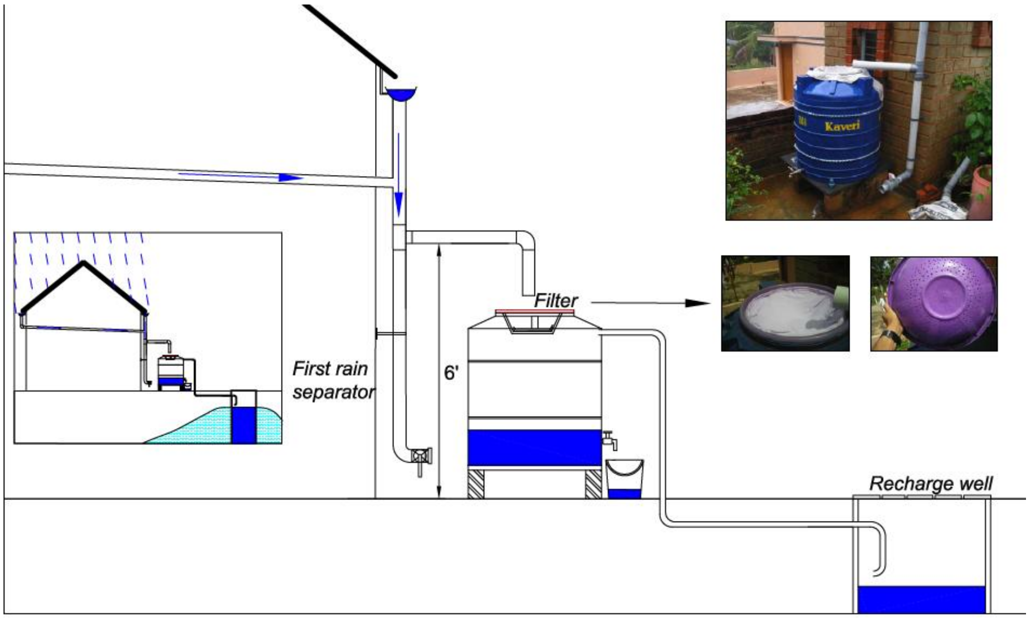

Figure 2: Components of Rooftop RWH system showing First flush diverter and Filter (Rainwaterclub.org)

Reuse of treated wastewater for recharging the groundwater is not a common practice in India. Considering the high potential of this method as future option, several pilot studies on this topic are in progress. In the case of wastewater effluent recharge systems, pre-treatment may be preliminary with settling and aeration or secondary treatment including physical, chemical and biological process. Jamwal and Mittal (2010) reported a primary and secondary treatment for the sewages from Delhi city. They used the activated sludge process (ASP) as the major primary treatment step together with an oxidation pond for a selected sewage treatment plants (STPs). As secondary treatment a fluidized bed, BIOFORE (ie, aerobic or anaerobic biological reactors) was used for bacteriological removal. The results of the treatment aspects used in the 8 investigated case studies are presented in Table 6.

Table 6: Pre-treatment aspects for MAR in India (based on 8 case studies)

Reference	Structures	Pre-treatment	Use of effluent
Ranga Reddy district, Hyderabad (Dwarakanath, 2006)	Roof-top RWH, Recharge pit with boulders and sand	Boulder and sandy filter in recharge pit	Drinking water
Osmania University Campus, Hyderabad (Dwarakanath, 2006)	Rooftop RWH, Infiltration with 5 Pits and 5 recharge wells	Sand and metal filters	Domestic
Padmavathi Nagar, Chennai (Jebamalar and Ravikumar, 2006)	Roof-top RWH connected to open wells	Filter, possibly sand filter	Drinking water
Balasore district (Hollander *et al.*, 2008)	ASR-Wells, channels for catchment	Sedimentation and Desilting Filter	Irrigation
RV College of Engineering Campus, Bangalore (Shivakumar, 2006)	Rooftop RWH to gravity injection well	Two settling tanks with sand bed and stone aggregate as a filter	Drinking water
Dhuri Drain,Punjab (Chadha, 2003)	Vertical Shafts (30) and Injection Wells(30)	Sand and gravel pack as filter	Not specified. Presumably used for irrigation
Sirsa branch canal (Kaledhonkar *et al.* 2003)	Two recharge tube wells	Filter pit and coconut coir wrapped on the slotted PVC pipe.	Presumably for irrigation
CSV, Wardha, Maharashtra (Kanhe and Bole, 2006)	RWH tank bore well, dug well, soak pit	Ground filters and Metallic filters	Mainly for domestic purposes

Analysis of MAR systems studied revealed that high percentage (38%) of the recovered water was used for drinking purposes. Among the other uses, 37% were used for irrigation and 25% were used for other domestic purposes. It should be noted that all the rooftop rainwater harvested water is used for the either drinking or domestic purpose after MAR. Still, no post-treatment was mentioned.

3.2 Groundwater quality and treatment in India

3.2.1 Groundwater quality

Groundwater is considered as safe drinking water source in many parts of India. A study in Gulbarga shows that about 80% of the population uses untreated or inappropriately treated groundwater for drinking (Saleem and Dandigi, 2011). The major water quality issues identified in groundwater in India are elevated concentrations of salinity (EC), Fe, F and As.

- High levels of fluoride (>1.5 mg/L) are reported from 16 of 28 states in India (Mariappan *et* al., 2000). The major origin of this *i*ion n is the naturally occurring fluorite in the form of fluorite, apatite, biotite and amphiboles in the country rocks (Reddy *et al*., 2010; Brindha *et al*., 2011).
- The permissible concentration of iron in drinking water is less than 1.0 mg/L as per the BIS Standard for drinking water. It is observed that higher concentrations of Fe (>1 mg/L) were found in 23 states in India. Sources of iron are largely controlled by the weathering of ferruginous minerals of igneous rocks such as hematite, magnetite and sulphide ores of sedimentary and metamorphic rocks (CGWB, 2010) under reducing conditions, frequently observed in groundwater.
- Arsenic is a geogenic pollutant frequently reported to be present in groundwater in West Bengal (Saha *et al*., 1999; Bhattacharya *et al*., 2001). Apart from West Bengal, elevated concentrations (> 0.05 mg/L) of arsenic have also been observed in Bihar, Uttar Pradesh, Assam and Chhattisgarh. It is present naturally in the rocks and sediments of this region. Arsenic is incorporated into the groundwater during its contact with aquifer materials depending upon the controlling factors such as organic matter, Fe, redox condition etc. (CGWB, 2010). Reddy (2012) reported that arsenic in the *Dhub*ri district in Assam is originating from the arsenic-rich iron hydroxides on weathering of minerals such as pyrite and arseno-pyrites.
- The BIS standard for nitrate in drinking water is 45 mg/L. CGWB (2010) points out that, at least 1 district in 23 states shows higher concentrations of nitrate than the standard limit (45 mg/L). Major origin of NO_3 in the groundwater is from leaching of chemical fertilizers, animal manures, groundwater pollution from septic tanks and sewage discharges etc. Some chemical and micro-biological processes such as nitrification and denitrification may also influence the nitrate concentration in groundwater. More or less the same sources were identified as the cause for elevated levels of nitrate at Anatapur, Andhra Pradesh (Reddy *et al*., 2009) and Lidar catchment, Kashmir (Dar *et al*., 2011).
- Salinity in groundwater is mostly influenced by nature of aquifer material, solubility of minerals, duration of contact, permeability of soil, drainage facilities, quantity of rainfall and above all, the climate of the area. In the coastal areas, airborne salts originating from air-water interface over the sea and excessive pumping of fresh

water and subsequent seawater intrusion are the major problems (CGWB, 2010; Mondal, 2010). However in the inland, anthropogenic factors control the salinity in groundwater. In such a case at Chennai city, Brindha and Elango (2012) reported that the tanning industries elevated the groundwater salinity up to 6690 µS/cm against the natural background value of 985 µS/cm in parts of Chennai city. 19 states in India have groundwater salinity over 3000 µS/cm in at least few locations.

- Heavy metals in groundwater were observed in 40 districts from 13 states of India (Kumar and Shah 2009). High concentrations of Cr (>0.05 mg/L) is reported around tannery industries in Chennai (Kumar and Riyazuddin, 2010), Vellore (Sundar *et al.*, 2010) and Dindigul (Mondal and Singh, 2010). High concentrations of Fe (>0.3 mg/L), Mn (>0.04) and Pb (>0.01 mg/L) have been reported in some parts of Assam (Haloi and Sarma 2011). Elevated levels of Cu (>0.03 mg/L) and Cr (>0.05 mg/L) were reported by Dhakate and Singh (2008) in Sukinda valley, Orissa. Metals such as Pb (>0.01 mg/L), Fe (>0.03 mg/L), Mn (>0.04 mg/L) and Cd (>0.01 mg/L) were observed at concentrations greater than WHO guideline values in parts of Bangalore (Singh *et al.*, 2010).

3.2.2 Groundwater treatment

High concentration of iron in the groundwater is treated in parts of Agarthala using conventional and packaged type water treatment systems (SIPMIU, 2011). The conventional treatment units consist of aeration (achieved through spray aeration) and subsequent filtration of the water through a bed of charcoal, possibly with a layer of sand (although sand is not mentioned in the report). Occasional chlorine dosing is done to expedite settling. Though modern treatment method such as packaged type iron removal system are available in recently constructed treatment plants, these have reported to be not so effective due to the improper maintenance (Saleem and Dandigi, 2011)

Chemical treatment methods of de-fluoridation use lime either alone or with magnesium and aluminum salts, with or without addition of a coagulant aid (CPCB, 2008). Other methods include addition of materials like magnesium, calcium phosphate, bentonite and fuller's earth to the high fluoride water and their separation from water by settling and filtration. A popular method developed by NEERI for removing the fluoride in groundwater is the so-called Nalagonda Technique. This involves the addition of two simple readily available chemicals Lime and Alum, followed by flocculation, sedimentation and filtration in sequence (NEERI,1987). Raw water is pumped or poured into the tank and the required amount of bleaching powder, lime or sodium carbonates are added prior to stirring and alum is added during stirring. The contents are stirred slowly for 10 minutes and are allowed to settle for 2 hours. The defluoridated supernatant water is withdrawn for supply through standposts and the settled sludge is discarded (CPCB, 2008). This is a batch method, and can be adopted for communities up to a population of 200. A simple ion exchange method, using aluminum oxide as ion exchange media, is available in India for both domestic and community use under the name "Prasanthi technique" (Rao, 1997).

A variety of methods are available for the treatment of arsenic contaminated groundwater in India. A detailed list of treatment methods and their capacity is presented in Table 7.

Table 7: Available methods for arsenic treatment and their capacity (Modified from CPCB, 2008)

Method of As removal	Capacity/Efficiency	Developed by
Adsorption of As (V) and As(III) using activated Alumina	The unit packed with 95 kg alumina can treat about 1 million litres of arsenic laden water.	B.E. College, Howrah
Coagulation-flocculation-sedimentation-filtration system	This system can treat is 10,000 - 12,000 litres of arsenic-rich water in 12 hrs.	AIIHPH, Kolkota
Table filter candle and chemical tablet made up fly ash used in arsenic removal	The filter in combination with a chemical tablet achieved almost 100% removal efficiency	Jadavpur University in collaboration with CSIR.
Adsorption of arsenic using a gravel pack along with Activated Enhanced Hybrid Alumina (AEHA)	50 litres of AEHA can treat 1,50,000 litres of arsenic-rich water at a flow rate about 15 L/min.	RPM Marketing Pvt. Ltd.

Disinfection by chlorination is the most common and important step in water treatment system for public supply from groundwater as the chlorine residual guarantees disinfection also within the distribution network (Gopal *et al*., 2007). The principle reason for chlorination is the removal of microorganisms in order to prevent water born diseases. Chlorine is applied to water either as elemental chlorine (chlorine gas), solutions of sodium hypochlorite or through the use of chlorinating chemicals such as calcium hypochlorite, bleaching powder etc. (WWC, 2008). In India, chlorination is usually achieved by following the latter method (bleaching powder), which reacts with water liberating free chlorine (CPCB, 2008). Chlorine is most widely and easily used, and the most affordable of the drinking water disinfectants. It is also highly effective against nearly all waterborne pathogens (WWC, 2008).

3.3 Theoretical assessment of pre- and post-treatment needs for MAR in India

3.3.1 Required source water quality for MAR

CGWB (2007) provides recommendations for the physical, chemical and biological source water quality for artificial recharge in India. Type and amount of suspended solids, temperature, and the amount of entrapped air etc. are the major physical parameters to be considered. Total dissolved solid (TDS) is the most important chemical parameter due to the tendency of groundwater to involve in the chemical reaction with aquifer materials. It is recommended that the recharge water should be chemically compatible with the aquifer material through which it flows and the native ground water to avoid chemical reactions. These reactions may result in the reduction of porosity and ultimately causes clogging. Microbial parameters and other living organisms are considered under biological quality, but for these no clear cut guideline value is defined. However, every recharge method is not suitable in case of extremely high concentrations for selected water quality parameters. For example, high concentrations of suspended solids cause immediate clogging for groundwater recharge techniques like deep pits, recharge shafts and wells. In this case ditch and furrow systems can be a better alternative than the deep structures when less/or no pre-treated water is used for recharge.

Chemical water quality is important because during recharge, water undergoes a series of chemical reactions like chemical precipitation and ion exchange, which may reduce the aquifer porosity and permeability. High sodium concentrations in the source water may result in the swelling of clay minerals due to cation exchange. Depending on the final water use the required minimum source water quality for artificial recharge can be relaxed.

The most important biological water quality parameters in India are algae, bacteria and organic waste. Injection of water containing bacteria and algae through wells is generally not recommended because this might cause clogging of well screens or aquifer materials, which is difficult and costly to remedy (CGWB, 2007). For spreading techniques, water can be recharged after sedimentation and secondary treatment. In addition biodegradation may take place during the infiltration through the unsaturated zone.

Although the recommendations given by CGWB (2007) cover many aspects, no quantitative thresholds are given and recommendations for practical tests and necessary investigations are lacking. At this point, recommendations adopted in other countries can be adopted. Clogging is the most common problem in most of the MAR systems. Source material for clogging and their management is one of the top prioritized areas in management of MAR. Source water quality is the principle factor that controls the clogging phenomena. Still definitive guidelines for the source water quality are not readily available today. Managed aquifer recharge practitioners in the Netherlands have determined, through trial and error, that the suitability of source water for injection into sandy aquifers is defined by a membrane filtration index of <3–5 s/L^2 and assimilable organic carbon of <10 µg/L, to manage physical and biological clogging respectively (Olsthoorn, 1982; Hijnen and van der Kooij, 1992). In Berlin, the permissible limit of TSS in the infiltrating water is <2 mg/L which is achieved by micro-sieving or flocculation/rapid filtration (TECHNEAU, 2009).

3.3.2 End-use dependent water quality standards

3.3.2.1 Drinking water – a comparative study with WHO guidelines

Provision of safe drinking water is one of the major priorities of the local and national governments in India. The Indian water quality standard for drinking water is formulated and maintained by the Bureau of Indian Standards (IS10500 1992). The standards are closely related to the WHO guideline values (WHO, 2008). However, there are differences in the permissible limits of drinking water standards depending on a number of reasons like geographical area, climate and water availability. A comparison between BIS standards and WHO guideline values for the drinking water quality is presented in Table 8. For many parameters WHO does not recommend a guideline value for the drinking water. Certain parameters like arsenic, chromium, selenium, lead and chloride have the same values in both standards. In case of TDS, WHO suggests 1000 mg/L, while BIS recommends a desirable limit of 500 mg/L with a possible extension till 1500 mg/L depending upon the site characteristics. BIS is permitting 400 mg/L of sulphates while WHO limit is restricted to 200 mg/L. In the case of fluoride, nitrate, cadmium and mercury BIS limits are stricter than the WHO guideline values. For fluoride and nitrate the permissible limits are 1.2 mg/L and 45 mg/L respectively in BIS, while concentrations up to 1.5 mg/L and 50 mg/L is permitted in the WHO guidelines values.

Table 8: Comparison of Indian Standards and WHO guideline values for drinking water

S.N.	Parameter	Unit	Permissible limit (IS10500 1992)	Permissible limit (WHO 2008)
1	Colour	TCU	5	
2	Turbidity	NTU	10	
3	Dissolved oxygen (DO)	mg/L	6	
4	Biological oxygen demand (BOD)	mg/L	2	
5	Total coliform bacteria	No/mL	.....	0
6	pH	-	6.5 -8.5	
7	TDS	mg/L	500	1000
8	Total Hardness	mg/L	300	
9	Calcium	mg/L	75	
10	Magnesium	mg/L	30	
11	Copper	mg/L	0.05	2
12	Iron	mg/L	0.3	0.009
13	Manganese	mg/L	0.1	0.4
14	Chloride	mg/L	250	250
15	Sulphate	mg/L	400	200
16	Nitrate	mg/L	45	50
17	Fluoride	mg/L	0.6 - 1.2	1.5
18	Phenols	mg/L	0.001	

19	Mercury	mg/L	0.001	0.006
20	Cadmium	mg/L	0.01	0.003
21	Selenium	mg/L	0.01	0.01
22	Arsenic	mg/L	0.05	0.01
23	Cyanide	mg/L	0.05	0.07
24	Lead	mg/L	0.1	0.01
25	Zinc	mg/L	5	
26	Anionic detergents (MBAS)	mg/L	0.2	
27	Chromium as Cr^{+6}	mg/L	0.05	0.05
28	Mineral Oil	mg/L	0.01	
29	Residual free Chlorine	mg/L	0.2	
30	Alkalinity	mg/L	200	
31	Aluminium as Al	mg/L	0.03	
32	Boron	mg/L	1	0.5
33	Sodium	mg/L	200	
34	Potassium	mg/L	10	
35	Phosphates	mg/L	0.3	

3.3.2.2 Irrigation

The irrigation water quality guideline in India (EcoHousing, 2009) is recommended and controlled by IS: 11624 (1986). This guideline considers various aspects like soil properties, characteristics of dissolved ions, nature of crops etc. Salinity, hardness, chloride, TDS and boron have a direct impact on the crops. However, majority of the water quality problems for irrigation are caused when two or more ions co-exist in the groundwater more than a certain critical limit. These cause various chemical reactions among themselves and with the soil. The problems with the concurrence of various ions can be studied using different indices such as Sodium Absorption Ratio (SAR), Residual Sodium Bicarbonate (RSBC), Percent Sodium (%Na), Permeability Index (PI), Kellys Index (KI), Magnesium ratio (MR) and Chloro alkaline indices (CAI-1 and CAI-2).

Table 9: Guidelines for water quality for irrigation in India

Parameters	Unit	Max. permissible limit	Reference
Fecal coliforms (FC)	Geometric mean no. per 100 mL	1000	WHO (1999)
Boron (B)	mg/L	2	IS 11624 (1986)
Chloride as chlorine	mg/L	500	IS 11624 (1986)
Sulphate	mg/L	1000	IS 11624 (1986)
Total dissolved solids (TDS)	mg/L	2100	IS 11624 (1986)
Hardness (as $CaCO_3$)	mg/L	<75	BIS (1998)
Salinity	mg/L	2250	IS 11624 (1986)
Sodium Absorption Ratio(SAR)	–	<10 or 10–18	IS 11624 (1986)
Residual Sodium Bicarbonate (RSBC)	meq/L	<5	BIS (1998)
Percent Sodium (Na%)	%	<20 or 20–40	IS 11624 (1986)
Permeability Index (PI)	%	Class 1 or 2	IS 11624 (1986)
Kellys Index (KI)	–	<1.0	IS 11624 (1986)
Magnesium ratio (MR)	%	Below 50%	IS 11624 (1986)

3.4 Pre- and post-treatment needs for Saph Pani case study sites

3.4.1 Raipur

Description of the study area

Raipur is located in the Hirri sub-basin and stratigraphically in the Chandi formation of the Raipur Group within the Chhattisgarh basin. The Chandi formation can be divided into the Raipur Limestone and the Deondongarh Shale. Raipur Limestone is characterized by grey, fine grained, horizontally bedded, stromatolitic, massive limestone, high secondary porosity due to joints and karstification but with negligible primary porosity (Bodhankar and Chatterjee, 1994; Mukherjee *et al*., 2011). The Deondonghar Shale is an aquiclude consisting mainly of laminated purple shale interbedded with ferruginous, thinly to thickly bedded sandstone (Mukherjee, 2011) with thicknesses of up to 4 m (Roy *et al*., 2009). The climate is sub-tropic with a minimum temperature of 13°C (December) and a maximum of 43°C (May). The average annual rainfall is 1,300 mm principally contributed by the monsoons from mid June to early October (Roy *et al*., 2009; Mukherjee *et al*., 2011).

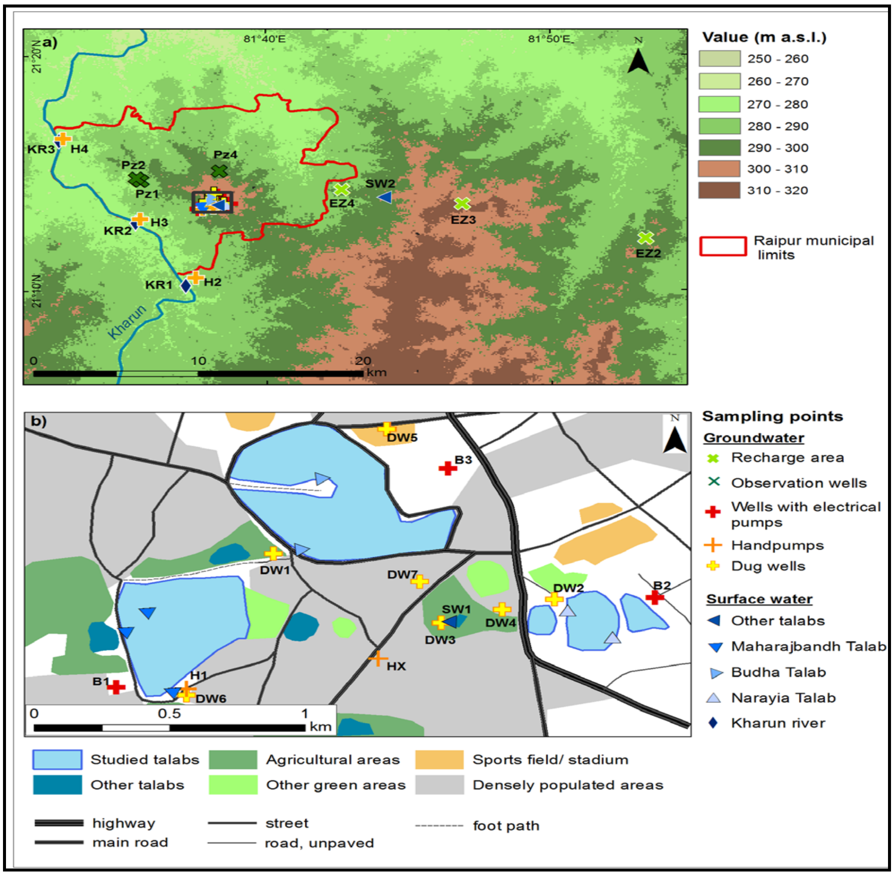

Figure 3: Elevation map of Raipur and surroundings (a) and location of the talabs and groundwater sampling points investigated in the FUB study (Gröschke, 2012)

The results presented in the following paragraphs are taken from a study that was carried out by the Freie Universität Berlin (Gröschke, 2012) in Raipur city around the Narayia Talab, the Budha Talab and the Maharajbandh Talab to assess the hydrogeological and hydrochemical characteristics. In the frame of this study 20 groundwater samples were collected from observation wells, dug wells and hand pumps (Figure 3) were sampled during June 2011 and analyzed for main cations and anions, nutrients, inorganic trace elements and stable isotopes. Although, according to Bornemann and Gröschke (2012) all groundwater samples show anthropogenic influence, this is probably not due to MAR activities as only little infiltration was observed from the talabs into the aquifers. Nevertheless, these samples give an indication of water quality that may be encountered if aquifer recharge is practiced.

Suitability of groundwater for potable use

With regard to drinking water quality data was available from the mentioned study (Gröschke, 2012) for 7 (43%) of the 16 parameters regulated by WHO (2008) and for 12 (32%) of the 37 parameters regulated by the IS 10500. The results of the available groundwater quality analyses with respect to these standards are presented in Figure 4.

Information from the shallow and deep aquifer was combined as no significant differences were observed between the two aquifers.

Groundwater pH showed an alkaline nature in both aquifers and falls within the prescribed limit of pH 6.5 to 8.5. The observed maximum values of TDS were 880 mg/L (shallow aquifer) and 906 mg/L (main aquifer) respectively. This shows, in general the water quality is permissible (TDS <1000 mg/L) for drinking purposes. The statistical summary of the ionic constituents resulted from this study show that majority of the samples has lower concentration than the Indian drinking water standard. However, few parameters such as Na, Cl, K, NO_3 Fe and Mn showed elevated concentrations than the recommended guideline value. Na and Cl concentration exceeded the permissible limit in singular wells from the main aquifer. The concentration of nitrate exceeded the permissible limit (45 mg/L) in 3 wells from the main aquifer, in which highest value 62 mg/L is recorded in the well DW6. It should be noted that the same well showed the highest concentration of Cl and is thus possibly influenced by the anthropogenic activities. Among the trace metals, Fe and Mn concentrations exceeded their permissible limit of 0.3 and 0.1 mg/L, respectively in 6 wells (3 wells from each shallow and main aquifer).

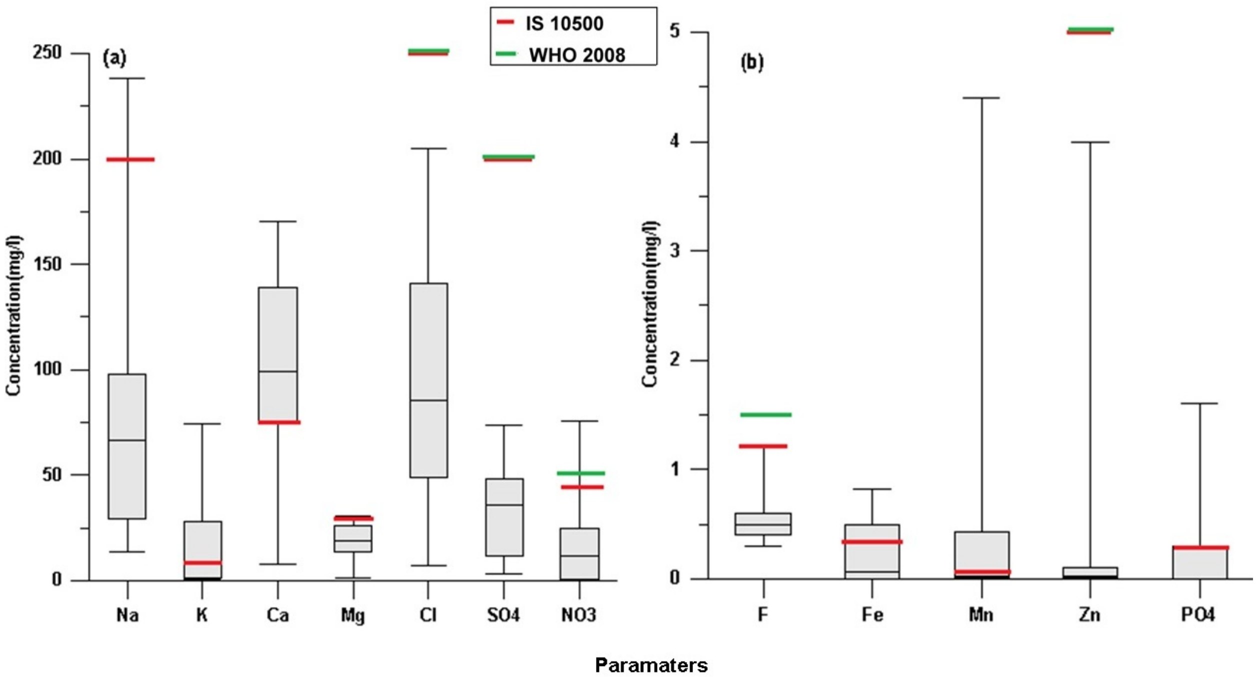

Figure 4: Distribution of groundwater quality in Raipur (a) Major ions (b) Minor ions and trace metals (Gröschke, 2012)

Suitability of Groundwater for Irrigation

The groundwater quality for irrigation purposes were evaluated based on the data from Gröschke (2012) and is presented in Table 10. The results were compared with Indian standard for irrigation water (IS:11624 1986). Both aquifers showed similar results. Groundwater concentrations of B, SO_4, salinity, Cl and TDS were found to be less than their corresponding guideline values (IS:11624 1986). Contrary to the single ions, most Irrigation indices (except for SAR) suggest that majority of the samples are unsuitable for irrigation (see Table 10). One sample from the deep aquifer showed the highest SAR of 39.47. Five samples from the main aquifer showed a permissible range for KI. Though, the indices values showing higher range, it is evident that the hazard will be imparted to the plants only when these indices accompanied with high salinity. When considering the low salinity values (<2250 µS/cm), groundwater can be very well used for the agricultural purposes.

Table 10: Groundwater quality for irrigation in Raipur (Gröschke, 2012)

Parameter	Unit	Min	Max	Mean	Max. Permissible limit	No of samples exceeded the permissible limit	Percentage of samples exceeded the permissible limit
TDS	mg/L	266	906	592	2100	0	0
Salinity	mg/L	415	1416	925	2250	0	0
Cl	mg/L	7	205	94	500	0	0
SO_4	mg/L	5	73	34	1000	0	0
B	mg/L	0	0	0	*2*	0	0
SAR	-	0.75	39.47	4.87	<10 or 10–18	1	5
RSBC	mg/L	3.19	9.46	6.07	<5	18	90
Na%	%	24.63	97.92	56.38	<20 or 20–40	18	90
PI	%	83.92	180.23	116.96	Class 1 or 2	20	100
KI	-	0.33	75.29	5.48	<1.0	15	75
MR	%	92.56	99.97	98.53	Below 50%	20	100

Pre- and post-treatment needs

In general and also for the parameters investigated, groundwater quality is suitable for drinking purposes except for a few samples which showed concentrations of Na, Cl, NO_3^-, Fe and Mn exceeding the guideline values. The study of Gröschke (2012) shows that the NO_3, Fe and Mn present in water probably need post-treatment before distributing it in public water supply system. Based on the experience at other sites in India, pre-treatment is required to remove suspended solids for improving the efficiency of infiltration. Also disinfection of the recovered water will most probably be necessary before distribution as drinking water.

3.4.2 Chennai

Description of the study area

The Araniar and Kosathalayar (AK) River Basin is a part of Chennai Basin group. It has an aerial extent of 7282 km² of which 5542 km² lies in Tamil Nadu and the rest in Andhra Pradesh (Bhola, 2012). Geographically the study area is marked by North latitude 12° 50'-13° 30' and East longitude 79° 15' to 80° 20' and lies within the tropical monsoon zone. Based on the hydrometeriological feature of the basin, the year is divided into 2 periods: a monsoon period spanning from June to December and a non-monsoon period spanning from January to May. The average annual rainfall is approximately 1100 mm. The river basin is built on marine, estuarine and fluvial alluvium over-lying Precambrian gneisses and Chamockites. The hard rocks include granite, gneissic complex, schists and charnockites associated with basic and ultra-basic intrusive. Fluvial alluvium is present along the shallow valleys of the Araniyar and Kosathayar rivers. The major landuse in the coastal area is agriculture. The major aquifer zones in the AK basin are alluvium formed by the two rivers and tertiary sandstone. The alluvial aquifer is more potential for recharge than the sandstone aquifer. The major factors controlling groundwater recharge are rainfall and the hydrogeologic conditions.

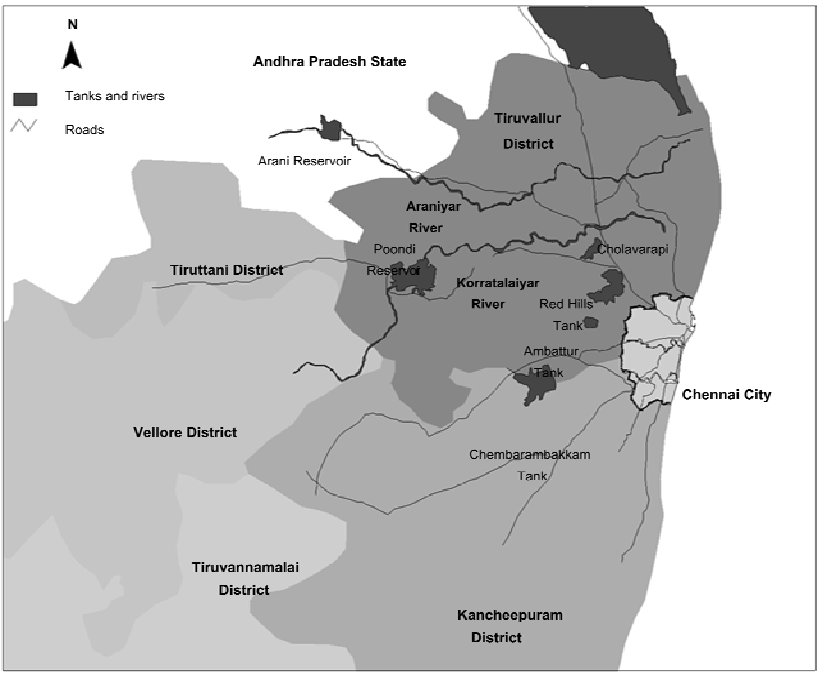

Figure 5: Location of AK river basin (Janakrajan, 2007)

Groundwater quality for drinking

The results of the hydrochemical survey conducted at Chennai by Anna University are adopted in this report in order to quantify the status of groundwater quality. The collected parameters were compared with WHO and IS 10500 standard guideline values. Over all water quality is summarized in Figure 6. Groundwater pH values vary between 7.4 and 9.2, and two samples out of 10 exceeded the permissible limit of pH, 8.5. TDS values exceeded the permissible limit 1000 mg/L in 60% of the samples (*n=6*) and the highest overstepping is recorded at Andarmadam 2 (4039 mg/L). Groundwater in the study region is hard (>300 mg/L) in 70% of the samples, making the water unsuitable for drinking according to the Indian Standards. Groundwater was unsuitable for drinking with respect to Na (>200 mg/L) in 30% of samples, K (> 10 mg/L) in 70% samples, Ca in 20% samples and Mg in 80% samples, Cl (>250 mg/L) in 60% samples, SO_4 in 20% of samples, NO_3 in 20% samples. However, the concentration of fluoride was far below the permissible limit 1.5 mg/L and PO_4 was absent in all the samples. From the present study, it is observed that salinity and high Mg concentration are the common water quality problem in this region.

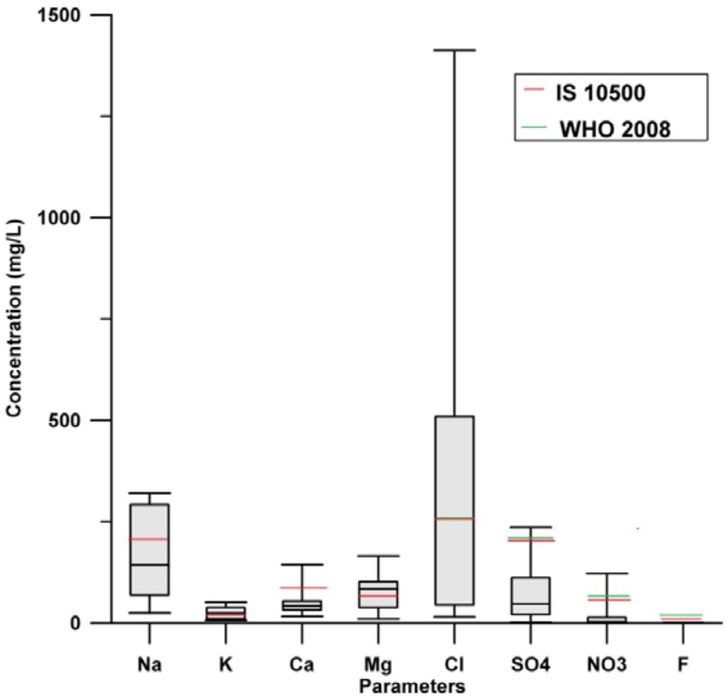

Figure 6: Selected drinking water quality parameters of the groundwater in Chennai

Groundwater quality for irrigation

Suitability of groundwater quality for the agricultural purposes was evaluated based on the data acquired by Anna University. 10 parameters were considered to assess the irrigation suitability based on the guidelines listed in the Indian standard for irrigation (IS10500 1992). The results of this analysis are shown in Table 11. In general, 70 % of the samples were fit for the irrigation purposes except for Magnesium ratio and Na%. 80% of the samples were above the permissible limit of MR (50%) and 40% exceeded the Na% (<40). Salinity and TDS exceeded the limit in 20% of the samples, while chloride in 30% samples. The levels of SO_4, SAR and PI were well within the guideline values.

Table 11: Groundwater quality for irrigation in Chennai

Parameter	Unit	Min	Max	Mean	Max. Permissible limit	No of samples exceeded the permissible limit	Percentage of samples exceeded the permissible limit
TDS	mg/L				2100	2	20
Salinity	mg/L	456	6214	1338	2250	2	20
Cl	mg/L	15	1412	264.8	500	3	30
SO_4	mg/L	1.56	236.3	27.1	1000	0	0
SAR	-	0.97	6.19	3.16	<10 or 10–18	0	0
RSBC	mg/L	-1.60	9.20	2.92	<5	2	20
Na%	%	25.4	55.7	38.9	<20 or 20–40	4	40
PI	%	38.37	67.16	57.0	Class 1 or 2	0	0
KI	-	0.36	1.38	0.75	<1.0	3	30
MR	%	32.89	89.29	67.15	Below 50%	8	80

Pre-and post-treatment needs

Salinity and the high magnesium are the major quality problems when using Chennai groundwater for drinking purposes. Concentrations of SO_4 and NO_3 exceeded the guideline value in 20% of the wells, raising problems for use as drinking water. This suggests that the groundwater needs pre-or post-treatment in terms of these parameters prior to the distribution-although widespread implementation of MAR structures might improve this problem. As in Raipur, the microbial quality is not monitored. If needed, chlorination is a cheap and effective post-treatment option to eliminate microbial contamination.

In the case of irrigation suitability, salinity and TDS are relatively high in a few samples. High Mg levels is observed in majority of the samples (80%) in terms of MR. Although data on turbidity in the source water is lacking, experience from Anna University shows that reduction of suspended solids improves infiltration rates. A pilot study conducted at Anna University Chennai using Soil Aquifer Treatment (SAT) showed high removal efficiency for nitrate (up to 98%) after 15 cycles (Deepa and Krishnaveni, 2012) under reducing conditions. Under these conditions SAT can be a cost-efficient treatment method for the removal of nitrate, which is encountered in few locations in the study area.

3.4.3 Maheswaram

Description of the study area

The experimental watershed being monitored for MAR studies in the Saph Pani project is located around the town of Maheshwaram, 40 km from Hyderabad, AP. With a total area of 54 km^2, it is located in a semi-arid hard-rock context typically representative of the entire region. The weathering profile controlling the hydrodynamics of the region has been previously documented (Dewandel *et al*., 2006). The watershed faces a strong overexploitation (Dewandel *et al*., 2010) which leads to an increase of the salinization of the groundwater (Perrin *et al*., 2011). The deterioration of the groundwater quality, used for irrigation and drinking purposes is furthermore enhanced by the rapid urbanization of the area and the increasing number of poultry farms (Khan *et al*., 2011). Among geogenic contaminations, fluoride in groundwater is the main threat in the watershed and the region as in various hard rock aquifers in the country. By allowing considerable amount of water to percolate locally through the soil, the unsaturated zone and the aquifer, MAR structures as percolation tank may have an impact in decreasing fluoride concentration by dilution or by controlling rock-water interaction by creating changed thermodynamic equilibrium.

As a part of MAR system implementation at Maheswaram watershed, Tummulur percolation tank (near Tummulur village) has been selected for investigations within the Saph Pani project. Figure 7 gives an overview of the tank. A bund can be observed at the north of the tank, with a mud track going throughout the length. The area of the lake is approximately 10 hectares (26 acres) with a clay deposit covering 1 hectare at the deepest part of it, near the bund on the north. On the surroundings of the tank 15 working borewells, used for irrigation (mostly paddy fields) have been identified, along with 2 abandoned borewells. The borewell M35, as shown in figure 7, at the north of the tank, used to be monitored as part of the ANR-MOHINI project from 2006 to 2009, providing a baseline data. The groundwater quality data collected are used in this report to evaluate the drinking and irrigation water quality of the groundwater.

The Tummulur percolation tank monitoring is carried out with two objectives: (i) to quantify infiltration rates and aquifer recharge by storage tanks; (ii) to assess the evolution of water quality during this infiltration.

SAPHPANI - Project
Percolation Tank - Borewells drilled (MHT) - Maheshwaram

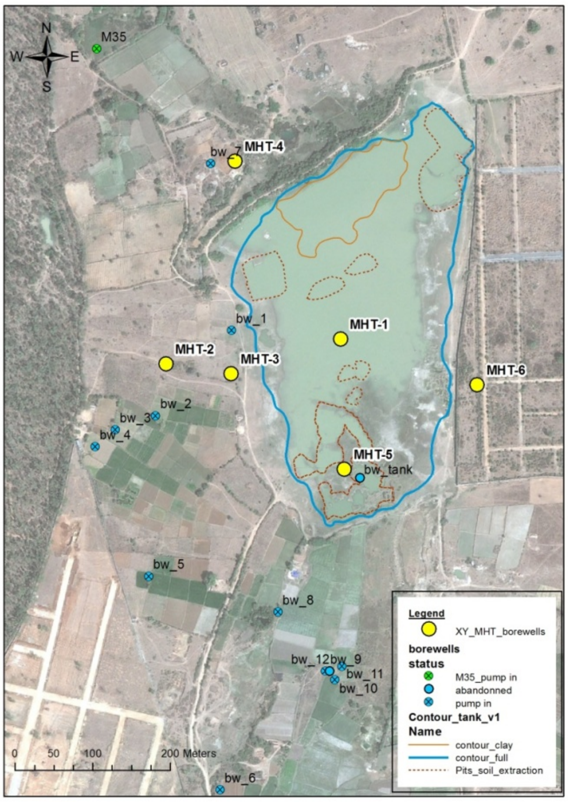

Figure 7: Location of the study area showing Tummulur percolation tank in Maheswaram watershed and Sampling well M35

Groundwater quality for drinking

<u>Situation at the Maheswaram watershed scale</u>:

At the watershed scale, the main identified and widespread threat in term of groundwater quality is the presence of fluoride. This situation is not isolated as high levels of fluoride are reported from 16 of 28 states (Mariappan *et al*., 2000), and are especially encountered in granitic terrains in southern India. Concentrations exceeding the WHO guideline value (1.5 mg/L) have been reported from Andhra Pradesh (up to 7.6 mg/L; *Reddy et al*., 2010), Tamil Nadu (up to 2.75 mg/L; Kumar 2012), Kerala (up to 5.75 mg/L; Shaji *et al*., 2007) and Karnataka (up to 5.35 mg/L; Mamata and Rao, 2010). Though the WHO guideline value for fluoride is 1.5 mg/L, this value may vary with different climatic regions, since the amount of water consumed and consequent fluoride ingested are influenced primarily by air temperature (Bell and Ludwig, 1970). In India, Bureau of Indian Standards specifies the maximum permissible limit of fluoride in the drinking water to be 1.2 mg/L and the most desirable limit being 0.6 -1.2 mg/L.

Out of 240 water samples collected from the watershed between 2006 and 2009, 43% showed fluoride concentrations above WHO guideline value and, compared to the limit of

1.2 mg/L recommended by the BIS, this rises to 55.6% with a maximum observed concentration of 4.67 mg/L. Figure 8 shows the fluoride concentration repartition over the watershed from a sampling campaign carried out in 2009.

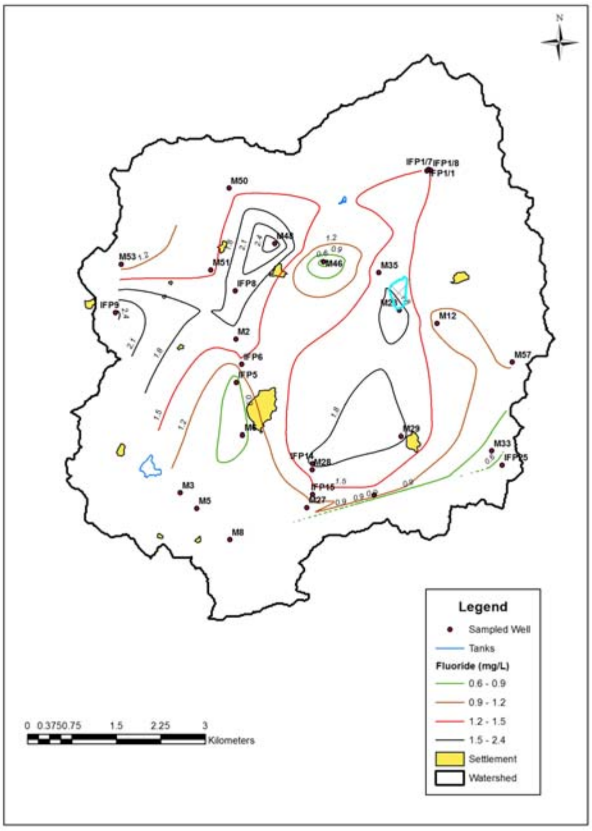

Figure 8: Fluoride concentrations in the watershed during the sampling campaign in February 2009. (Data interpolated through natural neighbor interpolation). Red lines refer to the WHO guideline values while the brown ones the BIS limit of 1.2 mg/L. Tummulur tank is highlighted in light blue on the eastern part of the watershed.

Elevated F^- concentrations in drinking water may lead to serious health problems such as dental fluorosis, skeletal fluorosis, and mental dementia especially for children. Impact of fluoride on the watershed population has been identified only recently (Bouzit *et al.*, 2012). This study reveals that large part of the children population is affected by dental fluorosis. Variations in hydrogeochemical conditions in the aquifer may affect the mobility of F in groundwater. A number of factors influence the availability and solubility of F-minerals: pH, temperature, anion exchange capacity of aquifer materials, residence time, porosity, soil structure, depth, groundwater age, concentration of bicarbonates (Apambire *et al.*, 1997).

The studies done previously completed on the area of interest provide precise local information on the fate of fluoride. Evaporation under arid and semi-arid climate can trigger calcite precipitation, reducing Ca^{2+} activity which is known to increase F^- concentration without fluoride precipitation (Jacks *et al.*, 2005). Here the process of F^-

accumulation is outlined in the small endorheic watershed (Negrel *et al*., 2011) where groundwater has high F^- concentrations up to 4.6 mg/L (Pauwels *et al*., 2010).

Modeling study by Pettenati *et al*. (2012) conducted on the fluoride release under rice paddy field with irrigation return flow reveals that among the minerals containing fluoride on granites (biotite, alanite, fluorapatite), fluorapatite ($Ca_{10}(PO_4)_6F_2$ is the main contributor. Those results are in accordance with the results of Negrel *et al*. (2011) who have shown through Pb isotopes that the water geochemistry reflects the weathering of the primary mineralogy (plagioclases and K-feldspar) as well as accessory minerals such as fluorapatite, allanite and biotite. The mechanisms controlling the fluoride release are the cation exchange capacity (CEC) in Ca/Na exchange and calcite precipitation, the kinetically controlled mineral dissolution, the possible immobilization by adsorption by iron hydroxides precipitation. Anthropogenic sources as fertilizer appear to be limited.

<u>Study site scale - Tummulur Tank</u>:

In the surrounding of the Tummulur tank, one well (M35) was continuously monitored from 2006 to 2009. The water quality data of physical parameters and cations for 6 seasons, anions for 7 seasons (2006-09) and trace metals data for 5 seasons (2006-08) are available. A total of 17 water quality parameters regulated for potable use were evaluated (Figure 9). The observed pH and TDS vales were within the permissible limits, except in June 2008, when the TDS was slightly higher than 1000 mg/L. Results of the average concentration of the major elements were well within their corresponding guideline values, except for magnesium, fluoride and calcium in few seasons. Magnesium has a higher concentration than the permissible value (<30 mg/L) in all the seasons. Though the average values are within the permissible limit, Ca concentration exceeded 75 mg/L in two seasons. This can be attributed to the seasonal variation in the hydrogeochemical processes. The major threat for the human health is high concentration of fluoride (average = 1.95 mg/L). Throughout the seasons the well showed an elevated concentration of F^- with a maximum of 2.27 mg/L in March 2006. Those high concentrations may be related to the closely located paddy irrigation which tends to increase F^- concentrations (Pauwels *et al*., 2011). Analysis of trace metal chemistry of water suggested their suitability for drinking purposes. For Fe, the data was available for only one season and it was within the permissible limit. A detailed summary of the analyzed parameters in the borewell M35 over the seasons are given in Figure 9.

Water quality for irrigation

Based on the available data from the Maheswaram-Tummulur field site, 9 parameters were considered to evaluate the groundwater quality for irrigation purposes. The standard guideline values for irrigation water (IS:11624, 1986) have been used to evaluate the suitability of groundwater. Most of the parameters except Na% and KI were found to be suitable for the irrigation purposes (see Table 12). However, all the samples exceeded the permissible limit for Na% and 57% of the samples showed a higher KI value. It is to be noted that these indices are valid only when the salinity values are high. Considering the low salinity in the region, groundwater can very well be used for irrigation.

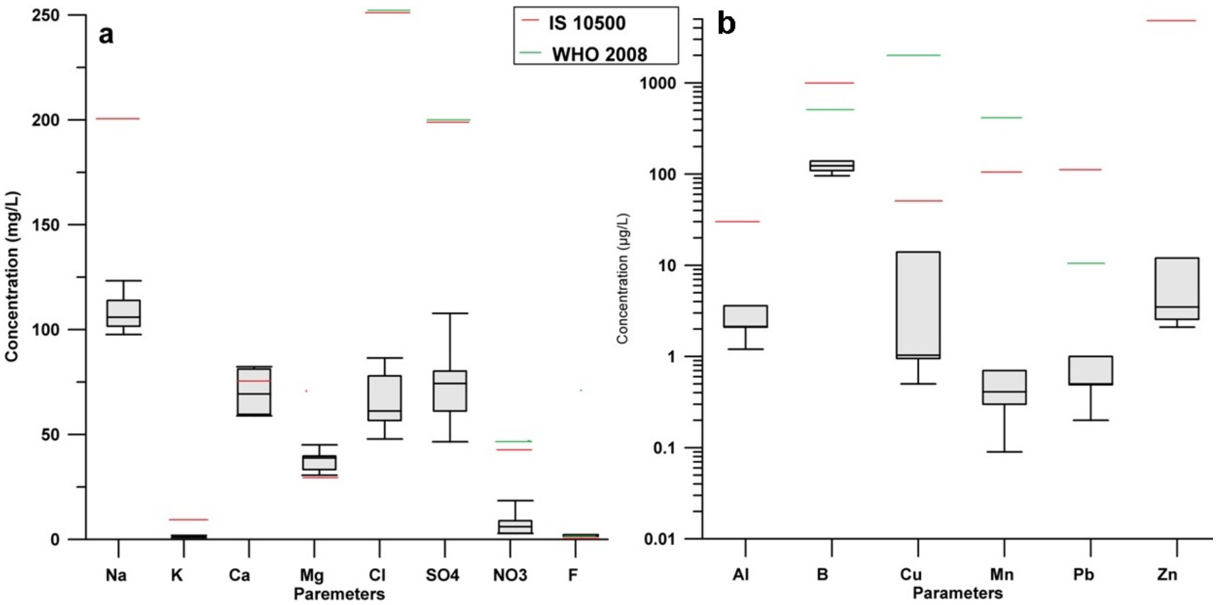

Figure 9: Groundwater quality in Maheswaram (a) Major ions (b) trace metals. The seasonal variation (2006-2009) of a well (M35) is presented in this figure

Table 12: Groundwater quality for irrigation in Maheswaram (7 seasons from 2006- 2009)

Parameter	Unit	Min	Max	Mean	Max. Permissible limit	No of seasons exceeded the permissible limit	Percentage of seasons exceeded the permissible limit
TDS	mg/L	753	1024	860	2100	0	0
Salinity	mg/L	878	1198	887	2250	0	0
Cl	mg/L	47.8	86.4	66	500	0	0
SO_4	mg/L	46.5	107.4	77	1000	0	0
B	mg/L	0.1	0.14	0.12	2	0	
SAR	-	13.6	15.5	14.74	<10 or 10–18	0	0
Na%	%	46.5	52.8	49.6	<20 or 20–40	7	100
KI	-	0.9	1.1	1	<1.0	4	57
MR	%	29.1	36.2	34.16	Below 50%	0	0

Pre- and post-treatment needs

The available data shows that, in general, most of the water quality parameters of the groundwater are suitable for drinking purposes. However, a few parameters like Ca and Mg were high at certain times. The major health hazard is due to the high F concentration in almost all seasons. So these 3 contaminants need to be treated after recovery. Among the numerous methods developed, lime softening is the most common and cheapest treatment method for F^- enriched groundwater (Crittenden *et al*., 2005). Coagulation and precipitation and activated alumina are also used, in certain region depending up on the cost and geological conditions. An overview of the methods used in India is given in table 13.

In regard to irrigation, the low salinity values show that the high KI and Na% can be discarded and no post-treatment is needed of any kind of treatment. Furthermore, as clay deposits in the tanks used for irrigation are reported, it is recommended to remove suspended solids present in the source water. There is no information about the microbial quality of the well water used for small-scale (household level) applications and irrigation. Microbial quality of the well water must be monitored and sufficient disinfection need to be provided if necessary.

Regarding fluoride, while it is obviously important to provide quickly post-treatment solutions to meet the drinking water quality standards, it is also important to understand the impact of MAR structures that may have on fluoride release on a long-term basis. As a geogenic contaminant fluoride is present all over the watershed and recent studies carried out on the watershed (Pauwels *et al*., 2011) highlight the relation between fluoride concentration and land use, especially the impact of rice paddy fields due to irrigation return flow. By adding locally important amounts of fluoride free rain water, the change of water composition may however enhance the fluoride release instead of having a dilution effect. As shown by Pettenati *et al*. (2012) fluoride release is a complex system involving, kinetic dissolution of minerals, cation exchange, and thermodynamic equilibrium. Fluoride release kinetics determination can hardly be done directly in situ, but good understanding of hydrodynamics on the site, travel time determination coupled with chemical sampling will allow quantifying the positive or negative impact of the structures. Reactive transport modeling should then be done for a better evaluation and quantification of the impact with the help of the collected data. This reactive transport modeling is included in the Saph Pani project where the reactive code PHREEQC, will be implemented in the 3D transport code MARTHE for an integrative study.

Table 13: Treatment options for F^- removal from groundwater in India [Meenakshi and Maheswari (2006) [1], Pranati and Devaraj (2011) [2]]

Method	Methods/ Reagents	Procedure	Scale and Efficiency	Costs	Advantages	Disadvantages
Coagulation and precipitation (Nalgonda Technique)	Lime and alum	Addition of lime increases the water pH and precipitates F as CaF_2, Alum is added as coagulant	- Possible at community level - Removal efficiency up to 72% (at pH: 5.5-7.5)	Maintenance costs [1]: 10 Rs/ m³ (3000 Rs/ month for 10,000 L/d) Annual costs [2]: annual costs Rs 20/- (domestic at 40 L/c*d) to 85/- (community level, 5000 persons)	- no electricity needed - little waste produced - can be used at domestic and community level - no special chemicals needed - high flexibility in design	- converts F^- into toxic aluminium fluoride complex ion - elevates SO_4 levels in water beyond guideline - needs large space for drying of sludge - well-trained operator needed
Adsorption (Prasanti technique)	Activated Alumina (AA), activated carbon or other media	Addition of adsorbent media under controlled pH and temperature conditions	- up to 400 people - F^- removal up to 90% is achieved at pH (5-6)	Investment costs [2]: 35,000 Rs per plant (at community level 200-400 persons); 1,300 to 1,700 Rs (per plant at domestic level) Contradictory information on Opex [2]: 0.6 – 0.8 Rs / m³.	- treated water meets the BIS standards - both community and domestic level is possible	- highly pH dependent - hardness has a negative effect on sorption. - pre-treatment necessary, - can result in high aluminum output (0.16 to 0.45 ppm) - regular regeneration necessary, - disposal of sludge and concentrated regenerant problematic
Ion exchange	Ion exchange resin (eg., carbion; Defluoron-1/ Defluoron-2)	Strongly basic anion-exchange resin containing quarternary ammonium functional groups are added to the F rich water, regeneration with Cl.	- can be installed at domestic and community level - Removes fluoride up to 90–95%.	[1]: Relatively expensive Operational costs [2]: Rs 0.3 to 7 / m^3 Investment costs [2]: Rs 2000 at domestic scale.	- retains the taste and colour of water intact. - no electricity needed - ion exchange media is reusable	- expensive because of the cost of resin - pre-treatment required to maintain the pH - regeneration and waste disposal necessary - treated water has low pH and high Cl levels
Membrane processes	Reverse Osmosis (RO) and Nano Filtration (NF)	F in the feed water is removed during the passage through membrane under high pressure	Efficiencies up to 98% were reported	Relatively expensive; technological advances have lowered the expenses	- highly effective in F^- removal. - little chemical requirement and maintenance - works under wide pH range	- comparatively expensive - post -treatment (remineralization, pH-adjustment) necessary - water gets wasted as brine and their disposal is a problem

4. Post-treatment for Constructed Wetlands and Other Natural Systems for Wastewater Treatment in India

4.1 Status of Constructed Wetlands and Other Natural systems for wastewater treatment and reuse in India

Natural treatment systems have been proven as an attractive alternative for wastewater treatment worldwide because of minimum energy requirements, reduced maintenance and higher degree of treatment as compared with conventional treatment systems (such as activated sludge process). NTSs are very suitable for small and medium size communities in the developing countries, where land resources are available and relatively cheap (Mara *et al*., 1992; Brix, 1994; Vymazal, 2002; Puigagut *et al*., 2007). In recent years natural treatment systems have been accepted as distinct systems for wastewater treatment in India.

There are different type of NTSs are available and the most common include constructed wetlands (CWs), hyacinth and duckweed ponds, lemna ponds, fish ponds, waste stabilization ponds (WSPs), oxidation ponds and lagoons and, algal-bacterial ponds. All NTSs in India are being preceded by some form of mechanical pre-treatment for the removal of gross solids. Where sufficient land suitable for the purpose is available, these systems can often be the most cost-effective option in terms of both construction and operation especially in rural areas and small towns.

From the national survey of CWs and other NTSs by IITB team approximately 108 locations of NTSs have been identified in India (Saph Pani D3.1, 2012). WSPs is the most prominent NTSs being practiced since many decades which are contributing to about 51.17% of total wastewater treated by means of NTSs. Polishing ponds are the second common NTSs in India contributing to 48.17% of total wastewater treated by means of NTSs. These polishing ponds are mostly installed after UASB units for improving the quality of treated effluent as polishing ponds are already proven technology in up gradation of wastewater effluents. Karnal technology, engineered constructed wetland and duckweed ponds are very rarely practices in India contributing about 0.88%, 0.62% and 0.15% respectively, of total wastewater treated by means of NTSs. The percentage contribution of total wastewater treated by means of CWs and other NTSs has been given Figure 10.

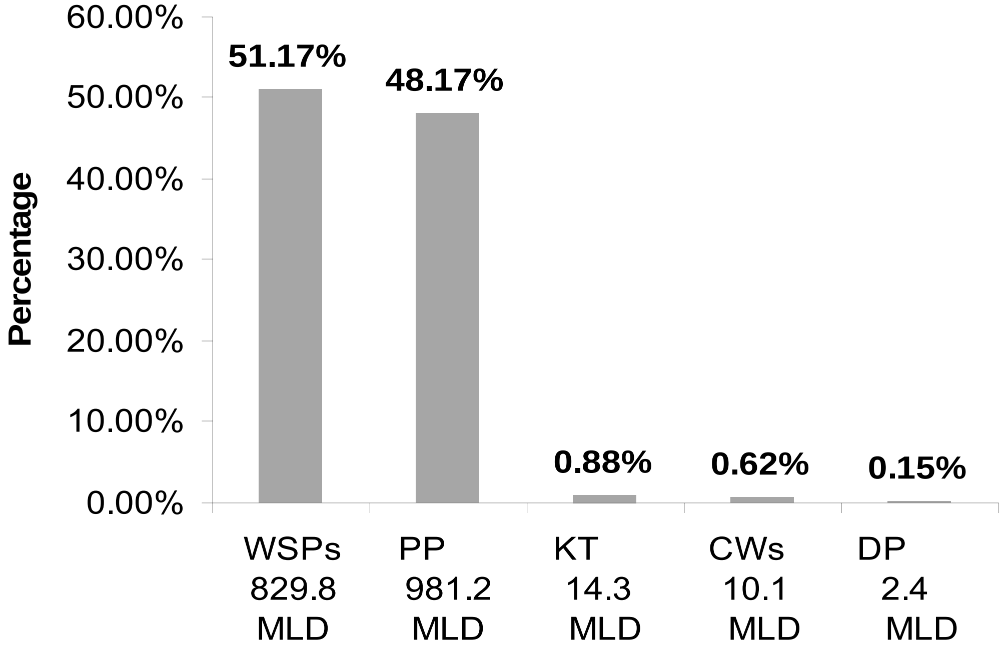

Figure 10: Practices of CWs and other NTSs for wastewater treatment in India

(Saph Pani D3.1, 2012)

Out of approximately 38,000 MLD of wastewater generated from the 70% population of urban India (about 350 million), merely 27% receives some kind of treatment. The remaining 73% population of India is residing small villages where wastewater collection and treatment at large-scale is not possible. The use of NTSs for domestic wastewater treatment is practically unrecorded in the past. The village tanks which invariably receive pollution and are commonly green can be taken as example, though unintended, of the early use of NTSs in India. The natural depressions in the rural areas where all sullage finds its way, creating ponds, could be considered as another example of NTSs. In recent years NTSs have, however, been accepted to be installed as distinct treatment devices, in India, designed on the basis of certain empirical or rational criteria. According to the recent projections, by the year 2051, the domestic wastewater generation is going to be around 83,300 MLD in India (Bhardwaj, 2005). As the water availability per capita is going to reduce due to increase in population, there will be growing reliance on contaminated surface waters for water supply in any urban centre. In that context reuse of the treated effluent from NTSs is an attractive option to reduce the water scarcity.

4.2 Primary water quality criteria for various uses of fresh water in India

A significant element in treated wastewater disposal is the potential environmental impact associated with it. Environmental standards have been developed to ensure that the impacts of treated wastewater discharges into ambient waters are acceptable. Local standards and guidelines play fundamental role in the determination of the level of wastewater treatment required and in the selection of the discharge location and outfall structures. The Central Pollution Control Board (CPCB), New Delhi has classified water resources of the country according to their uses for setting water quality objectives for different water bodies. The classification system is presented in Table 14.

4.2.1 Regulatory concerns of wastewater quality in India

Wastewater treatment plant in India is designed on the basis of downstream use of treated wastewater. In most of the cases the treated wastewater either discharged into a nearby river or reused in irrigation. Therefore, mainly two criteria for the designers of wastewater treatment plants are to meet either the standards of land irrigation or the standards for downstream discharge into the river.

CPCB New Delhi has fixed a set of standards for treated wastewater discharge into river/streams and for on-land disposal or irrigation. These set of standards are being used as minimum reference wastewater quality standards that should be achieved by all of the wastewater treatment plants. The performance of any wastewater treatment plant is being assessed and regulated with these sets of standards as given in Table 15.

All of the wastewater treatment plants in India are being operated to achieve quality standards or guidelines on account of the physicochemical parameters only. At present not a single wastewater treatment plant is being operated for achieving the desired range of fecal coliforms (to achieve < 5,000). In case of most of the wastewater treatment plants, microbial quality of treated wastewater has not been the focus.

Table 14: Primary water quality criteria for various uses of fresh water (CPCB, 2005)

Designated Best Use	Class	Criteria
Drinking water source without conventional treatment but after disinfections	**A**	Total coliform organisms 50 MPN/100 mL or less. pH between 6.5 and 8.5 Dissolved oxygen 6 mg/L or more Biochemical oxygen demand 2 mg/L or Less
Outdoor bathing (organised)	**B**	Total coliform organisms 500 or less MPN/100 mL pH between 6.5 and 8.5 Dissolved oxygen 5 mg/L or more Biochemical oxygen demand 3 mg/l or less
Drinking water source with conventional treatment followed by disinfection	**C**	Total coliform organisms 5000 MPN/ 100 mL or less pH between 6 and 9 Dissolved oxygen 4 mg/L or more Biochemical oxygen demand 3 mg/L or less
Propagation of wild life, fisheries	**D**	pH between 6.5 and 8.5 Dissolved oxygen 4 mg/L or more Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, con-trolled waste disposal	**E**	pH between 6.0 and 8.5 Electrical conductivity less than 2250 micro-mhos/cm Sodium absorption ratio less than 26 Boron less than 2 mg/L

Table 15: Regulatory Concerns of Wastewater Quality for NTSs in India (CPCB, 2005)

Parameter	pH	BOD_5 (mg/L)	COD (mg/L)	TSS (mg/L)	TDS (mg/L)
Standards for discharge in streams	5.5-9	30	250	100	2100
Standards for land irrigation	5.5-9	100	-	200	-

4.3 Effluent quality of the wastewater treated through CWs and other NTSs in India

The principal climatic factors for seasonal variation in quality of treated wastewater effluent from CWs and other NTSs are (i) temperature, (ii) solar radiation, (iii) wind speed, (iv) evaporation, and (v) rainfall. Temperature affects photosynthetic oxygen production, rate of organic degradation, and chemical and biochemical reactions occurring natural treatment systems. CWs and other NTSs operated in India have the great variability in terms of removal of various physico-chemical and bacteriological pollutants present in untreated wastewater. The major reasons for the variation in performance of CWs and other NTSs are of great variations in climatic conditions as well as variation in effluent quality of wastewater from one place to other. The performance of CWs and other NTSs across India has been studied by IITB in 2012 and found that most of the NTSs which are properly operated and maintained are performing well in terms of achieving standards prescribed by CPCB. Some of the case studies of wastewater treatment plants based on different types of NTSs including CWs, WSPs, DPs, sewage feed aquaculture and polishing and their treated effluent quality are available in Saph Pani D3.1.

4.4 Post-treatment and reuse of the wastewater effluents from CWs and other NTSs in India

A national survey of engineered CWs and other NTSs has been conducted by IITB in order to assess the potential of existing CWs and other NTSs for wastewater treatment and reuse across India. Through national survey, IITB has identified 108 sites with NTSs across India. Table 16 provides a summary of the available NTSs, post-treatment applied and downstream use of the effluents from different systems (see Annex A for the details). Out of these 108 sites of wastewater treatment based on CWs and other NTSs, very few (only 2) have a post-treatment facility. It was found that chlorination is the only method which is being practiced in India for post-treatment of effluent coming from CWs and other NTSs. Typically 1-2 mg/L of chlorine is added at the outlet before the effluent is being reused or discharged into the water body. The treated effluents from 22 out 108 NTSs are currently used for irrigation of agricultural fields. In other cases, the effluents from NTSs are directly discharged into the nearby rivers or other water bodies.

There is high potential to use the effluent from NTSs in agriculture because of its low cost and high nutrient content. For that infrastructure should be in place for transfer of the treated effluent from the treatment plants to the field. Furthermore, the farmers should be made aware of the implication of the wastewater reuse in agriculture and potential health effects. Furthermore, effluent from NTSs could also be used in some industrial processes after suitable post-treatment. Finally, artificial recharge of the treated effluent from NTSs is another attractive option to polish the effluent quality and to replenish the depleting groundwater reserves in different places in India.

Table 16: Summary of the available post-treatment and reuse of the wastewater effluents from CWs and other NTSs in India

SN	Type of NTS	Number of systems	Capacity range (MLD)	Post-treatment	Down streams use of treated effluent		
					Agriculture	River or Lake	Unknown
1	WSP	72	0.5 - 58	None	13	38	21
2	PP	15	14 - 152	2 - chlorination	5	4	6
3	KT	5	0.75 - 9	None		3	2
3	CW	10	0.5 - 7.8	None		1	9
5	DP	4	0.5 - 1	None	4		
6	OP	2	12 - 19	None		2	
TOTAL		108			22	48	38

5. Summary and Conclusions

Extensive literature review, field data collection and analysis was conducted to review the status of post-treatments of different NTSs (namely, BF, MAR, CW and other NTSs) for water and wastewater treatment and reuse in India. Based on the results obtained critical water parameters for each of these systems were identified and presented in Table 17. Summary of the findings for each of the NTSs studied are presented in the following sub-sections.

Table 17: Water quality parameters of concern for post-treatment for different NTSs and related case study site

Water Quality Parameter	Bank filtration	MAR*	CW and Others
Pathogens	X (Haridwar, Nainital, Srinagar))	X (Chennai)	X
Nutrients N, P	X		X
Bulk organics	X (Delhi, Mathura)		X
Trace organics	X		X
Inorganics As, F, Fe, Mn, NH_4^+	X (NH_4^+ Delhi, Mathura)	X (F Maheswaram)	
Turbidity	X	X	
Salinity		X (Chennai)	

* Also includes pre-treatment options

5.1 Post-treatment of bank filtrates

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

In general, pathogens, hardness, iron and manganese, ammonium, bulk organic matter and organic micropollutants (specifically in case of rivers with direct impact of wastewater and for future water quality considerations) are some of the critical water quality parameters of concern in India. As there is a relatively high concentration of organic matter in majority of the bank filtrates in India and chlorination is the only treatment applied, formation of disinfection byproducts is the main quality concern. Limited information is available on the concentrations of organic micropollutants in the raw water and filtrates at the bank filtration sites in India.

5.2 Pre- and post-treatment of MAR systems

Data available in the literature on pre- or post-treatment in India is scarce and covers MAR systems that mainly are linked to rooftop RWH and few surface runoff recharge systems only. The majority of the pre- and post-treatment systems found in literature are small in scale (capacity ranging from 14.4 to 8910 m^3/year), meant for very small communities. For these systems, no examples of pre- and post-treatments were found in literature. Thus the pre- and post-treatment needs were investigated a) from available data in literature on pre-treatment at existing MAR sites in India, b) from the available data on groundwater treatment in India and c) from already available data on water quality at the SAPH PANI case study sites Raipur, Maheshwaram and Chennai, in relation to water quality standards.

The parameters that need treatment are high amounts of suspended materials and turbidity along with elevated fluoride and nitrate concentrations in certain locations. The water quality problems found in literature on groundwater treatment in India (salinity, F, NO_3, Fe, Mn and pathogens) – which may give an indication for necessary post-treatment – are similar to those that have been encountered in the Saph Pani case study sites.

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

In the case of source water from harvested rain, a difference in the rainwater chemistry can be observed from rural to urban area. Sulphate, sea salt (Na and Cl) and ammonium are present in higher concentrations in urban regions than the rural areas. Microbial concentration was also found to much higher in water from roof top for urban areas.

Analysis of the data obtained from the Saph Pani field site show that a post- treatment is necessary to meet the guidelines for drinking water only. Low salinity in all 3 locations (except few wells in Chennai) suggests that groundwater is suitable for irrigation. The salinity in that region is mainly due to the seawater intrusion and it is expected to be pushed back after the implementation of MAR structures. Microbial quality of the groundwater has not been assessed in these cases. However, the most common disinfection method, chlorination will probably be applicable here as well. The parameters that need treatment are salinity, Mg hardness, Fe, Mn, NO_3 and F.

The treatment of fluoride deserves special attention due to its hazardous effects on human health. In general, rainwater recharge (normally acidic to neutral pH) will dilute the F-rich water and reduce the concentration. However, this is purely depending on the chemical composition of the source water. In Maheswaram, both rain water and surface runoff are contributing to the total recharge. In case the acidic pH of rainwater may change to alkaline during the interaction with aquifer, this will mobilize the F from the source rock. Moreover, the Na/Ca ratio in the study area is higher than 1, which also an important factor in elevating the F concentration. A possible treatment method would be to elevate the Ca concentration to a higher level than Na in the source water, so that the F will precipitate as CaF_2 and reduce the F in groundwater.

Further investigations in the Saph Pani project should focus on large-scale systems for pre-treatment for the removal of TSS and Turbidity. This may be achieved either through filters or by regular maintenance, a decision, which should be based on a cost-benefit analysis. Investigations on post-treatment must be focused on the available methods for Fe and Mn removal as well as disinfection. Potential for treating the fluoride as precipitate (CaF_2) by increasing the Ca/Na ratio in source water could be examined.

5.3 Pre- and post-treatment for CWs and other NTSs

Different types of NTSs employed in India for wastewater treatment include Constructed Wetlands (CWs), Hyacinth and duckweed ponds, Karnal Technology, Fish Ponds, Waste Stabilization Ponds (WSPs), Oxidation Ponds and Lagoons and, Algal-bacterial ponds. In India, WSPs is the most prominent contributing to 51 % of total wastewater treated by means of NTSs. Polishing pond are also equally practices as WSPs and contributing 48 % of total wastewater treated by means of NTSs. Karnal technology, engineered constructed wetlands and duckweed ponds are very rarely practices in India and contribute about 0.9%, 0.6% and 0.2% respectively of the total volume of wastewater treated by NTSs.

In India, all the wastewater treatment systems including CWs and other NTSs have been designed and operated in order meet the regulatory standards prescribed by CPCB for reuse and discharge into the water body. The major reuse of treated domestic wastewater effluent from CWs and other NTSs in India are irrigation of agricultural fields, gardening, sewage fed aqua culture and recreation ponds. The national survey conducted by IITB indicates that in most of the cases, the treated effluent from CWs and other NTSs is directly reused in agriculture or disposed into adjoining river. In most of the cases, treated wastewater from CWs and other NTSs contains a very high number of total coliform bacteria (10^4 to 10^6), which may impose the risk of ground water contamination of adjoining area. The reuse of secondary effluent without any post-treatment including disinfection may pose health hazards if the community access groundwater from nearby treated wastewater reuse or disposal site.

Based on the national survey of CWs and other NTSs by IITB, it was found that there is no post-treatment of the secondary treated effluent of CWs and other NTSs in India. Out of 108 operated sites of CWs and other NTSs, only two systems have the facility of chlorine disinfection. Hence post-treatment of the secondary treated effluents from CWs and other NTSs is almost absent in India. If a proper post-treatment system is provided, there is a high potential for reuse of treated effluent from CWs and NTSs in India for industrial reuse and artificial recharge of groundwater.

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ANNEX A: Available post-treatment and reuse of the wastewater effluents from CWs and other NTSs in India

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
1	WSP	14	2003	No Post-treatment	Godavari River	Ramagundam I, Andhra Pradesh
2	WSP	4	2003	No Post-treatment	Godavari River	Ramagundam II, Andhra Pradesh
3	WSP	4	2003	No Post-treatment	NA	Bhadrachalam, Andhra Pradesh
4	WSP	14	2004	No Post-treatment	Godavari River	Ramagundam IV, Andhra Pradesh
5	WSP	4	1988	No Post-treatment	Punpun, Ganga	Kermallichak, Bihar
6	WSP	2	1988	No Post-treatment	Ganga River	Chapra, Bihar
7	WSP	46	1965	No Post-treatment	Seonath River	Kutelabhata vill, Bhilai Nagar, Chhatisgarh
8	WSP	14	1965	No Post-treatment	NA	Risali village, Bhilai Nagar, Chhatisgarh
9	WSP	9	1965	No Post-treatment	NA	Bhilai House, Bhilai Nagar, Chhatisgarh
10	WSP	27.27	2003	No Post-treatment	Yamuna River	Timarpur, Delhi
11	PP	20	2000	No Post-treatment	Yamuna River	Faridabad I, Haryana
12	PP	45	2000	No Post-treatment	Yamuna River	Faridabad II, Haryana
13	PP	50	2000	No Post-treatment	Yamuna River	Faridabad III, Haryana
14	WSP	8	2000	No Post-treatment	Yamuna River	Karnal II, Haryana

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
15	WSP	1	2001	No Post-treatment	NA	Chhchhrauli, Haryana
16	WSP	1.5	2001	No Post-treatment	NA	Indri, Haryana
17	WSP	1	2001	No Post-treatment	NA	Radaur, Haryana
18	WSP	9	2003	No Post-treatment	Agricultural Field	Palwal, Haryana
19	WSP	3	2004	No Post-treatment	NA	Gharaunda, Haryana
20	WSP	3.5	2004	No Post-treatment	NA	Gohana, Haryana
21	WSP	19.45	2001	No Post-treatment	Tungabhadra	Davanagere, Karnataka
22	WSP	5.83	2001	No Post-treatment	Bhadra River	Bhadravati, Karnataka
23	WSP	1.47	2001	No Post-treatment	NA	Nanjagud, Karnataka
24	WSP	1.36	2001	No Post-treatment	NA	Sri Rangapatna , Karnataka
25	WSP	18.16	2003	No Post-treatment	Tunga River	Shimoga, Karnataka
26	WSP	1.45	2004	No Post-treatment	NA	K R Nagar, Karnataka
27	WSP	4.5	2007	No Post-treatment	NA	Pamba, Kerla
28	WSP	8	NA	No Post-treatment	NA	Bherkheda, Bhopal, Madhya Pradesh
29	WSP	52	2001	No Post-treatment	Shipra River	Ujjain, Madhya Pradesh
30	KT	1.67	2001	No Post-treatment	Shipra River	Barogarh, Ujjain, Madhya Predesh

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
31	KT	1.67	2001	No Post-treatment	Shipra River	Barogarh, Ujjain, Madhya Predesh
32	KT	1.2	2001	No Post-treatment	NA	Chapara, Madhya Pradesh
33	KT	0.75	2001	No Post-treatment	NA	Keolari, Madhya Pradesh
34	KT	9	2004	No Post-treatment	Betwa River	Vidisha, Madhya Pradesh
35	WSP	6	2005	No Post-treatment	Tapi River	Burhanpur, Madhya Pradesh
36	WSP	2.5	1995	No Post-treatment	Sina, Bhima River	Aurangabad, Maharashtra
37	WSP	5	NA	No Post-treatment	Salim Ali Lake	JNEC, Aurangabad, Maharashtra
38	OP	18.9	1995	No Post-treatment	Gima River	Jalgaon, Maharashtra
39	OP	12.87	Pre 95	No Post-treatment	Manjeera River	Latur , Maharashtra
40	WSP	26/8.9	2000	No Post-treatment	Godavari River	Nanded-Waghala, Maharashtra
41	WSP	1	2003	No Post-treatment	NA	Trimbakeshwar, Maharashtra
42	WSP	23.82	2004	No Post-treatment	Krishna River	Sangli-Miraj and Kupwad, Maharashtra
43	WSP	33	2003	No Post-treatment	Mahanadi River	Cuttak, Orissa
44	WSP	2	2005	No Post-treatment	NA	Talcher, Orissa
45	WSP	2.6	2003	No Post-treatment	NA	Sultanpur Lodhi, Punjab
46	WSP	2.56	2004	No Post-treatment	Satluz river	Phillaur, Punjab

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
47	PP	25	NA	**Chlorination**	Agricultural Field	Kapoorthala, Punjab
48	PP	22.73	2005	Information Not Available	NA	Raipur Kalan,Chandigarh,
49	DP	0.5	NA	No Post-treatment	Agricultural Field	Bais Village, Ludhiana, Punjab
50	DP	0.5	NA	No Post-treatment	Agricultural Field	Village Saidpur, Ludhiana, Punjab
51	DP	0.5	NA	No Post-treatment	Agricultural Field	Village Sandhuan, Roop Nagar, Punjab
52	WSP	0.5	NA	No Post-treatment	Agricultural Field	Village Dedwal, Ludhiana, Punjab
53	WSP	0.5	NA	No Post-treatment	Agricultural Field	Village Sandhuan, Roop Nagar, Punjab
54	DP	1	NA	No Post-treatment	Agricultural Field	Village Uncha, Roop Nagar, Punjab
55	WSP	20	2007	No Post-treatment	Agricultural Field	Village Nanded, Jodhpur, Rajasthan
56	WSP	20	2007	No Post-treatment	Agricultural Field	Vallabh Garden Bikaner, Rajasthan
57	PP	111	2004	No Post-treatment	Agricultural Field	Ludhiana, Zone B, Punjab
58	PP	152	2004	Information Not Available	Agricultural Field	Ballok, Ludhiana
59	PP	48	2005	Information Not Available	Agricultural Field	Jmalpur, Ludhiana
60	WSP	28	2003	No Post-treatment	Kaveri	Tiruchirappalli II, Tamil Nadu

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
61	WSP	3.94	2003	No Post-treatment	NA	Bhawani, Tamil Nadu
62	WSP	58	2004	No Post-treatment	Kaveri	Tiruchirappalli, Tamil Nadu
63	WSP	20	2004	No Post-treatment	Kaveri	Erode I, Tamil Nadu
64	WSP	3.96	1988	No Post-treatment	NA	Farrukhabad, Uttar Pradesh
65	WSP	9	1999	No Post-treatment	Yamuna River	Noida III, Uttar Pradesh
66	WSP	10	2001	No Post-treatment	Yamuna River	Peela Khar, Agra, Uttar Pradesh
67	PP	14	NA	**Chlorination**	Yamuna River	Dayal Bag, Agra, Utter Pradesh
68	PP	78	NA	No Post-treatment	Agricultural Field	Dhandpur, Agra, Utter Pradesh
69	WSP	2.5	2001	No Post-treatment	Yamuna River	Burhi ka Nagla, Agra, Uttar Pradesh
70	WSP	32	2001	No Post-treatment	Kali River	Muzaffarnagar, Uttar Pradesh
71	PP	70	2001	Information Not Available	NA	Hindone I, Ghaziabad, Uttar Pradesh
72	PP	56	2001	Information Not Available	NA	Hindone II, Ghaziabad, Uttar Pradesh
73	PP	34	NA	Information Not Available	NA	Noida I, Uttar Pradesh
74	PP	27	NA	Information Not	NA	Noida II, Uttar Pradesh

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
				Available		
75	PP	27.5	NA	No Post-treatment	NA	Mirzapur, Uttar Pradesh
76	WSP	14.5	2001	No Post-treatment	Agricultural Field /Yamuna River	Bangalighat dairy farm, Mahura, Uttar Pradesh
77	WSP	4	NA	No Post-treatment	Agricultural Field	Baba Temple, Vrindavan, Utter Pradesh
78	WSP	12.5	2001	No Post-treatment	Agricultural Field /Yamuna River	Masani, Mathura, Uttar Pradesh
79	WSP	0.5	NA	No Post-treatment	Agricultural Field	Kali Deh, Vrindavan, Utter Pradesh
80	WSP	10.45	2001	No Post-treatment	Yamuna River	Etawah Uttar Pradesh
81	WSP	10	1987	No Post-treatment	Ganga River	E (Madrail),Bhatpara, West Bengal
82	WSP	30	1987	No Post-treatment	Ganga River	.S.Sub-E, Kolkata, West Bengal
83	WSP	4.54	1987	No Post-treatment	Ganga River	Chandannagar II, West Bengal
84	WSP	8	1987	No Post-treatment	Beel	Baharampur, West Bengal
85	WSP	16.5	1988	No Post-treatment	Irrigation, Pissiculture	Panihati, West Bengal
86	WSP	45	1988	No Post-treatment	Irrigation, Pissiculture	Bally, West Bengal
87	WSP	14.1	1988	No Post-treatment	Irrigation, Pissiculture	Bandipur, West Bengal
88	WSP	4.54	1988	No Post-treatment	Irrigation, Pissiculture	Titagarh, West Bengal

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
89	WSP	10	1988	No Post-treatment	Ganga River	Nabadwip, West Bengal
90	WSP	3	2003	No Post-treatment	Ganga River	Khardaha, West Bengal
91	WSP	3.93	2003	No Post-treatment	Ganga River	Maheshtala, West Bengal
92	WSP	5.9	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
93	WSP	1	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
94	WSP	10.9	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
95	WSP	4.35	2003	No Post-treatment	Ganga River	Barrackpur, West Bengal
96	WSP	1.9	2005	No Post-treatment	NA	Murshidabad, West Bengal
97	WSP	0.52	2005	No Post-treatment	NA	Diamond Harbour, West Bengal
98	WSP	1.39	2006	No Post-treatment	NA	Jiagani Ajimganj, West Bengal
99	CWs	21.25 m × 5.5 m	NA	No Post-treatment	NA	Kakatiya Musical Garden of Warangal City, Andhra Pradesh
100	CWs	NA	NA	No Post-treatment	NA	Mahindra Mahindra, Igatpuri, Nashik.
101	CWs	NA	NA	No Post-treatment	NA	Presidency Kid Leather Ltd. Kannivakkam Tamil Nadu
102	CWs	NA	NA	No Post-treatment	NA	Guru govind singh Park (Ekant Park)

SN	Types of NTSs	Capacity (MLD)	Year of commissioning	Type of Post-treatment	Downstream use of treated effluent	Location
						Southern area, Bhopal
103	CWs	1	NA	No Post-treatment	NA	Kankhal, Haridwar, UttaraKhand
104	CWs	NA	NA	No Post-treatment	NA	Sainik School Bhuneshwar, Orissa
105	CWs	0.5	NA	No Post-treatment	NA	village Pipal Majra, District Ropar, Pumjab
106	CWs	2.5 acres	NA	No Post-treatment	NA	village Shekhupur in District Patiala, Punjab
107	CW	7.8	2008	No Post-treatment	Mansagar Lake (Recreational)	Mansagar Lake, Jaipur, Rajasthan
108	CW	NA	NA	No Post-treatment	NA	Ujjain

NA = Not Available, WSP = Waste Stabilization Pond, PP = Polishing pond, DP = Duckweed Pond, CW = Constructed Wetland, KT = Karnal Technology

[Source: D3.1 Interim report, Saph Pani project, October 2012]