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List of Abbreviations

AP	Anaerobic Pond
ARR	Artificial Recharge and Recovery
BF	Bank Filtration
BOD_5	Biochemical Oxygen Demand (5 day basis)
CWs	Constructed Wetlands
DOC	Dissolved Organic Carbon
DP	Duckweed Pond
FC	Faecal Coliform
HNM	Halonitromethane
KT	Karnal Technology
MAR	Managed Aquifer Recharge
MLD	Millions Liters per Day
MPN	Most Probable Number
NTS	Natural Treatment System
OP	Oxidation Pond
OMP	Organic Micropollutant
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
SFA	Sewage Feed Aquaculture
SS	Suspended Solids
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
WHP	Water Hyacinth Pond
WSP	Waste Stabilization Pond
UASB	Up-flow Anaerobic Sludge Blanket

1 Introduction

1.1 Background and scope of the report

Work package 4 of EU Saph Pani Project deals with the pre- and 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 objectives under this work package is to assess the efficiencies of the conventional pre-treatment and post-treatment systems applied to natural treatment systems (NTSs) to remove different contaminants. Analysis of the efficiencies and effectiveness of pre-treatment and post-treatment systems is important for the proper design and functioning of the NTSs and to ensure that the treated water from the NTSs meet the local water quality guidelines and standards for intended use.

This deliverable provides a general overview of some of the common conventional pre- and post treatment methods applied to different NTSs and their efficiencies for the removal of some key water quality indicators namely pathogens, turbidity/suspended solids, colour, bulk organics, metals and organic micropollutants based on literature view and laboratory and field pilot studies. Furthermore, it also presents the summary of the specific research studies carried out at different partner institutions to analyse selected water quality parameters requiring pre- and/or post-treatment and their removal.

1.2 Pre- and Post-treatment methods for natural systems their removal efficiencies

Pre-treatment refers to removing or reducing the concentrations of some of the critical contaminants in source water to enhance the performance of subsequent treatment systems. Pre-treatment may be required in NTSs to avoid clogging and contamination of the aquifers, to increase the run time, and to enhance the removal efficiencies of different contaminants. The type of the pre-treatment to be used mainly depends on the source water type and quality (rain water, urban runoff, river or lake water, wastewater treatment plant effluent) and as well as the type of NTS employed. In case of bank filtration (BF), no specific pre-treatment system is provided and therefore, proper siting and design of the abstraction wells (type, number, spacing and pumping rates) are critical to minimize clogging and to maximize the removal of the several contaminants during the soil passage. Pre-treatment is more relevant for artificial recharge and recovery (ARR) systems, constructed wetlands (CWs) and other NTSs for wastewater treatment and reuse. Sedimentation (using detention tanks, reservoirs, settling basin), filtration (roughing or rapid sand), are some of the common pre-treatment applied for ARR systems. Sometimes coagulation, adsorption, membrane filtration, advanced oxidation, disinfection and their combinations have been applied as pre-treatment in some NTSs (van der Hoek, 2000; van Houtte and Verbauwhede, 2005; Tielemans, 2007) to reduce clogging and contamination of the aquifer. Sedimentation and filtration are also commonly applied pre-treatment for CWs and other pond based NTSs, if any.

Post-treatment refers to further upgrading the quality of the "treated water" from different NTSs so that it meets the water quality requirements for different applications. Requirements for post-treatment of "product water" from natural systems vary significantly depending upon on the quality of the source water used, type, design, and operation of NTS employed, process conditions applied and applicable water quality guidelines or standards for intended use. 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 (OMPs), (iv) activated carbon filtration (with or without pre-ozonation) to remove the OMPs and colour/taste and odour present in the water, (v) softening and pH correction to remove the hardness and to ensure that there is no scaling or corrosion of water distribution system.

Table 1 provides an overview of main water quality concerns for different natural systems used in India and pre- and post-treatment applied.

Table 1: Pre-treatment and post-treatment applied to different NTSs in India

NTS	Pre-treatment applied	Main Water quality concerns in abstracted water	Post-treatment methods applied
Bank filtration	Not applicable	Pathogens, hardness, ammonium, nitrate (trace organics)	Disinfection, Lime softening, Aeration, Coagulation, Sedimentation, Rapid sand filtration
Artificial Recharge	Sedimentation, sand filtration	Iron, manganese, fluoride and arsenic in local groundwater (of geogenic origin)	Disinfection, Aeration + Sand filtration, Several adsorption and coagulation based systems for treatment of specific contaminants like arsenic and fluoride
CW and other natural systems for wastewater treatment	Sedimentation (septic tanks, settling basins), if any	Pathogens, organic matter, Nutrients N,P (trace organics)	Chlorination only (if any)

Short descriptions of some of the main conventional treatment methods applied and their removal efficiencies are presented in the following paragraphs:

1.2.1 Sedimentation

Sedimentation is the most common pre-treatment process applied to several natural systems to reduce the suspended solid loads in order to reduce the clogging and reduction in (in)filtration rates. Sedimentation tanks, detention chambers, retention ponds, settling basins are some of the common terminologies used for different types of structures employed for this purpose. The removal efficiency of the sedimentation process mainly depends on the type, size and concentration of the particles present, hydraulic loading rate applied, detention time and temperature designed.

Generally some detention tank and/or filters are provided to reduce the suspended loads of the stormwater before it is discharged to water bodies or used for recharging the aquifers. The typical suspended solids removal efficiency of these detention tanks/chambers vary considerably (from 20 to 90% for detention time of 1 to 48 hours), depending on their design. Furthermore, generally screens, grit chamber and sedimentation tanks/detention chambers are provided before CWs and pond systems. Table 2 summarizes the typical removal efficiencies of total suspended solids (TSS), BOD and pathogens from raw wastewater in primary sedimentation tank with and without chemical coagulation.

Table 2: Typical removal efficiencies of primary sedimentation of wastewater [Metcalf and Eddy, 2004]

Treatment system	TSS (%)	BOD (%)	Pathogens (%)
Sedimentation only	50 - 70	25 - 40	25 - 75
Chemical Coagulation followed by Sedimentation	80 - 90	50 - 80	80 - 90[c]

1.2.2 Filtration

Granular media filters namely roughing filters (media size = 4 to 20 mm) and rapid sand filters (media size = 0.8 to 4 mm) are generally used as pre-treatment used to reduce the turbidity and suspended solids concentrations of the water. Rapid sand filters are also used after aeration or coagulation + sedimentation to remove the particulate formed due to oxidation or precipitation of the target contaminants (iron manganese, ammonium, fluoride, arsenic). Slow sand filters are generally employed as biological systems to remove the pathogens and further polish the water quality after rapid sand filtration or other treatment steps. The removal efficiency of filtration system depends upon, among others, the size of the filter media, depth of the filter bed and filtration rate.

Roughing filters have achieved peak turbidity removals ranging from 60 to 90%; generally, the more turbid the water initially, the greater the reduction that can be achieved. These filters can achieve similar reductions of coliform bacteria. When followed by slow sand filtration, the removal reached 99.8%, with an overall combined pathogen removal efficiency of 4.9–5.5 log units (LeChevallier and Au, 2004). With pre-treated water, rapid sand filtration can produce water that has <1 NTU turbidity, with 90% removal of coliforms, 50-90% removal of cryptosporidium and Giardia cysts, 10% removal of colour, and 5% removal of total organic content. With slow sand filtration, the following removal efficiency can be achieved: turbidity to <1 NTU, Coliform 95%, *Cryptosporidium* and *Giardia* cysts, 99%, colour 75% and total organic content up to 10% (ITACANET, 2005). The typical removal efficiencies for stormwater filters are 76% for fecal coliform, 70% for suspended solids, 48% for total organic carbon and 46% for total Kjeldahl nitrogen (USEPA, 1999).

1.2.3 Coagulation

The process conditions (i.e. dose, type of mixing system and duration of mixing, pH, temperature, alkalinity, turbidity and the level and type of natural organic matter) affect the removal efficiency of coagulation process. When properly performed, coagulation, flocculation and sedimentation can result in 1–2 log removals of bacteria, viruses and protozoa which if combined with rapid sand filtration increases up to 4 log removals. Overall, iron-based coagulants were slightly more efficient than alum (aluminum hydroxide) or poly-aluminum chloride (PACl); however, site specific water-quality conditions have a dominant effect on removal efficiencies than the type of coagulant used. NOM removal by coagulation process depends on the type of organic matter present and is normally ≤ 60% (Bursil, 2001).

1.2.4 Disinfection

Disinfection (specifically chlorination) is the main and very often the only post-treatment applied to abstracted water from BF and ARR systems before supply as well as to the effluent of CWs and other natural systems for wastewater treatment (intended for reuse). The efficiency of the disinfectant depends upon the type and dose concentration (dose) of the disinfectant applied, contact time, type and concentration of microorganisms present and water quality parameters affecting disinfection process including pH, temperature and turbidity. The effectiveness of disinfection is measured as *Ct value = concentration of disinfectant x contact time*. Higher Ct values indicate relatively higher resistance to disinfectant, while lower Ct values indicate relatively low resistance to disinfectant chlorine. The same Ct value can be obtained by different combination of C and t. Table 3 presents the Ct value ranges for inactivation of various microorganisms by disinfectants (for 99% inactivation).

As the treated water after BF, ARR or CW and other pond systems have relatively lower number of pathogens, it was found during field survey that about 1 to 2 mg/L of Cl_2 (generally in the form of sodium hypochlorite or bleaching powder) is dosed to the treated water before supply to meet the microbiological water quality requirements.

Table 3: Summary of Ct values (mg/L.min) for 99% activation of different microorganisms at 5°C [Adapted from Clark *et al*., 1993]

Microorganism	Free chlorine (pH 6-7)	Mono chloramine (pH 8-9)	Chlorine dioxide (pH 6-7)	Ozone (pH 6-7)
E. coli	0.034 - 0.05	95 - 180	0.4 - 0.75	0.02
Poliovirus 1	1.1-2.5	768 - 3740	0.2 - 6.7	0.1 - 0.2
Rotavirus	0.01 - 0.05	3806 - 6476	0.2 - 2.1	0.006 - 0.06
Giardia	47 - 630		7.2 - 18.5	1.8 - 2.0[a]
Cryptosporidium	7200[b]	7200[c]	78[b]	5 - 10[c]

a. Values for 99.9% inactivation at pH 6-9

b. 99% inactivation at pH 7 and 25°C

c. 90% inactivation at pH 7 and 25°C

1.2.5 Adsorption and Ion Exchange Processes

Adsorption and ion exchange based processes have been use for the post-treatment of abstracted water in order to remove specific contaminants like arsenic, fluoride, nitrate, colour and odour compounds and OMPs. The removal efficiency of these processes depend on the adsorption/ion-exchange capacity and characteristics (grain size, specific surface area, pore size distribution, density)of the media used, concentration of the contaminant in influent and target effluent concentration, mode of application (batch, fixed bed or fluidized-bed).

Iron-based or iron oxide coated filter media have been extensively used to remove arsenic from groundwater, while activated alumina and bone char coal have been used for removal of fluoride. Activated carbon has been used for removal of colour and odour compounds as well as OMPs. As post-treatment, ion exchange processes have been used for reducing concentrations of nitrate, natural organic matter (colour compounds) and sometimes for removal of iron, manganese, arsenic and hardness.

2 Removal efficiencies of pre- and post-treatment methods applied at case study sites

This chapter presents the results of literature review and field data collection at Saph Pani case study sites in order to assess the removal efficiencies of different conventional treatment processes for post-treatment after NTSs. Study on post-treatment of BF focuses on Mathura RBF site in which post-treatment with and without bank filtration has been compared. This chapter also elaborates on TSS and turbidity removal by different pre-treatment systems at MAR sites and presents various methods available in India for removal of arsenic and fluoride from groundwater. Finally, efficiencies of different pre- and post-treatment methods applied to CW and other natural systems for wastewater treatment have been presented based on the results of national survey and specific case studies.

2.1 Removal efficiencies of disinfection and other post-treatment applied at bank filtration sites in India with specific reference to Mathura by the Yamuna river

2.1.1 Introduction

The most common post-treatment practiced at most BF sites known till date in India, especially those in Uttarakhand is disinfection by chlorination, as also reported in a review of post-treatment practices used at various natural treatment systems for water in India (Saph Pani D4.1, 2013). However, the Yamuna river at the BF site of Mathura has a relatively high organic and microbiological pollution compared to the surface waters at other BF sites in India, and thus bank-filtrate is aerated, filtered, chlorinated and distributed (Kumar *et al*., 2012). Consequently, the work describing the post-treatment at the Mathura BF site by Kumar *et al*. (2012) is discussed in this deliverable as it is the most relevant example of post-treatment till date at any known BF site in India. This entire section 2.1 (including its subsections 2.1.1 to 2.1.4) is thus an extract from the article “Riverbank Filtration: An Alternative to Pre-chlorination” by Kumar *et al*. (2012) which was published as part of the “Saph Pani” project in the “Special Issue on River Bank Filtration” in the Journal of Indian Water Works Association in December 2012. The work by Kumar *et al*. (2012) is based partly on previous studies by Singh *et al*. (2010) and Luckins *et al*. (2011) conducted on the Mathura BF site.

Pre-chlorination is commonly used to control the taste, odour, colour, iron and manganese in water. It is also used to control the algal growth inside water treatment units. If the concentration of organic matter is high in the raw water, pre-chlorination may cause a significant increase in concentrations of disinfection by-products (DBPs) in the treated water that are in-turn harmful because they are carcinogenic. Removal of organics to minimize formation of DBPs is a regulatory requirement in many developed countries. According to Kumar *et al*. (2012), the technical bulletin W296, published by the DVGW German Technical and Scientific Association for Gas and Water has recommended dissolved organic carbon (DOC) removal down to 2 mg/L to meet the trihalomethane (THM) guideline value of 100 µg/L (Frimmel, 2002).

This section (2.1) extracted from Kumar *et al*. (2012) presents a comparison of the quality of the water produced by two different treatment schemes {(i) with pre-chlorination (without RBF) and (ii) without pre-chlorination (with RBF)} located on a polluted stretch of the River Yamuna at Mathura, India. Mathura (27° 28' N, 77° 41' E; State-Uttar Pradesh: Northern part of India) was selected for the investigations for three reasons. Firstly, sites using each system existed close by, separately drawing water from the same river. The second reason concerns the characteristics of the Yamuna water exploited for the water production. At Mathura, river water is polluted, coloured and unacceptable for drinking. Only limited literature is available on the fate of surface water having considerable organic pollution and/or colour during RBF (Nestler *et al*., 1991; Cosovic *et al*., 1996; Miettinen *et al*., 1998; Singh *et al*., 2010). The third reason was the placement of the RBF well in the centre of the river, which is quite different from the well established practice in Europe and USA (Hunt *et al*., 2003). Singh *et al*. (2010) have carried out some water quality studies for such a well placed in the middle of the river Yamuna at Mathura. To reduce DOC to the desired level (<2 mg/L), the dose of ozone required for the riverbank filtrate was found to be considerably less than the ozone required for the river water.

In addition to comparison of the water quality produced by two different treatment schemes, chlorination experiments with the river and riverbed-filtered waters were carried out by Kumar *et al*. (2012) in the laboratory to evaluate the maximum THM yields. The study aimed to demonstrate the treatment impact of RBF on the polluted river water (having distinct disagreeable visual properties) and evaluate the possibility of eliminating the need for pre-chlorination (and hence DBPs) in such a situation.

2.1.2 Site description and research methodology

The Yamuna river originates from the Yamnotri Glacier in the Himalayas and after covering a distance of 1376 km it joins the River Ganga at Allahabad. According to Central Pollution Control Board about 85% of the total pollution in the river is caused by domestic sewage (CPCB, 2006). According to Kumar *et al*. (2012), water supply schemes at Mathura-Vrindavan and Agra utilize the polluted river water as raw water for the production of potable water. Mathura, which is 155 km downstream of Delhi, has two water supply schemes at two sites (Site 1 and 2) which are approximately 4 km apart.

At Site 1, an intake well pumps the river water, which is aerated, pre-chlorinated, coagulated, flocculated, settled and filtered. Alum and chlorine demands of raw water are determined. Chlorine is added during the pre-chlorination depending upon the quality of the raw water. Generally, adequate free residual chlorine remains till the end of the treatment. However, post-chlorination, whenever needed, is carried out prior to distribution. Chlorine demand varies from 8 to 85 mg/L (based on data of 2007). More than 90% of the chlorine demand values lie between 15 and 65 mg/L with a mean around 32.5 mg/L (Kumar *et al*., 2012). Use of such high doses of chlorine has not been reported in the recent literature on oxidation (or pre-chlorination) of raw waters. Thus, Kumar *et al*. (2012) stated that it is difficult to predict the nature and concentrations of DBPs that are produced after chlorination. For instance, in Germany, it is a general practice to use chlorine disinfection chemicals at the end of the treatment process. Cl_2 or ClO_2 are not allowed to be used for oxidation purposes. According to the German Drinking Water Regulations, the maximum allowable chlorine addition is only 1.2 mg/L. However, no such guidelines exist in India (Kumar *et al*., 2012).

At Site 2, sub-surface water is collected from a 25-year-old radial well, centered in the riverbed and having thirteen radials (total length of 522 m) laid at 15.5 to 18 m below and located entirely beneath the bed of the river. Bank-filtrate is aerated, filtered, chlorinated and distributed. Water is neither pre-chlorinated nor coagulated. Only post-chlorination (with a chlorine dose of around 1 mg/L) is practiced.

The details of the materials and research methodology used are described in Kumar *et al*. (2012). Accordingly, water samples from the River Yamuna at several locations around Sites 1 and 2, treated water at Site 1 and riverbank filtrate along with treated water at Site 2 were collected. The temperature, pH, conductivity, and dissolved oxygen (DO) were measured on-site, and samples were transported to the Environmental Engineering Laboratory, IIT Roorkee and analyzed for turbidity, major ions, DOC, colour, UV-absorbance, ammonium nitrogen, most probable number (MPN) of coliform bacteria and chlorine demand in accordance with the procedures laid down in the Standard Methods for the Examination of Water and Wastewaters (APHA, 2005). Some water samples collected were also analyzed at the DVGW Technologiezentrum Wasser (Water Technology Centre, TZW), Dresden, Germany. A set of samples were also analyzed at the Institute of Water Chemistry, Dresden University of Technology, Germany for DOC, UV-absorbance, and absorbable organic halogens (AOX).

2.1.3 Results and discussion

Treated waters at Site 1 (without RBF and with pre-chlorination) and Site 2 (with RBF and without pre-chlorination) have been referred as Treated Waters 1 and 2 respectively. Ranges of the values of selected water quality parameters for the River Yamuna, Treated Water 1, riverbed filtrate and Treated Water 2 are presented in Table 4. Desirable and permissible limits for drinking water as specified in the Indian Standard IS: 10500 (IS 1991) are also given in Table 4. Permissible limits represent the relaxations permitted in the desirable limits in the absence of an alternate source at a particular location.

According to the data presented in Kumar *et al*. (2012), and its perusal in Table 4, a variation in turbidity of the river water of only up to around 14 NTU is indicated. This was because the samples were collected in pre- and post-monsoon periods only. Turbidity of the River Yamuna water during monsoon ranged from 70 to 180 NTU (CPCB, 2006). The pH of the river water varied from 7.4 to 8.2. The average dissolved solids concentration of the river water was around 825 mg/L which is more than the desirable limit of 500 mg/L. Average conductivity (~1370 μS/cm at 25^oC) and alkalinity (~320 mg/L as $CaCO_3$) were also high, and average values of DOC (~7 mg/L), UV-absorbance (~21 m^{-1} at 254 nm) and colour (~55 colour unit, CU) indicated the presence of organic compounds in the Yamuna water (Kumar *et al*., 2012). The colour due to inorganic metal ions at pH 7.4 to 8.2 is unlikely. River water was found to be contaminated with coliform bacteria with the most probable number (MPN) in the range of 23 x 10^2 to 15 x 10^5 per 100 mL.

Sites 1 and 2 are located very close to the sampling site of the CPCB at Mathura. Based on the data of CPCB, the Yamuna at Mathura appears to be substantially polluted in terms of organics (COD: 13-94 mg/L and BOD: 3-21 mg/L), nitrogen (ammonia: up to 36.6 mg/L and total Kjeldahl nitrogen: 1.12-41.3 mg/L) and bacterial contamination (total coliforms: 13.2 x 10^3-26.1 x 10^6 and fecal coliforms: 9.0 x 10^2- 28.2 x 10^5 MPN per 100 mL). DOC, UV-absorbance and colour reported in Table 4 are also indicative of organic pollutants in the river. The BOD to COD ratio works out to roughly 0.25, indicating that organic matter is largely refractory in nature. Very high values of total and fecal coliforms are indicative of substantial bacterial contamination. The water quality data clearly prove that Yamuna river water at Mathura is grossly polluted. It is a difficult raw water source to be treated to the level of human consumption using only conventional treatment, making use of River Yamuna for water supply at Mathura questionable (Kumar *et al*., 2012).

For the water quality at Site 1 (pre-chlorination), colour removal by pre-chlorination and coagulation of the Treated Water 1, was found to be 46 to 78%. The UV-absorbance, however, did not follow the trend shown by the colour removal. The UV-absorbance ranged from 14 to 32 m^{-1} at 254 nm. It was nearly of the same order of magnitude as that of the river water. DOC removal during pre-chlorination was also very low (7 to 30%). These observations indicate the change in the nature of organic substances to the chloro-organics and not the reduction of organic compounds during pre-chlorination (Kumar *et al*., 2012).

According to Kumar *et al*. (2012), for the water quality at Site 2 (RBF without pre-chlorination), bed filtration effectively reduced colour, UV-absorbance and DOC by 55 to 82%, 36 to 54%, and 59 to 78% respectively. Accordingly, radial well water was found to have an average UV-absorbance of 9.6 m^{-1} at 254 nm, DOC of 4 mg/L and colour of 23 CU. Total coliforms in the river water (23 x 10^2 to 15 x 10^5 MPN/100 mL) were reduced to between 43 and 75 x 10^3 MPN/100 mL, a reduction of around two logs. The high removal rates are indicative of a longer travel time of the bank-filtrate than calculated based on the simple grain-size analysis. This could be a result of the river bed clogging in the vicinity of the well as the quantity of the water withdrawn has reduced over the years. Bed filtered river water is post-chlorinated to maintain a residual chlorine concentration of 0.2 mg/L.

Colour removal by pre-chlorination and coagulation ranged from 46 to 78%, whereas colour removal by RBF ranged from 55 to 82% at Site 1 and 2. The decrease in UV-absorbance due to RBF ranged from 36 to 54% while in the case of pre-chlorination, UV-absorbance did not significantly decrease (Kumar *et al*., 2012). They state that UV-absorbance of a water sample at 254 nm is a measure of the prevalence of organic compounds. During RBF organics are sorbed and/or degraded, whereas during pre-chlorination and coagulation, the form or nature of the organics is changed. Natural organic matter (NOM) and other complex organic compounds are probably broken down into small organic molecules, which do not respond to colour testing but absorb in the UV-range. This is supported by the observations made of the DOC concentration of the samples.

Table 4: Water quality parameters at Site 1 and 2 [Kumar *et al.*, 2012]

Water quality parameters	River water (n[a]=17)	Site 1: Treated water 1[b] (n=7)	Site 2: Riverbed filtrate (n=13)	Site 2: Treated water 2 (n=31)	Desirable limits for drinking water (BIS 10500: 1991)
Temperature (ºC)	19.8 - 21.6	20.0 - 24.0	21.4 - 24.7	21.6 - 24.4	--
Conductivity (µS/cm at 25ºC)	1170 - 1527	1362 - 1575	1292 - 1483	1391 - 1515	--
Total dissolved solids (mg/L)	690 - 902	663 - 721	622 - 934	683 - 954	500 (2000)[c]
Turbidity (NTU)	3.83 - 13.60	2.32 - 3.21	0.67 - 4.29	0.15 - 3.48	5 (10)
pH	7.43 - 8.20	6.70 - 7.46	7.18 - 8.23	7.69 - 8.20	6.5 - 8.5
Colour (CU)	40 - 166	9 - 89 [46.4 - 77.5%][d]	18 - 29 [55 - 82.5 %]	15 - 20 [62.5 - 88 %]	5 (25)
UV absorbance (m^{-1} at 254 nm)	11.0 - 28.0	14.0 - 31.5 [0 - 11.1%]	7.00 - 13.0 [36 - 54%]	7.0 - 11.0 [36 - 61%]	--
DOC (mg/L)	4.04 - 29.1	3.75 - 20.3 [7 - 30.2%]	1.65 - 6.30 [59.2 - 78.4%]	2.32 - 5.77 [43 - 80.2%]	--
DO (mg/L)	5.14 - 7.17	--	0.22 - 0.97	5.36 - 6.68	--
Ammonia (mg/L)[e]	10.2	-	15.4	-	--
Bromide (µg/L)[e]	263	189	371	372	--
TC (MPN/100 mL)	23×10^{2} - 15×10^{5}	< 3	43 - 75×10^{3}	< 3	< 3
FC (MPN/100 mL)	150 - 23×10^{4}	--	43 - 93×10^{2}	--	< 3

[a] n indicates the number of samples analyzed. [b] Without RBF, with pre-chlorination.
[c] Values in parentheses ( ) in the last column indicate the permissible limits in the absence of alternate source (BIS 10500: 1991).
[d] Values in brackets [ ] in the 3rd, 4th and 5th columns indicate percent decrease.
[e] Limited data: analysis carried out only during seventh and sixth sampling respectively

The Specific UV Absorption Coefficient (SUVA) of river water of around 1.18 L/ (m) (mg) was found to increase by more than two times to around 2.52 L/ (m) (mg) in bank-filtrate. If data of only the seventh sampling investigation is considered, SUVA was estimated to increase from 0.68 L/ (m) (mg) (river water) to 2.33 L/ (m) (mg) (bank-filtrate). There is a major shift in the character of the organic matter reflecting preferential removal of organics of a particular character during RBF and unequal removal of materials of different characters. The removal mechanisms in the subsurface (e.g. biodegradation, sorption, filtration) appear to respond differently to various molecular-weight fractions of DOC during ground passage. The increase in SUVA value in the river bed indicates a stronger attenuation of non-UV-active compounds compared to UV-active compounds. Although RBF produced water of low DOC, neither the water treated with a heavy dose of chlorine nor collected through RBF met the guideline of 2 mg/L (Kumar *et al*., 2012).

According to Kumar *et al*. (2012), the distribution of THMs (chloroform, bromodichloromethane, dibromochloromethane, bromoform) in different water samples collected in December. 2007 (sixth sampling) is shown in Figure 1. River water, bank-filtrate, and treated water after RBF were found to have very low values of total THMs. Bank-filtrate (without any pre-chlorination) and RBF-treated waters (with post-chlorination, using a dose of 1 mg/L chlorine) had total THMs < 1 µg/L. Giger *et al*. (2003) studied occurrence and the fate of THMs in the finished waters of eight Hanoi water treatment plants. Under typical treatment conditions (Cl_2 dose ≤ 1.5 mg/L, Cl_2 residual = 0.5-0.8 mg/L) total THM formation was always found below EU and USEPA guideline values of 100 and 80 µg/L, respectively. Kumar *et al*. (2012) state that at Mathura, the summation of THM species in Treated Water 1 (i.e. pre-chlorinated, chlorine dose of 40 mg/L and retention time of 2.5 hours) amounted to 30.5 µg/L, which is less than the guidelines suggested by EU, USEPA etc. Considering the high dose of Cl_2 applied at the treatment plant on the date of sampling, this THM concentration appeared to be quite low.

To investigate this aspect further, chlorination of the river water was carried out by Kumar *et al*. (2012) using the Cl_2 dose of 40 mg/L for retention time of 0.5 hour and the radial well water samples using the separate Cl_2 doses of 1 and 10 mg/L for 0.5 hour. Results are compiled in Table 5. Concentrations of THM species were found to be either low or less than detectable. According to Kumar *et al*. (2012), total THMs and the distribution determined for the samples collected from Mathura (Figure 1) and samples generated in the laboratory by adding Cl_2 (Table 5) matched quite well. It confirmed that, in case of Mathura water, THMs were not being produced in spite of substantial dose of Cl_2. Free Cl_2 concentrations were found to be very low while concentrations of bound Cl_2 were high (Table 5). It was presumed that Cl_2 could bind to ammonia nitrogen and/or to organic compounds resulting in production of chloramines, chloroorganics and N-nitrosamine compounds.

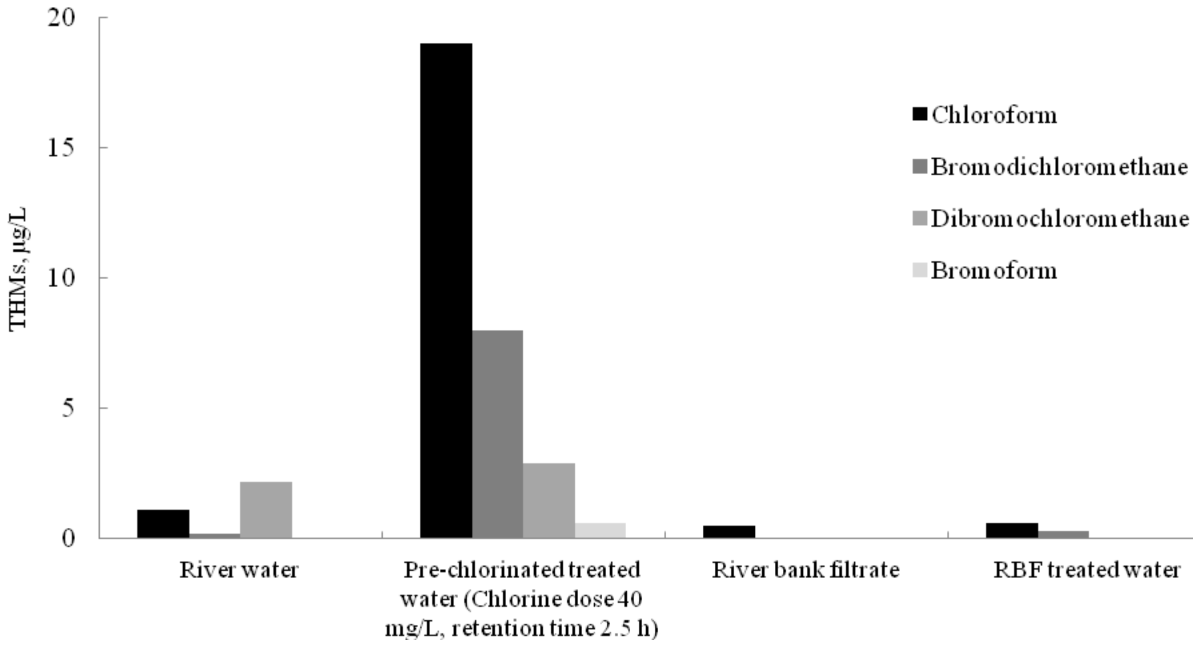

Figure 1: THM distribution in different waters at Mathura, India (Kumar *et al.*, 2012)

Table 5: Investigation of chlorine demand of Yamuna water and bank filtrate [Kumar *et al.*, 2012]

Sample	Cl_2 dose (mg/L)	Retention time (hour)	Bounded Cl_2 (mg/L)	Chloro-form (µg/L)	Brom-dichloro-Methane (µg/L)	Dibrom-chlor-methane (µg/L)	Bromo-form (µg/L)	Free Cl_2 (mg/L)
River Yamuna	40	0.5	34.2	3.1	0.3	ND	ND	<0.05
Bank filtrate	1	0.5	0.76	0.3	ND	ND	ND	<0.05
	10	0.5	6.8	2.4	0.6	ND	ND	0.1

Accordingly, water samples collected during the seventh sampling campaign were also analyzed for ammonia, inorganic ions, AOX, THMs, and selected trace organics in addition to parameters analyzed earlier. DOC and colour of river water were found to be higher than in earlier campaigns. Their reductions during RBF were also higher. DOC was reduced substantially from 29.1 mg/L to 4.0 mg/L (~86% reduction) while colour was reduced from 166 CU to 29 CU, a reduction of ~82%. AOX concentrations in different waters at Mathura are given in Figure 2. While AOX concentration was low in the river water (23.5 µg/L) and bank-filtrate (17.5 µg/L), it was found to be as high as 268 µg/L in the pre-chlorinated treated water (Kumar *et al.*, 2012).

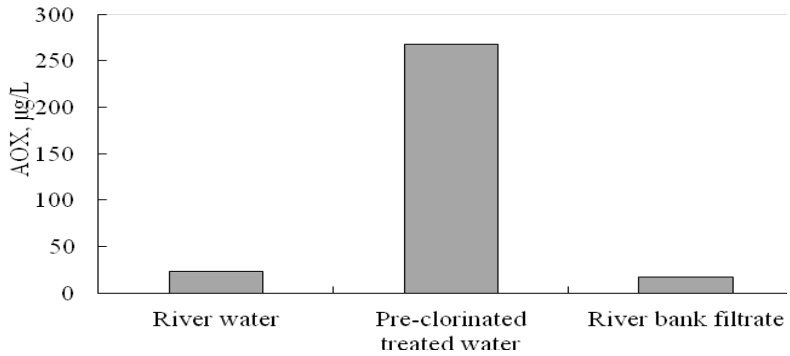

Figure 2: AOX concentrations in different waters at Mathura, India (Kumar *et al*., 2012)

According to Kumar *et al*. (2012) water samples were screened for OMPs. 4-fluorohistamine and 9-octadecenamide were detected in the river water while 2-aminodiphenyl ether was detected in the bank-filtrate. Treated Water 1 (pre-chlorinated river water without RBF), however, showed the presence of 6-chlorohexanol, heptanol, benzaldehyde, benzophenone, and the two halonitromethanes (HNMs) i.e. trichloro- and dibromo-nitromethanes in addition to four THMs. Out of these different trace organics, only a peak for dibromonitromethane was significant. HNMs are structurally similar to the THMs but have a nitro-group (NO_2) in place of hydrogen bonded to the central carbon atom. There is a need to determine the concentrations of HNMs at Mathura to realize the likely effects of the finished water on human health.

Both river water and bank-filtrate contained ammonia concentrations in excess of 10 mg/L. Hypochlorous acid is known to react with ammonia to form chloramines like mono-, di-, and tri-chloramines, supposed to be about 100 times less efficient than chlorine as disinfectants. Chloramines are known to produce considerably lower levels of THMs (<3%) and total organic halogens (TOX, 9-48%) than chlorine alone (Zwiener, 2006). Ammonia concentrations together with chlorination result in the formation of N-nitrosodimethylamine (NDMA), a potential human carcinogen (Giger *et al*., 2003; Zwiener, 2006; Charrois *et al*., 2007). NDMA is a non-halogenated DBP, and has a drinking water unit risk two to three orders of magnitude greater than currently regulated halogenated DBPs. Other N-nitrosamine compounds N-Nitrosopyrrolidine and N-nitrosomorpholine have also been identified in drinking water. Growing evidence suggests NDMA occurs more frequently and at higher concentrations in drinking water systems than chloramines compared to chlorination-only systems. N-Nitrosamine monitoring efforts in drinking water continue to increase (Kumar *et al*., 2012). With the inclusion of NDMA and five other N-nitrosamines in the Unregulated Contaminant Monitoring Regulation 2 (UCMR 2) (USEPA, 2005), it is reasonable to anticipate that additional utilities will be identified as having elevated N-nitrosamine concentrations, when more systems start analyzing for them. However, no investigations on NDMA in waters in India are known so far. Moreover, waters having >10 mg/L ammonia and being pre-chlorinated with high doses of chlorine (15 to 65 mg/L) on a regular basis need to be tested for NDMA and other N-nitrosamines as a priority (Kumar *et al*., 2012).

2.1.5 Conclusions

As compared to the direct pumping of river water, RBF was confirmed to be an effective method of surface water abstraction to improve raw water quality. RBF at Mathura resulted in significant reduction of turbidity, organic contaminants, colour, UV-absorbing compounds, coliform bacteria etc. (Kumar *et al*., 2012). Since the need for pre-oxidation or chlorination is reduced or eliminated with RBF, AOX, ammonia-chlorine complexes, and DBPs do not build-up. However, in the case of polluted river waters, the need for an additional post-treatment step such as adsorption cannot be completely ruled out or eliminated and nevertheless the overall advantages of the natural bank filtration are significant. Despite considerable pre-chlorination, the concentration of THMs in the treated water in Mathura was relatively low. According to Kumar *et al*. (2012), for the presented case at Mathura, there is however a need to quantitatively assess the role DBPs like HNMs and N-nitrosamines play in RBF.

2.2 Removal efficiencies of pre- and post-treatment applied at different MAR sites in India

Based on the literature survey and case studies reported in the D4.1 Saph Pani (2013), the major water quality problems encountered in relation to MAR in India are TSS, fluoride, arsenic and pathogens. It has been reported that sedimentation and sand/metallic filters are widely used for pre-treatment in the MAR schemes to remove TSS. Chlorination is also identified as the widely used disinfection method against pathogens (post-treatment).Though fluoride and arsenic have been identified as water quality problems, there is no documentation available in connection with MAR. Therefore also laboratory and pilot scale studies were analyzed from the existing literature to obtain the treatment efficiencies. This section presents critical review of different methods and their efficiencies to suggest the suitable one according to field conditions.

2.2.1 TSS removal efficiencies of MAR pre-treatment methods

Clogging by suspended solids is reported from many MAR sites in India (Saph Pani D4.1, 2013). Though different pre-treatment methods such as sedimentation, sand filtration, metallic filters are used, documentations about the efficiencies of these methods are lacking. Due to this unavailability of the pr-treatment specifically with respect to MAR, few waste water treatment plants were considered from India to evaluate the TSS removal efficiencies. In a MAR case study from Orissa (India), Hollander *et al*. (2009) reported that sedimentation has removed 50-70% of the TSS in the source water as pre-treatment. Removal efficiency of up to 70-90% has been achieved by the combined use of sedimentation with desilting filters. The reed bed used at a stormwater recharge site at Salisbury (AUS) was proved very efficient (up to 90% removal), by reducing the TSS level from 14.8 to 4 mg/L (Page *et al*., 2009). This plant has a treatment capacity of 2.25 m^3/h. A wastewater treatment plant found from Chennai (Sundara Kumar *et al*., 2012) has the TSS removal facility comprises of sedimentation, aeration and filtration. The median TSS removal efficiency was 93% for the treatment plant of 958 m^3/hr capacity. Two other treatment plants (Nagasandra and Mailasandra) from Karnataka, with aerator and clarifier to remove TSS, showed a median removal efficiency of 98% (Ravi Kumar *et al*., 2009). Removal efficiencies and the changes in concentrations of TSS observed in the case studies are presented in Figure 3.

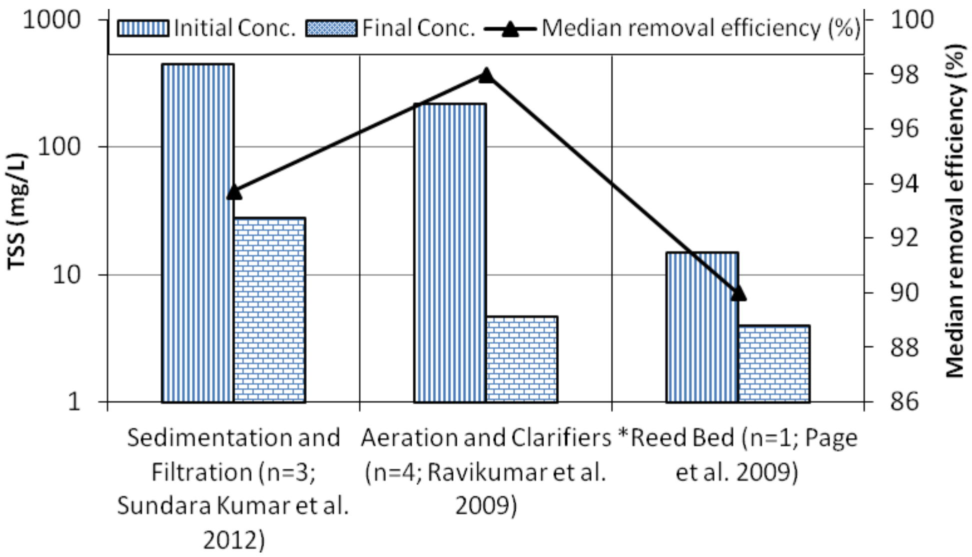

Figure 3: Median removal efficiency of TSS pre-treatment using different methods. Starred reference indicating the actual observed value; not median

2.2.2 Fluoride removal methods and their efficiencies

In the Saph Pani case study at Maheshwaram, elevated concentrations of F were observed in the groundwater. Since the awareness and the analytical possibilities of MAR have only inceased recently in India, cases of fluoride contamination in connection with MAR is poorly documented. As this is a widespread groundwater problem in most of the South Indian states several treatment methods for F-rich groundwaters are already existing. Meenakshi and Maheshwari (2007) and Pranati and Devaraj (2011) have reported the major technologies used for fluoride removal from drinking water. Though different materials are used in the treatment process, generally these methods can be classified into adsorption, coagulation and precipitation, ion exchange and membrane based processes. The cases documented here are small scale water treatment units working on site. The median values of minimum and maximum concentrations and the removal efficiencies (except ion exchange) of four major techniques are presented in Figure 4. Adsorption method using activated alumina and saw dust has shown a median removal efficiency of 73%. Coagulation and precipitation method, widely known as Nalagonda technique in India, has shown a median efficiency of 71%. Both adsorption and Nalgonda techniques have approximately similar efficiencies. A higher removal efficiency up to 95% was observed for the Ion exchange processes performed using resins like carbion, Defluoron-1/ or Defluoron-2. Membrane techniques such as reverse osmosis have also shown efficiency up to 92%. Though the efficiency is slightly less, the adsorption and Nalgonda techniques are widely used because of the local availability of materials and less operational cost.

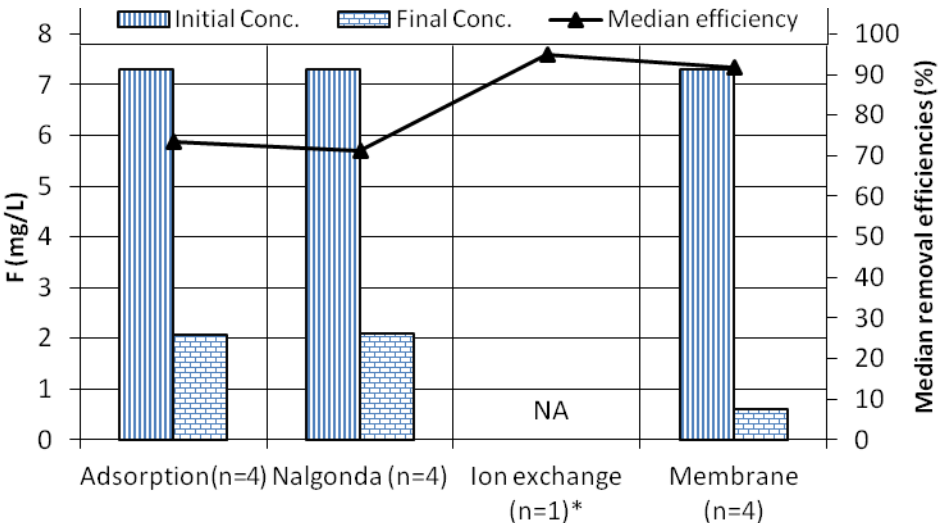

Figure 4: Median removal efficiencies for Fluoride using different methods. Most of the data collected from Meenakshi and Maheshwari (2002). The starred value is sourced from Pranati and Devaraj (2011).

2.2.3 Arsenic removal methods and their efficiencies

Groundwater contamination with Arsenic (As) is a prevalent problem in many parts of India especially in NE states like Bengal, Jharkhand, Bihar, Uttar Pradesh in flood plain of the Ganga River, Assam and Manipur (Ghosh and Singh, 2009). MAR in the arsenic affected regions may result in high concentration of As in the recovered water. In this case the concentration must be reduced to an acceptable drinking water concentration prior to the supply to public water distribution systems. Due to the hazardous nature and wide occurrence of As contamination in the West Bengal region, the Universities and research institutes have developed numerous small-scale As removal techniques. The commonly used techniques and their median efficiencies are shown in Figure 5.

Among the most widely used methods, the most efficient methods listed in the literature are coagulation and filtration, membrane based processes (RO and NF), adsorption, ion exchange and oxidation. The principles remain same and the chemicals/or materials used in the different case studies may vary considerably. So the median values of available data were taken into account to assess the efficiency. Two cases of coagulation based treatment reported by USEPA (2000) showed a median efficiency of 66%. Adsorption using different materials from India has shown median removal efficiency of 96% (Chakravarty *et al.*, 2002; CPCB, 2000; Saha *et al.*, 2001). Treatment efficiencies of nanofiltration and reverse Osmosis were 93% (Akin *et al.*, 2011; Saitua *et al.*, 2011). The highest efficiency is observed for ion exchange processes, the median value for 3 entries were 99.43%. Oxidation using different methods such as cupric oxide, lime, tomato and lemon showed a median removal efficiency of 91% (Majumdar *et al.*, 2012; Reddy and

Roth, 2013). Considering the cost of operation and the availability of materials coagulation with sedimentation and filtration as well as adsorption using activated alumina are the most suitable methods for large scale water treatment plants. Moreover the coagulation based technique has proven its applicability in large water treatment system; a treatment capacity up to 94,635 m^3/h is reported from US (USEPA, 2000).

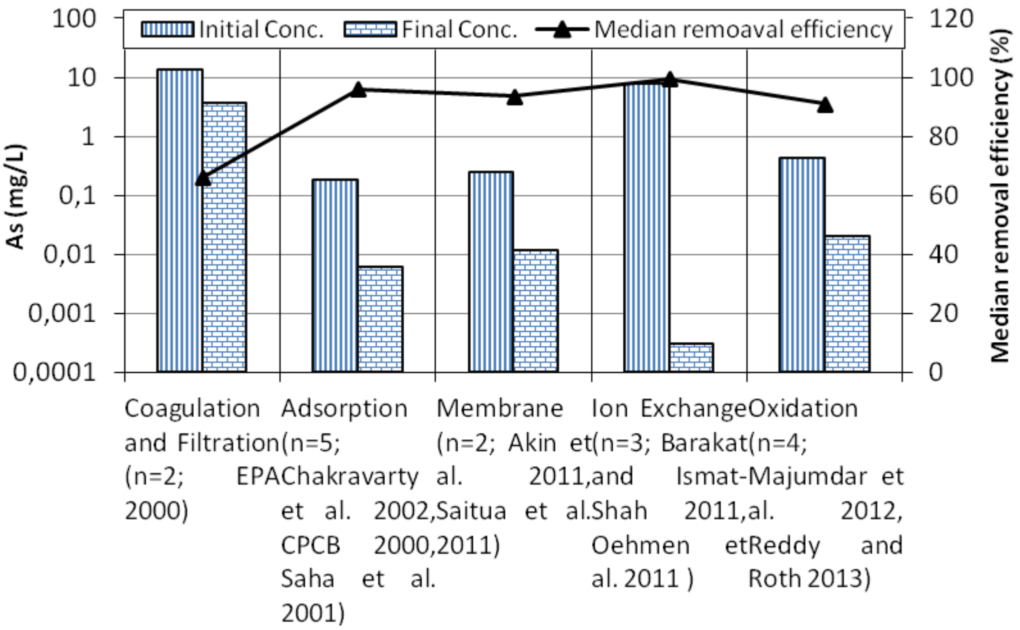

Figure 5: Median removal efficiencies for arsenic using different methods

2.2.1 Disinfection methods and their removal efficiencies

Free chlorine is the most widely used disinfectant in the world (Crittenden *et al*., 2005). CPCB (2008) reported that chlorination is the most widespread pathogen removal method used in all the major drinking water treatment plants in India. An overview of the commonly used disinfection methods are given in Table 6. In the context of MAR, chlorination found to be implemented in the available MAR case studies (Saph Pani D4.1, 2013).

A very high log removal efficiency of 2.3 were observed for chlorination using free chlorine from a waste water treatment plant with 1891 m/hr from Madhya Pradesh (MP) in India (Mamta *et al*., 2012). Application of Ozone and Ultraviolet (UV) radiations are the other two important disinfection methods that are widely used for drinking water treatment. A Study by Jyoti and Pandit (2004) showed that ozonation gave median log removal of 1.52 for pathogens, in which the initial concentration 2.3 (log) was reduced to 0.23 (log). Sharrer and Summerfelt (2007) reported a log removal of 1.15- 1.62 for ozonation. The same study has showed an improved efficiency of 2.72 log removal by the combined use of ozonation and UV.

Table 6: Most common disinfectants used in drinking water treatments and their efficiencies [Crittenden *et al*., 2005; WHO, 2004]

Disinfectant used	**Removal Efficiency for different microorganisms (%)**			
	Bacteria	**Viruses**	**Protozoa**	**Endospores**
Free chlorine	Excellent (90-100)	Excellent (90-100)	Poor to Fair (20-60)	Poor to Good (20-90)
Combined chlorine	Good (60-90)	Good (60-90)	Poor (0-20)	Poor (0-20)
Chlorine dioxide	Excellent (90-100)	Excellent (90-100)	Good (60-90)	Fair (20-60)
Ozone	Excellent (90-100)	Excellent (90-100)	Good (60-90)	Excellent (90-100)
Ultraviolet light	Good (60-90)	Good (60-90)	Excellent (90-100)	

Bergmann *et al*. (2002) reported that the concentration (log 10) was reduced from 7.6 to 4.3 with a removal rate of 2 log. The median log removal rate for pathogens are presented in Figure 6. Comparison of both methods shows that UV treatment is slightly more efficient than ozonation. However, a combined method will probably have much more efficiency.

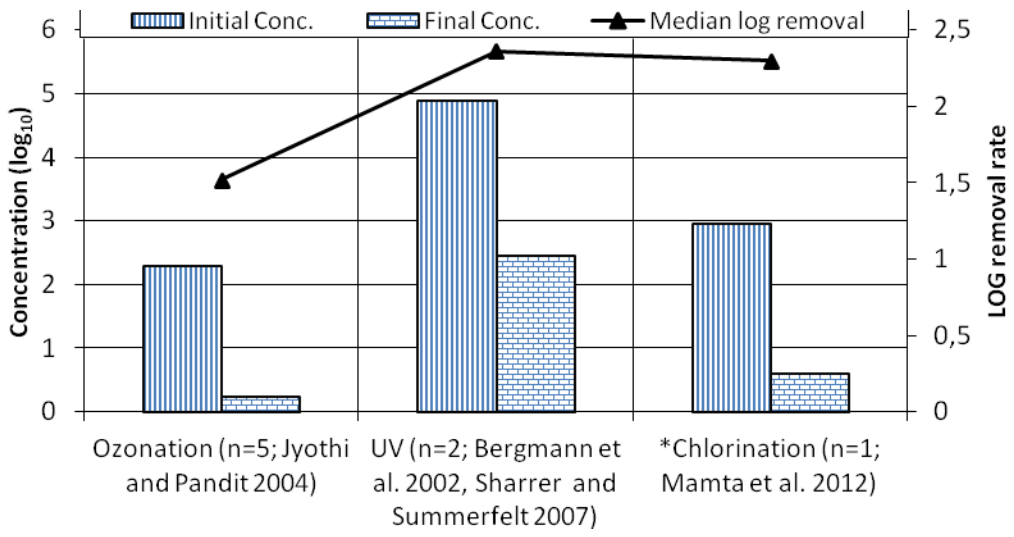

Figure 6: Comparison of disinfection efficiencies using Ozone, UV and chlorine. Starred value represents the actual value; not median.

Two alternative methods that receives with increasing attention - chlorine dioxide (ClO_2) and peracetic acid ($C_2H_4O_3$) are critically evaluated based on their efficiencies in the following section. Stampi *et al*. (2002) reported the different removal efficiencies of these two materials on different pathogens in field scale in Italy. The details of initial and final concentration with log removal efficiencies are presented in Figure 7. This study shows that disinfection with ClO_2 has much higher efficiencies over the same with $C_2H_4O_3$.

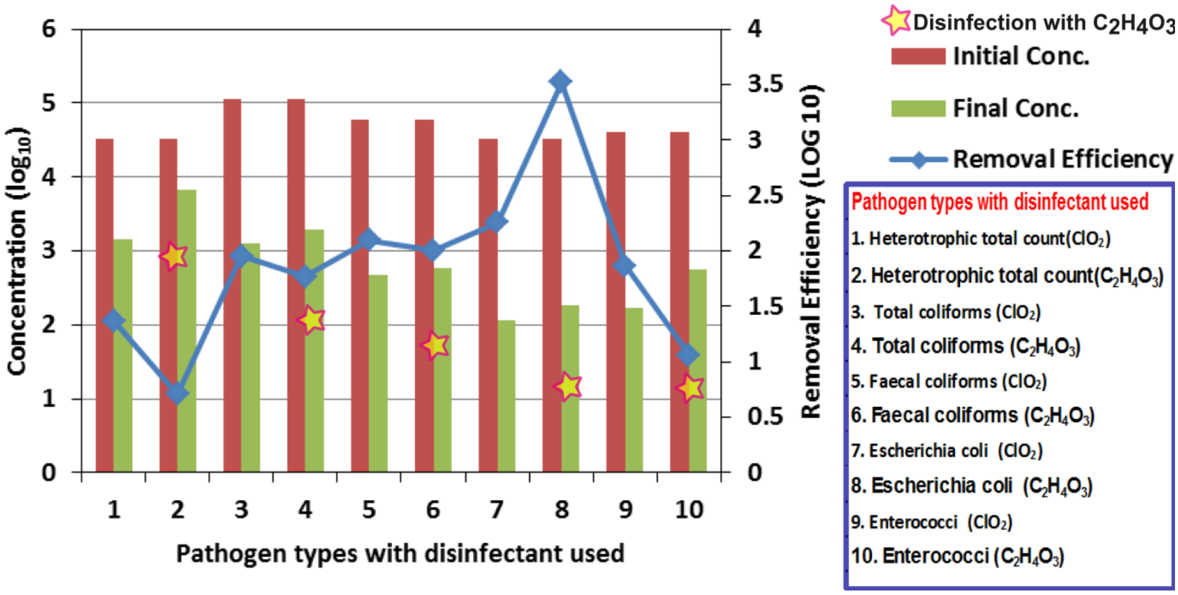

Figure 7: Removal efficiencies of disinfection using ClO_2 and $C_2H_4O_3$ (Stampi *et al*., 2002)

2.3 Removal efficiencies of pre- and post-treatment methods applied to constructed wetlands and other natural treatment systems in India

Different types of NTSs are available for treatment of wastewater and the most common NTSs in India include: Constructed Wetlands (CWs), Hyacinth and Duckweed Ponds, Karnal Technology (KT) for on-land disposal of wastewater, Fish Ponds, Waste Stabilization Ponds (WSPs), Oxidation Ponds and Lagoons and, Algal-bacterial Ponds. Polishing Pond (PP) is the most commonly employed NTSs since many decades in India - which contributes nearly 53% of total wastewater treated by NTSs (total load serviced by NTSs is around 1838 MLD).

Research at IIT Bombay has shown that that among different NTSs, the CW systems can be effectively combined with advanced tertiary treatment alternatives and the resulting high quality treated effluents can be recycled into production and sanitation applications. In addition, CWs are most prone to engineering adaptation and modular applications and thus have been proved to be helpful in addressing sewage treatment challenges in a variety of remotely located small villages and towns in developing world. For example, KT for on-land disposal of wastewater is essentially a variant of engineered CW and can be practiced at about any scale typically encountered in a small community.

Similarly, Duckweed Ponds (DPs) also seem to cater to lower amounts of wastewater. Large numbers of NTSs are used as decentralised systems for treatment of sewages generated in remotely located small villages and towns (KTs, CWs and DPs). Therefore, the NTSs including KTs, CWs and DPs may play a significant role in development of appropriate wastewater management infrastructure small communities in India shortage of electrical power, trained work-force and varying site conditions is a common challenge. The decentralized wastewater treatment and management systems are appropriate and cost-effective solution for such small communities where restricted local budgets, lack of local expertise, and lack of funding (USEPA, 2005).

One of the impressive features of the PP is its versatility. Several PPs have been employed for municipal as well as industrial wastewater treatment all over India. Most of these applications are essentially a post-treatment to the effluents from UASB (Up-flow Anaerobic Sludge Blanket) reactors which are good at treating wastewaters having variable influent quality as well as flow rates but are not efficient in removal of pathogens. For improving the quality of the effluents from UASB reactors before the final disposal, it has been established that PPs can bring down the pathogen count drastically (depending on retention times provided in the ponds). In case the microbial quality is still not up to the mark after PP, in some systems chlorination has been augmented to the treatment train (e.g. STPs at Nashik Municipal Corporation, City of Nashik, State of Maharashtra or Agra Municipal Corporation, City of Agra, State of Uttar Pradesh in India).

WSPs are also equally utilized for wastewater treatment in India and they account for nearly 45% of total wastewater volume treated by means of NTSs in India. Few WSPs have been providing satisfactory service to several large communities. One limitation is that the quality of treated effluent is at best of the legal standards suitable for disposal to surface waters designated by the regulatory agencies – but not nearly of "reuse" quality. In other words, many NTS options are suitable to address situations at a variety of locations and community sizes; but among all, CWs are probably the best suited to generate reusable water and blend most easily with the expectations and aspirations of small and rural communities, like in India.

2.3.1 Pre-treatment of wastewater effluents before NTSs in India

The various primary treatment units (pre-treatment systems) have been installed at NTS based sewage treatment plants in India for improving their overall removal efficiencies. These include (i) Grit Chamber, (ii) Sedimentation Tanks or Settling Basins Septic Tanks, (iii) Baffled Septic Tank, (iv) Baffled Septic Tank with Anaerobic Filter, (v) Two-step Upflow Anaerobic Reactor, (vi) Hydrolytic Upflow Digester, (vii) Pre-composting Tanks, (viii) Imhoff Tank and (ix) Primary Decanters. A summary of various types of primary treatment units installed for different types of NTSs in India, their objectives and typical removal performances are summarized in Table 7.

Table 7: Primary treatment units installed at different kinds of NTSs and their removal efficiencies

Type of NTSs	Typical primary treatment steps before NTSs	Objective of primary treatment systems	Typical removal efficiencies of primary treatment systems
Constructed Wetlands	Screen, Septic Tank Baffled Septic Tank	Removal of floating matter, grit and TSS	TSS = 40-50% BOD = 40% Pathogens = N.A.
Waste Stabilization Pond	Screen followed by grit chamber	Removal of floating matter and grit	TSS = Negligible BOD = Negligible Pathogens = Negligible
Duckweed Pond	Screen followed by settling basin	Removal of floating matter and grit	TSS = Negligible BOD = Negligible Pathogens = Negligible
Polishing Pond	UASB	Removal of BOD, COD, TSS	TSS = 60-70% BOD = 60% Pathogens = N.A.
Karnal Technology	No primary treatment	-	-

2.3.2 Post-treatment and reuse of the wastewater effluents from NTSs in India

A national survey of CWs and other NTS by IITB has identified 108 sites with wastewater treatment facilities using NTSs across India. Out of these 108 sites, very few of them have the post-treatment facility. It was observed that there is no post-treatment (except disinfection) of the secondary treated effluent of CWs and other NTSs. During disinfection, 1-2 mg/L of chlorine is dosed at the outlet of secondary treated effluent. Out of 108 operated sites of CWs and other NTSs, only two have the facility for chlorine disinfection. Hence post-treatment to effluent from CWs and other NTSs is almost absent in India.

All wastewater treatment systems including CWs and other NTSs have been designed and operated in order meets the regulatory standards prescribed by CPCB, New Delhi for reuse and discharge into the water body (CPCB, 2009). Most of the treated domestic wastewaters from NTSs in India are being reused in irrigation of agricultural fields and gardens. Another substantial use is observed as disposal into sewage fed aqua-culture ponds. In most of the cases, the treated effluent from CWs and other NTSs directly reused in agriculture or disposed into nearby river.

The reuse of secondary treated effluent from any kind of treatment technology without any post-treatment may pose the health hazards. On the other hand pathogen removal from wastewater through chlorination always leads to formation of potentially carcinogenic DBPs. If properly designed and operated, NTSs could be very effective for pathogens removal by natural die-off and reduce the need or dose for chlorination and hence reduce DBPs formation.

The wastewater containing significant organic wastes introduce nutrients into the water bodies. The resulting heavy algal growth cause difficulties in water treatment in downstream supplies and promote eutrophication in affected water bodies (Arceivala and Asolekar, 2012; Asolekar *et al*., 2013). The accumulation of detergents, pesticides, heavy metals and other non-biodegradable substances in the downstream waters can also adversely affect the beneficial use of water resources (Arceivala and Asolekar, 2006). Therefore, post-treatment is indispensable for secondary effluents, which contain significant amount of pollutants before their disposal into water body or any reuse.

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

The principal climatic factors that cause seasonal variation in quality of treated wastewater effluent from NTSs are temperature, solar radiation, wind speed, evaporation, and rainfall. Temperature affects photosynthetic oxygen production, rate of organic degradation, and chemical and biochemical reactions occurring in NTSs. NTSs operated in India have the great variability in terms of removal of various physico-chemical and microbial pollutants present in untreated wastewater. The major reasons for the variation in performance of NTSs are due to differences in climatic conditions and quality of wastewater effluents from one place to another.

Picture 1: CW, Pipar Majra, Ropar, Punjab, India

Picture 2: WSP, Masani, Mathura, Utter Pradesh, India

Picture 3: Sewage-fed aquaculture, Kathal Road Karnal, Haryana, India

Picture 4: UASB-PP, Sector 4, Karnal, Haryana, India

Picture 5: Chlorination unit installed for disinfection at UASB-PP, Agra, Utter Pradesh, India

Picture 6: DP, village Saidpur, Ludhiana, Punjab, India

Plate1: Various types of NTSs operated in India for wastewater treatment and reuse

The performance other NTSs across India has been studied by IITB in 2012 (case studies depicted in **Plate 1**) and it was observed that most of the NTSs which are properly operated and maintained are performing well in terms of achieving standards prescribed by CPCB, New Delhi (India). Some of the case studies of different types of NTSs used for wastewater treatment in India including CWs, WSPs, sewage feed aquaculture, DPs, and PPs are presented hereafter.

Case study 1: Sewage treatment plant at Pipar Majra, Ropar, Punjab

The CWs of 0.5 MLD capacity has been constructed in 2006 for treating the domestic wastewater of village community. The system is performing satisfactorily in achieving design norms of treated effluent. In treatment train, septic tank was installed as the primary treatment of the raw wastewater. The effluent from the septic tank is further treated through CW. The CW bed was constructed by using river sand with the emergent plant species of *Typha latifolia* (Common Cattail). The treated effluent from CW bed is being discharged into the adjacent fish pond. Presently, STP is under stress as the clear sign of clogging in the bed reflected from first sight. The problem of bed clogging arises because of improper functioning of the primary treatment unit. The improper functioning of septic tank arises due to negligence of operating agencies, as de-slugging of septic tank has not been done regularly. Due to the improper functioning of settling unit, the floating sludge from septic tank continues to enter into the CW bed which results in clogging. The system may deteriorate beyond the recovery if proper attention is not given, especially immediate cleaning of septic tank. The treated effluent quality of CW is given in Table 8.

Table 8: Treated effluent quality of constructed wetlands

Parameter	Unit	Raw Sewage	Treated Sewage	Design Value
BOD_5	mg/L	200-220	10-20	10-20
COD	mg/L	NA	NA	NA
pH	-	7.5	7.7	5.5-9
TP	mg/L	7-9	2-3	NA
TSS	mg/L	350-400	20-40	≥10
TDS	mg/L	NA	NA	NA
Total Coliform	Per 100 mL	10^7	5.5×10^4	NA
Fecal Coliform	Per 100 mL	NA	NA	NA

Case study 2: Sewage treatment plant, Masani, Mathura, Utter Pradesh

The WSP of capacity 15.59 MLD at Masani, Mathura, was established in 2001 under Yamuna Action Plan, for treating domestic wastewater of Mathura city. The Jal Nigam Mathura, Utter Pradesh, is the agency responsible for operation and maintenance of the STP since it was established. STP is not able to meet the prescribed standards because plant is overloaded in terms of flow. Some amount of treated wastewater is being reused in agricultural field for irrigation and remaining is discharged into the Yamuna River. There are no means available for post-treatment at the treatment plant site. The quality of untreated and treated wastewater is presented in Table 9.

Table 9: Treated effluent quality of waste stabilization pond

Parameter	Unit	Raw Sewage	Treated Sewage	Design Value
BOD_5	mg/L	220-240	40-60	≤ 30
COD	mg/L	490-520	100-120	250
pH	-	7.35	7.5	5.5-9
TP	mg/L	NA	NA	NA
TSS	mg/L	435	40-60	100
TDS	mg/L	NA	NA	2100
Total Coliform	Per 100 mL	7×10^7	10^6	NA
Fecal Coliform	Per 100 mL	NA	NA	NA

Case study 3: Sewage treatment plant, Kaithal Road Karnal

A sewage-fed aquaculture based on WSP of 8 MLD capacity is performing satisfactorily in achieving design norms of treated effluent. At this STP, facultative and maturation ponds are being utilized for pisciculture. The quality of untreated and treated wastewater is presented in Table 10.

Table 10: Treated effluent quality of sewage-fed aquaculture based waste stabilization pond

Parameter	Unit	Raw Sewage	Treated Sewage	Design value
BOD_5	mg/L	198	10	< 30
COD	mg/L	680	52	250
pH		7.4	8	5.5-9
TP	mg/L	7.3	6.24	NA
TSS	mg/L	524	48	100
TDS	mg/L	NA	NA	2100
DO	mg/L	0	2.6	NA
Total Coliform	Per 100 mL	18×10^6	10^5	NA
Fecal Coliform	Per 100 mL	9×10^5	10^4	NA

Sometimes, fish-die offs have been reported in the facultative pond due to high organic loading. When fish start to die, plant operators are using lime to precipitate suspended particulate matter in the facultative pond. The pisciculture activities in WSP treatment units are generating the revenue of about INR 1,000,000 per year. The treated effluent is directly used in irrigation without post-treatment, as there are no means available for microbial decontamination at the treatment site.

Case study 4: Sewage treatment plant, Sector 4, Karnal Haryana

The STP was commissioned in 2000 through the funding provided by Yamuna Action Plan (YAP). The treatment plant is operated and maintained by Municipal Corporation of Karnal, Haryana. The PP of 40 MLD capacity was installed after the UASB unit for upgrading the secondary effluent. STP is performing satisfactorily in achieving treated effluent quality as designed. The quality of untreated and treated wastewater is presented in Table 11. Presently, treated effluent is not being reused but directly discharged into the Yamuna River. Around the STP, there is ample scope of utilizing the treated effluent in agriculture fields. The sludge generated from UASB unit is being dried through sludge drying bed by taking appropriate health measures as it is later being used as fertilizer in agricultural fields.

Table 11: Treated effluent quality of UASB polishing pond

Parameter	Unit	Raw Sewage	Treated Sewage	Design value
BOD_5	mg/L	60	25-28	<30
COD	mg/L	200-230	130-160	250
pH		6.9	7.30	5.5-9
TP	mg/L	5-8	5-7	NA
TSS	mg/L	250	80	100
TDS	mg/L	NA	NA	2100
DO	mg/L	0	1.5	NA
Total Coliform	Per 100 mL	NA	NA	NA
Fecal Coliform	Per 100 mL	10^7	10^5-10^6	NA

Case study 5: Sewage treatment plant, village Saidpur, Ludhiana, Punjab

The DP of capacity 0.5 MLD was established in 1998 for treating the domestic wastewater of village community. In the treatment train, the wastewater is first treated by screen and grit chamber before entering into the DP. The treated wastewater from DP is fed to fishpond. The quality of untreated and treated wastewater is presented in Table 12. The DP system is performing well in terms of reuse standard for disposal on land and irrigation. Previously, pisciculture activities during sewage treatment were generating the revenue of about INR 50,000-70,000 per year – which was utilized for operation and maintenance of treatment plant by Village Council. Presently, the pisciculture activities in fishpond have been discontinued because of some Village Council disputes. The treated effluent is directly being reused for irrigation without any post-treatment.

Table 12: Treated effluent quality of duckweed pond

Parameter	Unit	Raw Sewage	Treated Sewage	Design value
BOD_5	mg/L	180-200	10-20	<30
COD	mg/L	300-350	100-150	250
pH	-	7.09	7.30	5.5-9
TP	mg/L	NA	NA	NA
TSS	mg/L	NA	NA	100
TDS	mg/L	NA	NA	2100
Total Coliform	Per 100 mL	10^7	10^5	NA
Fecal Coliform	Per 100 mL	NA	NA	NA

These detailed case studies and national survey of CW and other NTSs for wastewater treatment in India clearly showed that post-treatment is not applied in most of systems and effluent from NTSs are directly used for irrigation, fish pond or discharged to the nearby river.

3 Analysis of the removal efficiencies of different methods based on laboratory and field-pilot studies

This chapter presents the results of the different laboratory and field sampling studies (as parts of MSc research) carried out by project partners to analyze in detail the specific water quality problems at some selected case study sites and to assess the removal efficiencies of post-treatment methods for different NTSs. The following specific research studies are elaborated further in this chapter.

(i) Lake bank filtration at Nainital: Water quality assessment (IITR+HTWD)

(ii) Identification of surface and groundwater interaction by geobiochemical method in Arani River (ANNA)

(iii) Tertiary treatment of output from CWs aimed at reuse of treated wastewater (IITB)

(iv) Removal of ammonium and nitrate by riverbank filtration and subsequent post-treatment (UNESCO-IHE)

3.3 Bank filtration at Nainital: Water quality assessment (IITR+HTWD)

3.3.1 Description of Nainital bank filtration site

Nainital is a popular tourist hill station of North India located in the Kumaon region in the state of Uttarakhand (Figure 8). The Nainital Lake is a major source of drinking water for the inhabitants. The lake has a maximum depth of 27.3 m and a mean depth of 18.5 m. Population around the lake was estimated to be around 50,000 in 2008 with a daily influx of about 5,000 in the summer season (Dash et al 2008). Between 1990 and 2007, the concept of bank filtration was introduced in Nainital to obtain cleaner water for municipal supply (including for drinking) from bank filtration process than the direct lake water, which was being used at that time. During this period, five production wells were installed adjacent to the Lake with their depth ranging between 22.6 to 33.3 m (Dash et al. 2008). Two more tube wells of depth 36.7 and 35.9 m were commissioned in 2006. All the tube wells are located <100 m from water line of the lake. Due to the increased demand of water, additional 5 tube wells were drilled after 2009.

Of the 12 tube wells (labeled as NTW 1-3 old and NTW 1-9 new), NTW 1 - 9 new are currently being used for obtaining water for supply to the town. NTW 1 old and 3 old are not used regularly and mostly used as monitoring well. NTW 2 old has been decommissioned. NTW 5 and 8 had some operational problem for the past few months, but now are working. Water from tube wells is collected in two separate storage tanks at the pumping station and at “Jal Sansthan” collection tank. The only post treatment done is chlorination and then water is directly put in to supply. A desalination plant is also installed at the pumping station which is not operational for more than a year.

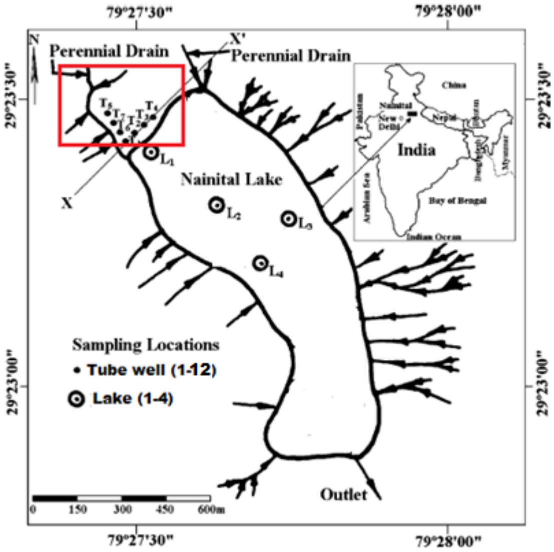

Figure 8: BF study site at Nainital (adopted from Dash et al, 2008)

3.3.2 Monitoring and methodology

Sampling procedure

The water samples from the lake and tube wells were collected on monthly basis in cleaned 1 Litre Polypropylene (PP) bottles for physico-chemical parameters, 250 mL sterile glass bottles for bacteriological analysis, and 15 mL plastic bottles for O-18 isotope analysis. The samples are immediately stored in the ice box at ~4°C till they are transported to the laboratory at IIT Roorkee.

Water quality analysis

Various water quality parameters were analyzed using standard methods given in Eaton *et al*. (2005). Temperature, dissolved oxygen, pH, and electrical conductivity are measured at the field site. Measurements of turbidity, UV absorbance at 254 nm, alkalinity, and screening of trace organics by GC-MS were done in the laboratory. The bacteriological parameters (total coliform and fecal coliform) were estimated using Lauryl tryptose broth by MPN technique. The major cations and anions were determined by ion chromatography.

3.3.3 Water quality results

Variations of various water quality parameters in Nainital lake water (NL) and various production well waters are given in Figures 4 to 8. As there is no major industrial activity in the catchment, the main water quality parameter of concern in the abstracted production well water is pathogens. Total coliform in lake water is relatively stable at around 2000 MPN/100 mL from June to beginning September 2012 (Figure 9). However, towards the end of September 2012 the total coliform count dropped and thereafter increased marginally to 50 MPN/100 mL in January 2013. Faecal coliform in this water ranges from 44 MPN/100 mL in September 2012 to <2 MPN/100 mL in January 2013. In some of the production wells, tests for total coliforms showed occasional presence of coliforms up to 17 MPN/100mL, but faecal coliforms were absent in all the production-wells and hence the water can be considered suitable for drinking purposes after disinfection.

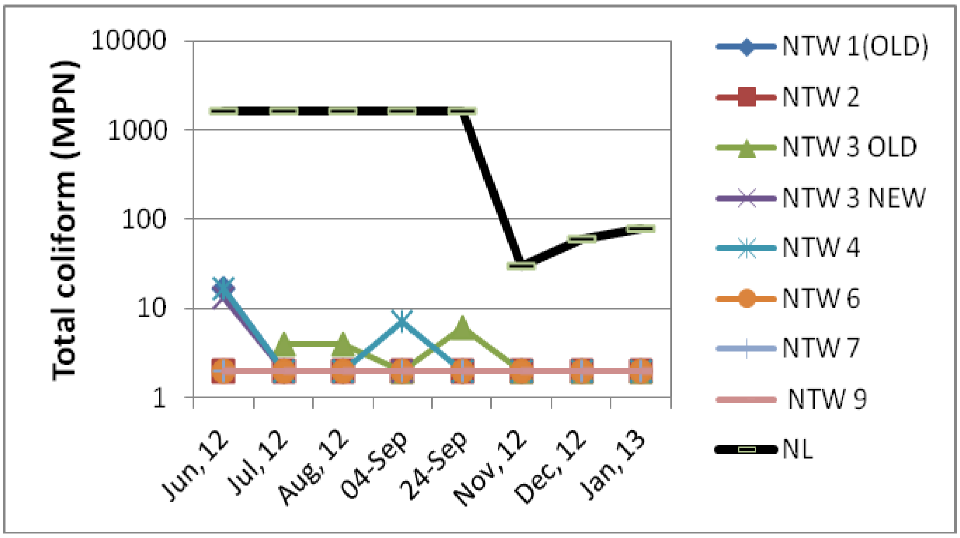

Figure 9: Total coliform count (in MPN / 100 ml) for lake and production well water

Turbidity of lake water is almost within 5 NTU guideline value and in all the production wells, it is less than 2 NTU, except in old well 3 which is not used for regular water pumping (Figure 10). Lack of regular pumping might be responsible for unusually high turbidity in the water of old well 3. These turbidity values are well within the range of Indian standards of drinking water IS: 10500.

In last 2 years, aerators have been installed in the lake at several places which keep the lake water dissolved oxygen (DO) concentration between 5-9 mg/L. Abstracted waters from many of the tube wells show a low level of DO (< 2 mg/L), except for some wells which occasionally show a DO up to 6.0 mg/L.

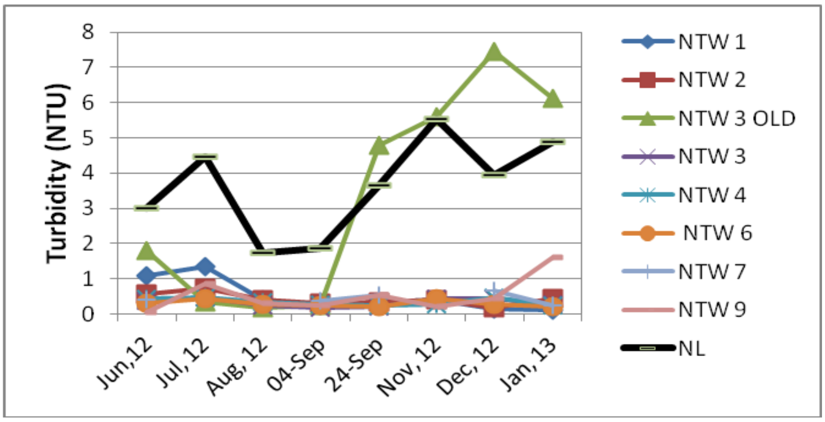

Figure 10: Turbidity of lake and production well water

Electrical conductivity of lake water is consistently around 600 µs/cm, and that of production well waters are consistently above the lake water value and ranges between

600 and 900 µs/cm (Figure 11). Concentration of major ions like Na^+, Ca^{++}, Mg^{++}, HCO_3^+, Cl^- and SO_4^{--} were also found to be more in the tube well than in the lake. Concentrations of Mg^{++} in some of the well waters were above the prescribed limits for drinking water given by Indian standards of drinking water.

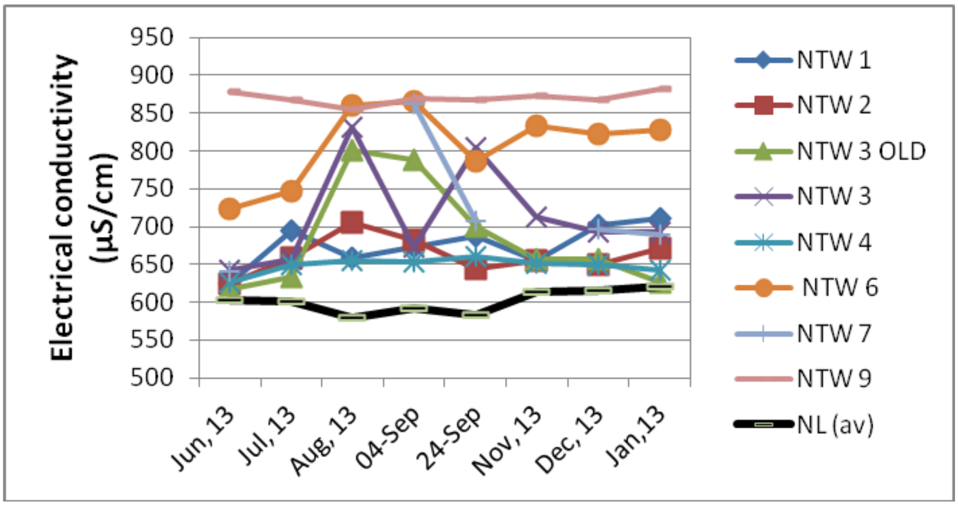

Figure 11: Electrical conductivity of lake and production well water

A lower UV absorbance of bank filtrate than the lake water showed that the amount of organics in the waters was very low (Figure 12).

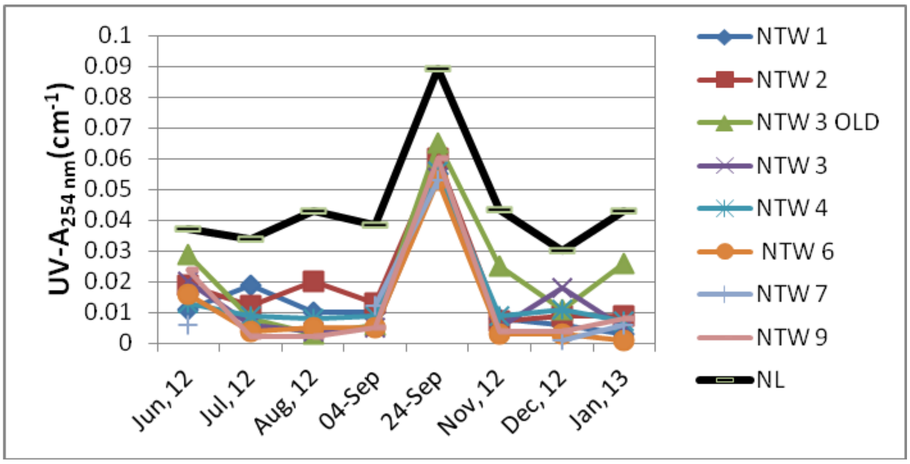

Figure 12: UV Absorbance of lake and production well water

The GC screening of the lake and production well waters indicated that several compounds which are found in the lake water are not found in production well water (Table 12). The subjective qualitative results (Table 13 and Figure 13) indicate that considerable removal of these compounds occur during subsurface passage.

Table 13: GC-MS screening result for Nainital Lake and production well samples for the month of April & May 2012

	Name of the compound	NL	NTW - 1	NTW-4	NTW-6	NTW-7
1.	Vitamin E	√		√		
2.	Octatriacontyl pentafluoropropionate	√	√		√	
3.	Benzothiophene-3-carboxylic acid, 4,5,6,7-tetrahydro-2-(1-chloro-2-oxopropylidenhydrazino)-, ethyl ester	√			√	√
4.	Cholestan-3-one, 4,4-dimethyl-, cyclic 1,2-ethanediyl acetal, (5α)-	√				
5.	Phenol, 2,5-bis(1,1-dimethylethyl)-	√				
6.	Oxopowelline, 2,4-dinitrophenylhydrazine	√				
7.	Benzoxazole, 2,2'-(2,5-thiophenediyl)bis[5-(1,1-dimethylethyl)-	√				√
8.	Oleic Acid	√			√	√
9.	Oxalic acid, cyclobutyl dodecyl ester	√		√		
10.	Propanoic acid, 2-(3-acetoxy-4,4,14-trimethylandrost-8-en-17-yl)-	√				
11.	Phthalic acid, isobutyl 2-pentyl ester	√				
12.	2,2-Dimethyl-3,3-bis(methylthio)-N-(1,1,3-trimethyl-2,3-dihydro-1H-inden-4-yl)cyclopropanecarboxamide	√				
13.	7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	√		√		√
14.	Benzenepropanoic acid (used in plastics manufacture; under check in Canada)	√				
15.	Phthalic acid, butyl 2-pentyl ester	√				
16.	2-Chloro-N-(2,6-dichlorophenyl)benzamide	√				
17.	4-[α-Carbethoxy-α-diethylaminoacetyl]-2-[2-thienyl]-6-chloroquinoline	√		√		
18.	9H-Carbazole, 9-ethyl :	√				
19.	16,19-Secostrychnidine-10,16-dione, 21,22-epoxy-21,22-dihydro-4,14-dihydroxy-3-methoxy-19-methyl-, (21α,22α)-	√				
20.	Benzothiophene-3-carboxylic acid, 4,5,6,7-tetrahydro-2-(1-chloro-2-oxopropylidenhydrazino)-, ethyl ester		√			
21.	Phenol, 2,4-bis(1,1-dimethylethyl	√	√	√		
22.	2-Ethoxycarbonyl-3-methyl-4-azafluorenone, 2-fluorenylimime		√			√
23.	Phthalic acid, 6-ethyl-3-octyl isobutyl ester		√	√	√	
24.	1,2-Benzenedicarboxylic acid, butyl 2-ethylhexyl ester		√	√	√	√
25.	Aconitane-1,7,8,14-tetrol, 20-ethyl-6,16-dimethoxy-4-(methoxymethyl)-, 14- acetate, (1α,6β,14α,16β)-		√	√		
26.	psi.,.psi.-Carotene, 1,1',2,2'-tetrahydro-1,1'-dimethoxy		√			
27.	3,4-Dihydroisoquinolin-7-ol, 1-[4-hydroxybenzyl]-6-methoxy-			√		
28.	3-Pyridinecarboxylic acid, 6-[(trimethylsilyl)oxy]-, trimethylsilyl ester			√		
29.	α-Lumicolchicine			√		
30.	Naphthalene, decahydro-2,2-dimethyl			√		
31.	Pentafluoropropionic acid, hexadecyl ester			√		
32.	Methotrimeprazine			√		
33.	γ-Lumicolchicine			√		
34.	Cytosine, N-(tert-butyldimethylsilyl)-, tert-butyldimethylsilyl ether			√		
35.	4-Aminothiocolchicine			√		
36.	Isonipecotic acid, N-allyloxycarbonyl-, undecyl ester			√		
37.	5α-Cholestan-19-oic acid, 2β-methoxy			√		

38.	Cephalotaxine, 11-(acetyloxy)-, acetate (ester), (11α			√		
39.	16,19-Secostrychnidine-10,16-dione, 21,22-epoxy-21,22-dihydro-4,14- dihydroxy-3-methoxy-19-methyl-, (21α,22α)-			√		
40.	β-Lumicolchicine			√		
41.	Tungsten, dicarbonylbis(η-4-2-methylenecycloheptanone			√		
42.	Propanoic acid, 2,2-dimethyl-, N'-(6-chloro-3-cyano-4-methyl-2-pyridinyl)- N'-methylhydrazide				√	
43.	Condyfolan, 14,19-didehydro-16-methylene-, (14E)-				√	
44.	Carnegine				√	
45.	i-Propyl 9-tetradecenoate				√	
46.	2-Imino-6-mercapto-4,4-dimethyl-1,2,3,4-tetrahydro-pyridine-3,5- Dicarbonitrile					√
47.	Cyclododecanemethanol					√
48.	Dasycarpidan-1-methanol, acetate (ester)					√
49.	Hydroxylamine, O-decyl-					√
50.	Isopropyl Myristate					√
51.	Dibutyl phthalate					√
52.	γ-Lumicolchicine					√
53.	Nickel, (1,3-dimethyl-η-3-allyl)-pentamethylcyclopentadienyl-					√

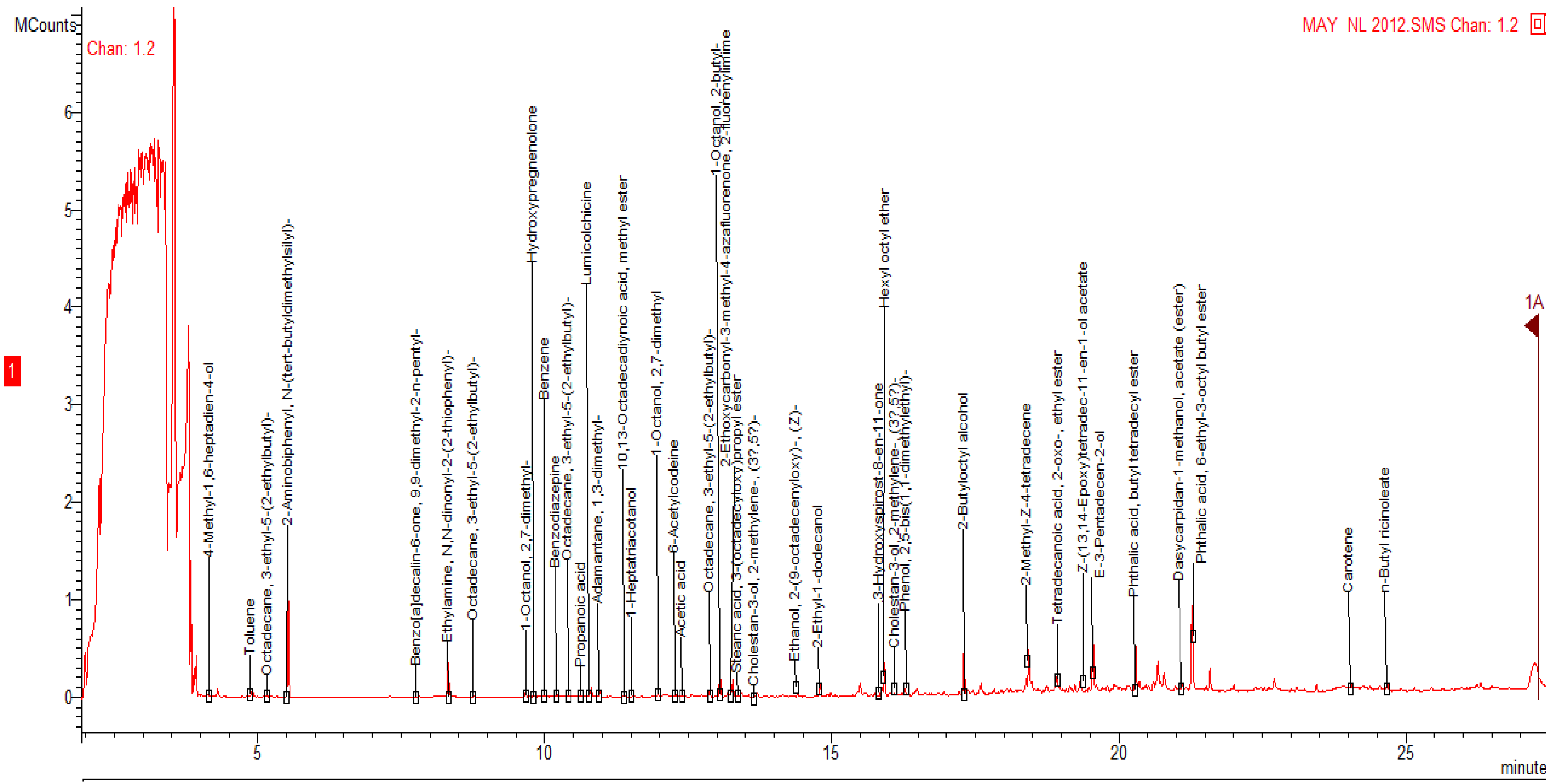

Figure 13: Chromatograph for Nainital lake sample for the month of May 2012

3.2 The identification of surface and groundwater interaction by geobiochemical method in Arani river (ANNA)

3.2.1 General

As a part of EU Saph Pani Project an MSc study titled "The identification of surface and groundwater interaction by geobiochemical method in Arani river" was carried out by Mr. Koilakh Badar Sayeed at Anna University (December 2011 - June 2012). The study was carried out in a part of Arani river, Tiruvallur district, Tamil Nadu state, India (Figure 14). It is located at about 40 km north of Chennai. Arani river enters Tamil Nadu at Uttukottai and ends in Bay of Bengal. This area falls in the latitude of 13°18'N and its longitude position is 80°02'E. Arani basin covers 764 km^2. Arani river is a seasonal river and carries substantial flow during monsoon only. The study area consists of sand, clay and recent alluvium overlying on a thick pile of Gondwana shales, clays and sandstones rocks. This area has an average elevation of 25 m above mean sea level and has a very gentle easterly slope with a few isolated hillocks and depressions.

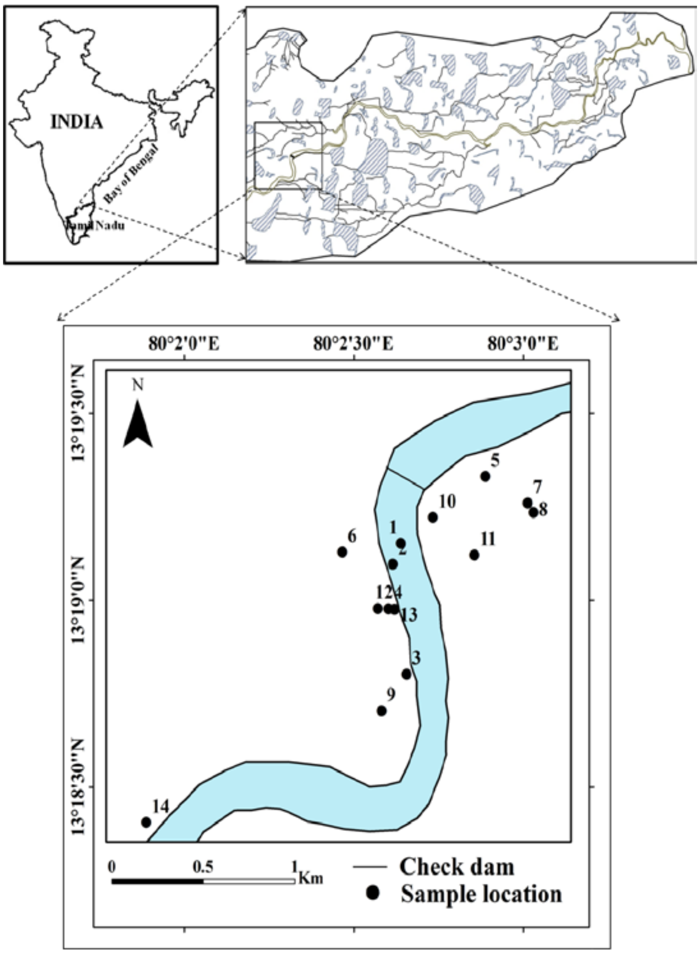

Figure 14: Location of the study area - Arani river

The study area experiences tropical and dry climate. The period between late May and early June is the hottest period of the year during this time the maximum temperature goes up to 38 °C - 42 °C and the minimum temperature will be 18 °C - 20°C. The average annual rainfall is around 1200 mm, 35% falling in the southwest monsoon (June - Sep.) and 60% during the northeast monsoon (Oct. - Dec.). Rainfall is the major source of recharge for groundwater of this area. Hence, in order to augment the groundwater resources a series of check dams are being constructed across the Arani and Koratalai rivers flowing north of the city. One such check dam completed in August 2010 across the Arani river was chosen to take up the present study. This check dam is of 260 m length with the crest height of 3.5 m. The objective of this study is to assess the water quality for drinking purpose and to identify the interaction between surface and groundwater.

Groundwater and surface water samples were collected once in a month from February 2012 to May 2012. Physical parameters such as pH, electrical conductivity (EC) and total hardness (TH) were measured immediately after sampling. Chemical parameters such as Na, K, Ca, Mg, Cl were analyzed by standard titration method. Microbial load in both surface and groundwater were analyzed using nutrient media. Geochemical data and biological data will be used to identify the interaction of surface and groundwater.

3.2.2 Water quality for drinking purpose

Table 14 shows the minimum, maximum and mean values of various surface and groundwater samples with limit prescribed by WHO (2008) for drinking purpose. Measurements on physical parameters such as pH, EC, TDS, TH of surface water samples are less when compared with groundwater samples. All the water quality parameters are within the prescribed limit, which indicates that water in this area can be used for domestic purpose without any further water treatment. Comparison of geochemical parameters of surface and groundwater show that all the geochemical parameters of surface water samples are lower than that of the groundwater samples as in the case of geochemical parameters. Increase in physico-chemical parameters of groundwater is due to the interaction of groundwater with the aquifer formation in the study area.

Table 14: Minimum, maximum and mean of various surface and groundwater samples

Parameter	Units	Surface water			Groundwater			WHO (2008)
		Minimum	Maximum	Mean	Minimum	Maximum	Mean	
pH	-	7	7	7	6.8	7	7	8.5
EC	µs/cm	500	946	723	600	1100	850	1500
TDS	mg/L	320	605	462	384	704	544	TDS>1000 brackish, TDS < 1000 fresh
Total Hardness	mg/L	85	90	87	135	175	150	300
Ca	mg/L	35	42	38	60	90	75	75
Mg	mg/L	12	15	13	17	12	14	30
Na	mg/L	20	70	44	20	98	60	200
Cl	mg/L	43	47	45	38	98	78	200

3.2.3 Microbiological analysis

Microbiological load present in the surface and groundwater samples were analyzed using nutrient media. Plate count test indicated the number of bacteria present in 100 mL of water samples. Figure 15 shows the presence of bacteria in a surface and groundwater.

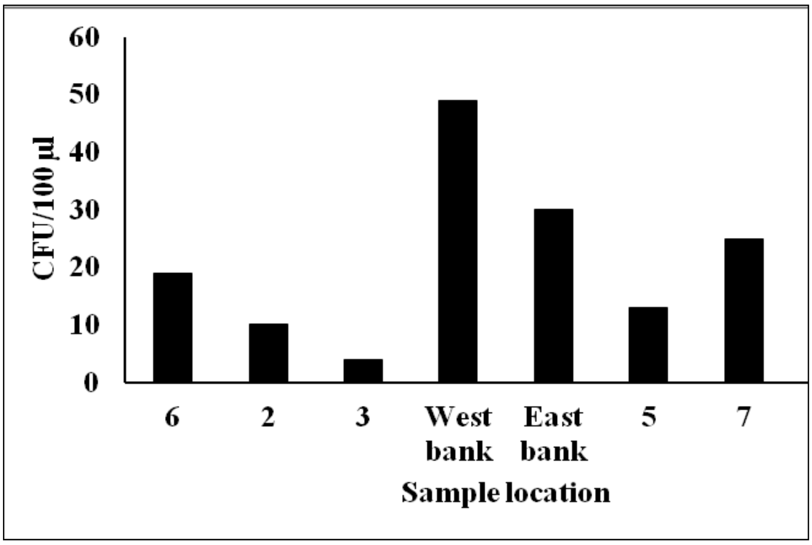

Figure 15: Microbiological load in surface and groundwater

Number of bacteria present in the surface water varied from 30 CFU/100 µL to 49 CFU/100 µL, whereas in groundwater it varied from 4 CFU/100 µL to 25 CFU/100 µl. Higher count of microbiological load in surface water is due to the anthropogenic activities.

3.2.4 Interaction between surface and groundwater using electrical conductivity

EC of water is a good indicator helps in identifying the interaction between surface and groundwater. The EC against the distance of sampling location measured from the riverbank is shown in Figure 16. It indicates that the wells located at a closer distance from the river have EC similar to that of surface water. As the distance increased from the river, the EC of groundwater samples also increased and reached the background EC of the study area which is about 1500 µS/cm. This indicates that the wells located within 40 m are having the highest interaction and the wells located 40 m to 600 m are having the high interaction of surface water interaction.

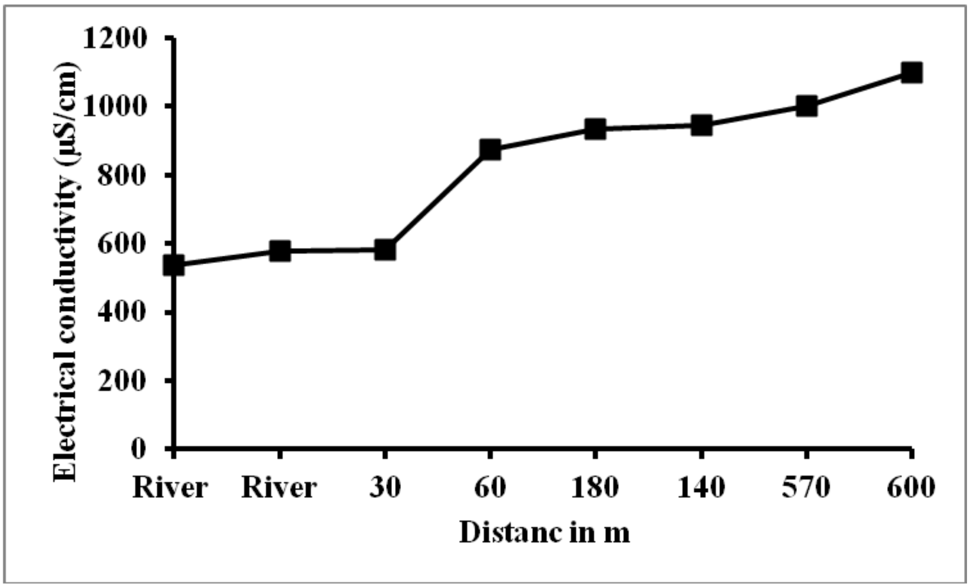

Figure 16: Variation of EC with respect to distance from the river

In order to assess the water quality for drinking purpose and to identify the interaction between surface and groundwater in Arani River, Tamil Nadu (India), surface and groundwater sample were collected and analyzed for physico-chemical and biological parameters. Based on the WHO guideline values, both surface water and groundwater samples showed that these sources are suitable for domestic uses. It was also observed from physico-chemical studies that due to the interaction of surface water the EC of groundwater is substantially improved. Study on microbiological load indicated that surface water has more microbiological load and groundwater has comparatively less microbiological load. This higher load in surface water is due to the anthropogenic activities taking place in that area.

3.3 Tertiary treatment of output from constructed wetlands aimed at reuse of treated wastewater (IITB)

In recent years NTSs have been accepted as distinct wastewater treatment systems in India, designed on the basis of certain empirical or rational criteria. NTSs have been proven as a better alternative of wastewater treatment worldwide because of minimum energy requirements, reduced maintenance and higher degree of treatment as compared with conventional mechanized treatment systems for the sanitation of small communities. There are different types of NTSs in use in India and the most common include CWs, hyacinth and duckweed ponds, lemna ponds, fish ponds, WSPs, OPs and lagoons and, algal-bacterial ponds.

NTSs, especially CWs, can contiunously produce reasonably good quality treated water in terms of removal of pollution indicators like BOD, COD, TSS etc. The wastewater treated by CWs may directly be reused for non-potable purposes if some additional treatment is provided to remove the remaining traces of pollutants like nutrients and pathogens. Removal of these pollutants from treated wastewater from CWs may enhance the potential of reuse. Advanced nutrient removal by applying the physico-chemical methods as well as an appropriate disinfection for pathogen removal will facilitate and ensure that the treated water from NTSs is safe to reuse for different purposes.

Phosphorus removal has been variable in CWs because substrates are selected based on local availability and particle size for reduced clogging without consideration for their capacity of phosphorus removal (Yang *et. al,* 2001). CWs have high buffering capacity and their removal efficiency depends on temperature, hydraulic retention time (HRT), organic loading rate and are highly variable (Rousseau *et. al,* 2008).

Table 15: Nutrient uptake capacities of macrophytes used in CW systems [Brix, 1994]

Macrophyte	Uptake Capabilities (Kg/h/yr)	
	Nitrogen	Phosphorus
Cyperus Papyrus	1100	50
Phragmites Australis	2500	120
Typha Latifolia	1000	180
Eicchornia Crassipes	2400	350
Pistia Stratiodes	900	40
Potamageton pectinus	500	40
Ceratophylum demersum	100	10

Nutrient removal, especially phosphorus is not appreciable in CWs. At low phosphorus concentration, typical removal efficiency can be up to 60-90% and effluent concentration of 1 mg/L or lower can be achieved (Rousseau *et. al,* 2008). However, Margaret and Wooley (1999) reported that effluent phosphorus concentration exceeds influent when plant is operated for a long time. This is due to ‘’aging phenomenon’’ of CW in which media is saturated with adsorption and precipitation of effluent pollutant (USEPA, 1988). Phosphate uptake capacity of macrophytes is also limited as shown in the Table 15 (Brix, 1994).

3.3.1 Research objectives of proposed M.Sc. study at IITB

Besides BOD, pathogens and nutrients are also removed significantly in the treated wastewater from CWs. The quality of treated effluents from properly operated and maintained CWs are comparable with that of mechanized treatment systems in terms of physico-chemical parameters. The additional benefit observed in the treated effluent from CWs is the lower count of pathogens as compared to conventional sewage treatment plants – which may give better opportunity to reuse the treated wastewater.

The treated wastewater quality from CWs is generally superior to that from conventional mechanized treatment systems including Activated Sludge Process, Sequencing Batch Reactor, Membrane Bioreactor, Trickling Filter, Oxidation Ditches, Extended Aeration Basin, Rotating Biological Contractors, Moving Bed Biofilm Reactor. However, the quality still remains unfit for body contact because of the presence of relatively higher number of pathogenic bacteria than that considered safe for body contact. Another important limitation of CW system (as depicted in Table 15) is its limited ability of phosphorus removal.

The phosphorus cycle can be characterized as closed in CWs and only removal is through plant system, if harvested. The removal and storage of phosphorus from wastewater can only occur within the CW media and plant biomass. Phosphorus is sequestered within a CW system by binding with organic matter as a result of incorporation into living biomass or precipitation of insoluble phosphates with iron, calcium, and aluminum found in CW (Mitsch and Gosselink, 1986). Therefore, the some post-treatment is essential for effluent from CWs for high-end applications, e. g. industrial boiler fed makeup water and various other useful applications.

The M.Sc. study titled "Tertiary treatment of output from constructed wetlands aimed at reuse of treated wastewater" (from May 2012 to May 2013) at IIT Bombay predominantly focuses on how to improve the overall quality of treated effluent from CW aimed at recycle and reuse. The specific objectives of the study are:

1. Elaboration of possible ways of physico-chemical treatment methods in removal of nitrogen and phosphorus from treated water from CWs
2. Investigation of appropriate method of pathogen removal from treated water from CWs.

3. Cost evaluation of post-treatment methods for upgrading the quality of effluents from CWs.

3.3.2 Research methodology

The study is focusing on analysis of physico-chemical methods for nutrients and pathogen removal in order to upgrade the quality of treated effluent. The major parameters that are being analyzed routinely during last eight months of research include nitrogen, phosphorus and pathogens (before and after the applied tertiary treatments). For removal of nutrients, various adsorption media like charcoals and biochars were converted into magnetized form by adopting the standard methodology. The work is in progress to analyze the effectiveness of these specific materials for polishing the effluents from CWs. The cost evaluation of different options will also be carried out in order to establish the most feasible means of tertiary treatment for upgrading secondary effluents from CWs.

Procedure used for the preparation of magnetised char:

1) Solution of $FeCl_3$ 20 gm in 1.5 L of distilled water
2) 100 gm biomass immersed in $FeCl_3$ for 2 hours under air
3) Biomass then put in hot air over for 24 hours
4) Biomass then pyrolysed at 500 degree Celsius for 1 hour
5) Biochar formed is crushed to fine particle and passed through 0.5 mm sieve
6) Only >0.5 mm particles were used to minimise residual ash particles
7) Samples were then washed with distilled water several times, oven dried and sealed in air tight wrap before use

3.3.3 Summary of the results obtained until April 2013

The research is in progress and some of the key results obtained so far are summarized in the following paragraphs:

1) It is probably better to use washed char to avoid escalation of TDS and salinity in case of treatment of effluents from CWs. The causative agent in biomass that enhances salt contents in chars and associated ashes need to be investigated further.
2) Char from many biomasses may also act as liming agents and hence remove phosphorus up to some extent.
3) Char has additional water retention capacity, its implications need to be analysed further.
4) Magnetised char from certain species showed appreciable removal of phosphorus ranging from 40% in *Colocasia* stem to 90% in *Cana Indica*.
5) Optimum removal is shown at the time interval of 15 minutes followed by increase in concentration gradually which perhaps shows the leaching of phosphate from the adsorbent.

3.4 Removal of ammonium and nitrate during river bank filtration and subsequent treatment (UNESCO-IHE)

3.4.1 Background and objectives

The concentrations of ammonium and nitrate are increasing in many surface waters worldwide due to discharge of untreated or partially treated wastewaters, industrial effluents and agricultural runoffs. This in turn is increasing the cost of water treatment for utilities which are using these wastewater-impacted or polluted sources for drinking water production. Many studies have demonstrated that BF technology is capable of remove or reducing the concentrations of most of the contaminants in surface waters including ammonium and nitrate. Ammonium and nitrate removal efficiencies of RBF systems worldwide vary considerably (Table 16). Ammonium and nitrates are removed fully or partially in some RBF systems while others show no removal at all or even increased concentrations of these compounds in bank filtrate (Doussan *et al*., 1997; Wu *et al*., 2007; Dash *et al*., 2008). Furthermore, different post-treatment methods have been utilized for further removal of nitrogen species from bank filtrates which include chlorination, sand filtration, ozonation, ion-exchange and activated carbon filtration.

Some BF sites in India also show relatively high concentrations of ammonium (Delhi) and nitrate (Srinagar). Furthermore, as the rivers/lakes in India are often polluted with untreated or poorly treated sewage and industrial wastes, the removal of bulk organic matter and nitrogen species during BF and subsequent pre-treatment will be main requirements for using these sources for water supply. Despite the capability of RBF systems to produce biologically and chemically stable water, there are process conditions which cause some system inefficiencies to remove ammonium and nitrate completely or up to drinking water standards. The mechanism of removal of ammonium and nitrate during RBF and the factors affecting them are not fully understood. This study aimed to assess the potential of RBF for removal of ammonium and nitrate under different water qualities and process conditions and analyze subsequent options for post-treatment of bank filtrates.

Table 16: Summary of ammonium and nitrate removal efficiencies at different existing BF sites

BF Site	Total Nitrogen Removal [%]	NH_4^+ Removal [%]	NO_3^- Removal [%]	Reference
Sidfa RBF plant, Nile River (Egypt)	-	-	Increased by 93% [1]	Shamrukh and Abdel-Wahab (2008)
Kuihe River, Xuzhou, Jiangsu (China)	95% [2]	-	-	Wu *et al*. (2007)
	0% [3]	-	-	
Henry RBF, Illinois River (USA)			Vary from >99% to 10% [4]	Ray *et al*. (2002b)
The Lower Nakdong River Basin (Korea)	-	-	64%	Lee *et al*. (2009)
Jacksonville III, Illinois River (USA)	-	-	71%	Ray *et al*. (1998)
Siene River (France)	-	Increased concentration	100%	Doussan *et al*. (1997)
Nainital (India)	-	53% [5]	Increased concentration[5]	Dash *et al*. (2008)
	-	90% [6]	Increased concentration[6]	
Torgau, Elbe River (Germany)	-	-	Below detection limit[7]	Ray *et al*. (2002a)
	-	-	100%[8]	

[1] = *concentration of NO_3^- for Nile River water was at an average 3.1 mg/L, background groundwater 21 mg/L and bank filtrate 6.1 mg/L.*

[2] = *under saturated percolation condition*

[3]= *under unsaturated percolation condition (no removal)*

[4]= *peak concentration of nitrate in pumped water could vary from less than 1% to 90% of that in the river*

[5]= *monsoon season*

[6]= *non-monsoon season*

[7]= *most of the year*

[8]= *summer season*

3.4.2 Materials and methods

Laboratory-scale soil column (SC) and batch reactor (BR) experiments coupled with intensive desk study were carried out to analyze the effect of bulk organic matter present in raw water on the removal of ammonium and nitrate during BF. Three identical soil columns, each of 4 m long uPVC pipe with 57 mm internal diameter filled with silica sand of size 0.8 to 1.25 mm, were used for simulation of BF. Furthermore, batch reactors each comprising of 1 litre glass bottle which contained silica sand (size 0.8 - 1.25 mm) were used. The characteristics of three different types of source water used in this study are presented in Table 17. The SCs and BRs ripened (bio-acclimatized) for 90 days and 57 days respectively until there was steady state with respect to DOC removal before spiking ammonium for analysis of nitrification and dentrification. Mixtures of different source waters namely primary effluent (PE), Mass River Water (MRW) and Delft Canal water (DCW) were spiked with 18 mg/L of NH_4^+-N to produce wastewater-impacted feed water with different background organic matter concentrations. The influent waters used for both experimental setups included MRW+NH_4^+, PE+MRW (1:1), DCW+NH_4^+, PE+DCW (1:1) and PE. Details of the experimental set-ups used, procedures as wells analytical methods applied are presented in Mutabuzi (2013).

Table 17: Average water quality characteristics of influent waters used

Parameter	Unit	Primary Effluent PE	Delft Canal Water DCW	Mass River Water MRW
pH	-	7.2 ± 0.4	7.3 ± 0.4	7.8 ± 0.3
Temperature	^{o}C	15.1 ± 1.8	2.6 ± 5.7	3.9 ± 8.5
DO	mg/L	3.1 ± 1.9	6.9 ± 1.0	7.1 ± 0.8
EC	µs/cm	1273 ± 411	751 ± 171	624 ± 16
DOC *(after aeration in the lab)*	mg/L	37.5 ± 13.4	11.2 ± 0.3	4.9 ±0.7
NO_3-N	mg/L	0.4 ± 0.3	2.7 ± 0.4	3.0 ± 0.9
PO_4-P	mg/L	7.0 ± 1.2	0.5 ± 0.1	0.3 ± 0.1
NH_4-N	mg/L	36.0 ± 10.8	0.10 ± 0.03	3.9 ±1.0
UVA_{254}	1/cm	0.545 ± 0.134	0.380 ± 0.004	0.150 ± 0.014
SUVA	L/mg.m	1.7 ± 0.7	3.26 ± 0.12	3.10 ± 0.57

3.4.3 Results and discussion

Batch experiments showed high potentials of ripened silica sand for the removal of ammonium under aerobic conditions. The results showed that removal of NH_4-N in MRW+NH_4^+, PE+MRW (1:1), DCW+NH_4^+, PE+DCW (1:1) and PE was 100%, 100%, 100%, 100% and 99.38% respectively. On the other hand, less NO_3^--N removal efficiencies (19 - 49%) were observed in BR studies. The BRs were able to remove NO_3^--

N from waters of different bulk organic contents in the descending order of PE+MRW (1:1), MRW+NH_4^+, PE, PE+DCW (1:1) and DCW+NH_4^+.

SCs studies showed that after feeding comparable NH_4^+-N concentration in all influent waters (approx. 18 mg/L NH_4^+-N), the effluents exiting the SCs showed different concentrations of this compound. The average NH_4-N removal in columns fed with MRW+NH_4^+ (SC1), DCW+NH_4^+ (SC2) and PE+MRW (1:1) (SC3) waters were 97.81%, 99.92% and 93.16% respectively. On the other hand, the removal of NO_3^--N in columns fed with MRW+NH_4^+, DCW+NH_4^+ and PE+MRW (1:1) was observed at an average of 11.18%, 18.47% and 29.17% respectively. The background DOC concentrations and removals of DOC, NH_4^+ and NO_3^- in different soil columns are summarized in Table 18. These results clearly showed that bulk organic contents present in raw water had significant effect on nitrification and denitrification processes during bank filtration. It is to be noted that these results are based on the soil columns 4 m deep. It is likely that nitrate removal will be increased in field conditions with larger depth of the aquifer and more anoxic conditions. Furthermore analysis of subsequent post-treatment methods, for removal of nitrogen from the filtrates of soil columns revealed that breakpoint chlorination and ion exchange can be used as polishing step for ammonium and nitrate respectively.

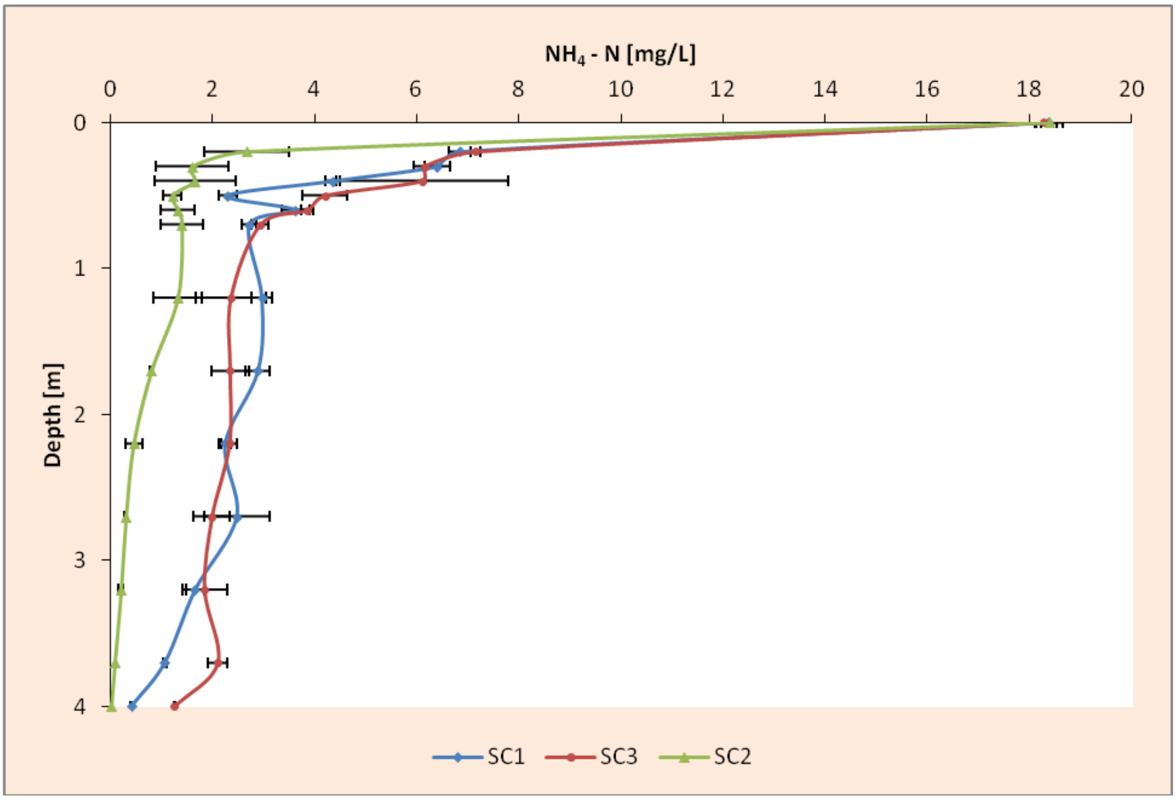

Figure 17: Ammonium removal profiles along the soil columns fed with different types of feed water (HLR = 1.25 m/day, media = sand 0.8 - 1.25 mm, aerobic conditions)

Table 18: Summary of the results of removal of nitrogen in SCs

Soil Column	Type of Influent Water	Avg. Influent DOC [mg/L]	Removal [%]		
			DOC	NH_4- N	NO_3- N
SC1	MRW + NH_4^+	5.1 ± 0.6	31.6	97.8	11.1
SC2	DCW + NH_4^+	13.0 ± 0.3	8.3	99.9	18.5
SC3	MRW + PE	12.8 ± 0.4	42.3	93.6	29.2

Table 19 and 20 provide summaries of post-treatment methods for removal of ammonium and nitrates. As shown in the tables, each of these treatment methods has their advantages and limitations. The selection of the post-treatment method for the given BF site should be guided by capital and O&M cost considerations and local water quality requirements. Very often it should be possible to combine the post-treatment requirements for different contaminants and to use a multiple-objective treatment process which could be utilized for the removal of several contaminants in a single process.

Table 19: Summary of post-treatment technologies for ammonium removal from bank filtrates

Ammonium treatment method	Process conditions	Advantages	Disadvantages	Removal efficiency [%]
Breakpoint chlorination	- Rate of formation of mono and dichloramines - pH = 7.0 - 8.0 (optimal 7.5) - Actual ratio $[Cl_2]:[NH_4^+]$ = up to 25:1 (theoretically = 7.6:1) - Reaction time = 30 - 60 min. - Temperature $\geq$ 20°C	- No waste disposal required - No post-treatment required - Low operating cost	- Forms harmful DBPs including THMs and HAAs - Bitter taste complaints due to NCl_3 formation	~100
Air stripping[1]	- pH = 10 - 11 - Temperature 20°C - 40°C - High air/water ratio - pH adjustment after aeration required for subsequent processes	- Does not form DBPs - Not sensitive to toxic substances	- Requires waste disposal (stripped gas/air) - Post-treatment required - Very expensive due to high energy & chemicals used - High air/water ratio - Clogging due to $CaCO_3$ scaling	95 - 99
Rapid sand filtration	- V_f = 5-15 m/h - Filter bed = 0.6 - 1.0 m - sand size = 0.5 - 2.0 mm - Head loss = up to 3.0 m - Length of run = 1 -3 days - Backwash water = 3 - 6% of filtered water (chlorine free)	- Does not form DBPs - Medium investment costs	- High operating costs	40 - 50
Dry filtration	- V_f = 2 - 5 m/h - Filter bed = 1.5 - 2.0 m - Sand size = 1.5 - 3.0 mm - Air/water ratio = 0.5 - 1.0 - Equal distribution of feed water over filter surface - 3.5 mg O_2/L per 1 mg NH_4/L - Backwash water should be chlorine free	- High capacity to remove ammonium (up to 20 mg/L) - Does not form DBPs	- Requires further polishing filtration step (RSF) to remove formed bacteria during the process - High operating costs	~100
Ion exchange[2]	The process conditions vary per type of exchanger. Factors affecting the process include :- - pH e.g. 7.2 - 7.6 (for natural zeolites) - Temperature e.g. $\geq$2 0°C (for natural zeolites) - Contact time - NH_4^+ adsorption capacity e.g. 2 - 30 mg/g (for natural zeolites)	- Does not form DBPs - High cation-exchange capacity	- Requires waste disposal - Post-treatment required - Presence of competitive ions e.g. potassium reduces adsorption capacity - High investment and operational costs	~ 97

[1]= *Huang and Shang (2006))* [2] = *Wang and Peng (2010)*

Table 20: Summary of post-treatment technologies for nitrate removal

Nitrate treatment method	Process conditions	Advantages	Disadvantages	Removal efficiency [%]
Ion exchange[1]	Process conditions vary with type of ion exchange media Factors affecting the process include: - Resin type e.g. those with higher selectivity for nitrate are very effective - Contact time - NO_3^- adsorption capacity - Resin regeneration efficiency	- Medium operating costs - Does not contribute toxic organic chemicals to treated water	- Requires waste brine disposal - Post treatment required to reduce corrosivity	≃ 90
Reverse Osmosis[2]	- Commonly used membrane type is cellulose acetate - Pressure = 2.07 - 10.35 MPa - Pre-treatment to minimize deposition problems	- Higher degree of rejection of ion which is proportional to the valence of ions present in water supply	- Requires waste disposal (with high TDS) - Application problems including fouling, compaction and deterioration - Post-treatment required to reduce corrosivity - High operating costs	> 95
Adsorption[3]	Process conditions vary with type of adsorbent used Factors affecting the process include: - pH = 2 - 8 - Temperature = 5 - 30°C - Adsorption capacity = 1 - 104 mg/g - Contact time = 5 min - 24 h	- Does not require post-treatment - Medium operation costs	- Requires waste disposal (saturated adsorbent)	71 - 99.5
Chemical denitrification[4]	- Al:NO_3^- ratio = 1.16:1 - pH = 9.0 - 10.5 - Temperature effects very important	- Does not require waste disposal	- Post treatment required - High operating costs	60 - 70
Biological denitrification[5]	- Temperature = 10 - 20°C - C:N ratio = 0.8 - 2.0 - S:N = 2 - 5 - Optimum pH = 7.5 - Effective configuration of reactor is fluidized bed sand - HLR = 12 - 20 m/h	- Medium operating costs	- Requires biomass waste disposal - Post-treatment required (disinfection and to remove introduced substrate e.g. methanol)	> 99

[1 - 5] = *Kapoor et al. (1977); Bhatnagar and Sillanpaa (2011)*

This study exhibited that BF has enormous potentials to remove different contaminants from surface water. Specifically, BF can be used as a major treatment step for removal or considerable reduction of nitrogen species from source water (depending up background organic matter and redox conditions), which may require some additional post-treatment for polishing ammonium and nitrate to meet local water quality standards.

4. Summary and Conclusions

Pre-treatment and post-treatment are required for different NTSs in order to improve their performance and to meet the water quality standards and guidelines for intended use. The type of the pre-treatment and post-treatment that should be applied, however, depends mainly on the source water quality, the type of NTSs being used, the process conditions applied as well as the intended use of the "treated water" from the NTSs. Removal efficiencies of different pre- and post-treatment methods applied to NTSs (BF, MAR and CWs and Other wastewater treatment systems) were analyzed based on literature review, field data collection at case study sites and laboratory-based studies.

Pre-treatment is not applicable for BF systems while several conventional water treatment methods namely disinfection, lime softening, aeration, coagulation, sedimentation, rapid sand filtration as well as activated carbon filtration has been used for post-treatment of BF worldwide. The removal efficiencies of these post-treatment units vary considerably depending upon the process conditions (hydraulic retention time and filtration rate, chemical dose, depth and type of filter media) applied. Disinfection (by chlorination) is the most common post-treatment applied to bank filtrates in India while few systems also use aeration followed by rapid sand filtration before chlorination (e.g. Mathura, Ahmedabad). In the most of the BF systems in India, chlorination has been sufficient to meet the drinking water quality requirements. In view of deteriorating water quality of rivers in some parts of India, the existing post-treatment methods in some sites (e.g. Mathura) may not be sufficient to meet the water quality requirements in the future. The elevated concentrations of DBPs and presence of OMPs in the treated water is likely to be water quality concerns in future requiring post-treatments before supply.

Suspended solids removal by sedimentation in settling basins, detention tanks/chambers or ponds followed by sand filtration is the most common pre-treatment applied to rainwater or stormwater or riverwater used for MAR in India. Sometimes both of these two pre-treatment processes (sedimentation and filtration) are achieved in a combined unit which forms a part of recharge structure. Depending upon the sediment load (type of source water) and detention time, the TSS removal efficiencies of sedimentation system may range from 20 to 70%. The stormwater filters, depending upon the design, may give to TSS removal efficiency of 70 to 80%. Removal of fluoride and arsenic is one of the common geogenic water quality problem associated with groundwater use in India. Several adsorption and precipitation based systems are available to remove these contaminants. The removal efficiencies of these systems vary significantly (from 60 to 99%) depending on the type of the adsorbent used, influent concentration and process conditions applied.

Screens, septic tanks (with or without baffles), grit chambers, settling basins and UASB reactors and their combinations have been used as the primary or pre-treatment before various CWs and other NTSs for wastewater treatment in India. The objectives of these pre-treatment systems are to remove floating matters, grits and reduce the concentration of TSS. Depending upon the type of the type of the pre-treatment used, the typical TSS and BOD removal efficiencies of these systems ranges from 40 to 70% and 40 to 60% respectively. Removal of pathogens and phosphorus has been identified as the key water quality concerns for further reuse of effluents from NTSs in India. Post-treatment of effluents from CWs and other NTSs for wastewater is nearly absent in India. Effluents from these NTSs are generally used for irrigation and discharged to nearby water bodies without further treatment. Chlorination is the only post-treatment applied in 2 of the 108 NTSs surveyed. Further removal of bulk organic matter, pathogens and nutrients through appropriate post-treatment would be necessary to reuse the treated water from these NTSs for industrial and non-potable municipal applications.

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