TECHNEAU

WP 5.2:
Combination of MAR and Adjusted Conventional Treatment Processes for an Integrated Water Resources Management

Deliverable 5.2.4:
Feasibility Study on Post-treatment Options after Riverbank Filtration in Delhi:
Minimum Requirements

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Eric Hoa

KOMPETENZZENTRUM Wasser Berlin

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Title
Feasibility Study on Post-treatment Options after Riverbank Filtration in Delhi :
Minimum requirements of post-treatment techniques

Author
Eric Hoa, KompetenzZentrum Wasser Berlin gGmbH

Quality Assurance
Yann Moreau, KompetenzZentrum Wasser Berlin gGmbH
Gesche Grützmacher, KompetenzZentrum Wasser Berlin gGmbH
Jon Rostum, SINTEF

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List of Acronyms

BDOC	biodegradable dissolved organic carbon
DBP	disinfection by-products
DOC	dissolved organic carbon
DVGW	"Deutscher Verein für das Gas und Wasserfach": German Association for Gas and Water
GAC	granular activated carbon
MF	micro filtration
NCT	National Capital Territory (of Delhi)
NF	nano filtration
NOM	natural organic matter
OBM	process developed within TECHNEAU: "Oxidation + Biofilter + Membrane"
PAC	powdered activated carbon
RBF	river bank filtration
TDS	total dissolved solids
UF	ultra filtration
WA	TECHNEAU work area

Extended Abstract

River Bank Filtration (RBF) is a drinking water (pre-)treatment that can remove a wide variety of surface water contaminants . However, the efficiency of this natural treatment process depends on hydrochemical, aquifer- and operational characteristics. Therefore, complementary treatment options may be required in order to build up a multiple-barrier-system and obtain drinking water quality. As a follow-up to the TECHNEAU WP5.2 field investigations, this report aims at identifying potential post-treatment schemes for drinking water production at three river bank filtration sites in New Delhi - Palla, Nizamuddin and Najarfgarh – for which physicochemical parameters as well as levels of inorganic and trace organic substances and microbial contamination have been measured during field campaigns in 2007 and 2008 (see deliverables D5.2.2 and D5.2.6).

The three investigated RBF sites in Delhi have distinctive geographical locations and contamination exposures. For each of them, critical water parameters were identified that present a challenge with regards to drinking water production, for which different treatment technologies are envisaged (see table below). For Palla and Najafgarh, one specific water component (fluoride and salinity, respectively) requires targeted treatment. For Nizamuddinm, however, where surface water is highly exposed to contamination from poorly treated waste water, theoretical post-treatment options are no longer efficient and extensive conventional wastewater treatment is recommended.

One other possible option for Nizamuddin is the Oxidation / Biofiltration / Membrane technology (OBM process) developed by NTNU and SINTEF within the TECHNEAU project and a specific report on its application to Delhi is planned within TECHNEAU WP7.9.

Palla	uncritical (except F^-)	■ (Activated Alumina)
Nizamuddin	As, Fe, Mn, F and NH_4 critical in shallow wells	■ Extensive conventional treatment necessary ■ Oxidation + Biofilter + Membrane (OBM)
Najafgarh	groundwater salinity	■ Desalination via Reverse Osmosis

This report shows the theoretical post-treatment options for river bank filtration sites in Delhi. The strong technological requirements for Nizamuddin and Najafgarh seem inadequate to be currently implemented. The priority in Delhi would be to develop an integrated water and wastewater management, in order to reduce contamination in the surface water and thereby lower the technological requirements for drinking water production.

1 Introduction

River Bank Filtration (RBF) is a drinking water (pre-)treatment that can remove a wide variety of surface water contaminants . However, the efficiency of this natural treatment process depends on hydrochemical, aquifer- and operational characteristics. Therefore, complementary treatment options may be required in order to build up a multiple-barrier-system and obtain drinking water quality.

As a follow-up to the TECHNEAU WP5.2 field investigations, the following report aims at identifying potential post-treatment schemes for drinking water production at three river bank filtration sites in New Delhi - Palla, Nizamuddin and Najarfgarh. At these sites physicochemical parameters as well as levels of inorganic and trace organic substances and microbial contamination have been measured in previous field campaigns (see deliverables D5.2.2 and D5.2.6).

2 New Delhi Field Sites

2.1 Location of the field sites

In 2006 and 2007 three active or potential bank filtration sites in New Delhi (Figure 1) were investigated and characterised with respect to hydrogeological, geochemical and hydrochemical context:

- The Palla field site is an active well field located in the northern part of New Delhi, on the flood plain of the western bank of the Yamuna River, upstream of the urbanised parts of New Delhi. The area covers 18 km² with around 100 abstraction wells, which provide ~10% of the water supply in Delhi.
- Nizamuddin site is situated in the urban central part of the city, on the eastern bank of the Yamuna River, about 100 m upstream of Nizamuddin brigde. Through its flow in the city, the quality of the Yamuna River is significantly affected by untreated urban wastewater.
- Najafgarh site is located in the rural southwestern part of the National Capital Territory (NCT) of Delhi, at approximately 10 km south-western of the Najarfgarh village. The Najarfgarh drain is also used as a sewage canal as it flows through the city where it merges with the Yamuna River.

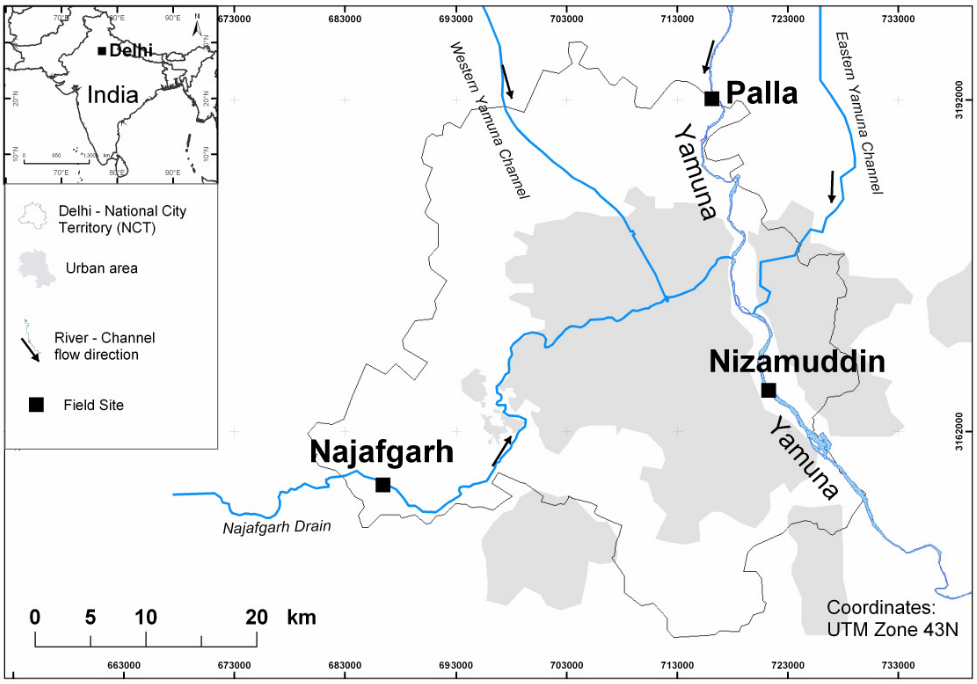

Figure 1: Location of the study sites (Pekdeger et al. 2006).

2.2 Effects of RBF and Identification of Critical Parameters

The following conclusions were derived from the montly monitoring program. Details are given in the TECHNEAU deliverables D5.2.2 and D5.2.6. (www.techneau.org).

2.2.1 *Palla Field Site:*

Figure 2 and Figure 3 present the surface water quality and the bankfiltrate quality, respectively, in Palla, which is located upstream the centre of Delhi and therefore it is not intensely exposed to human contamination.

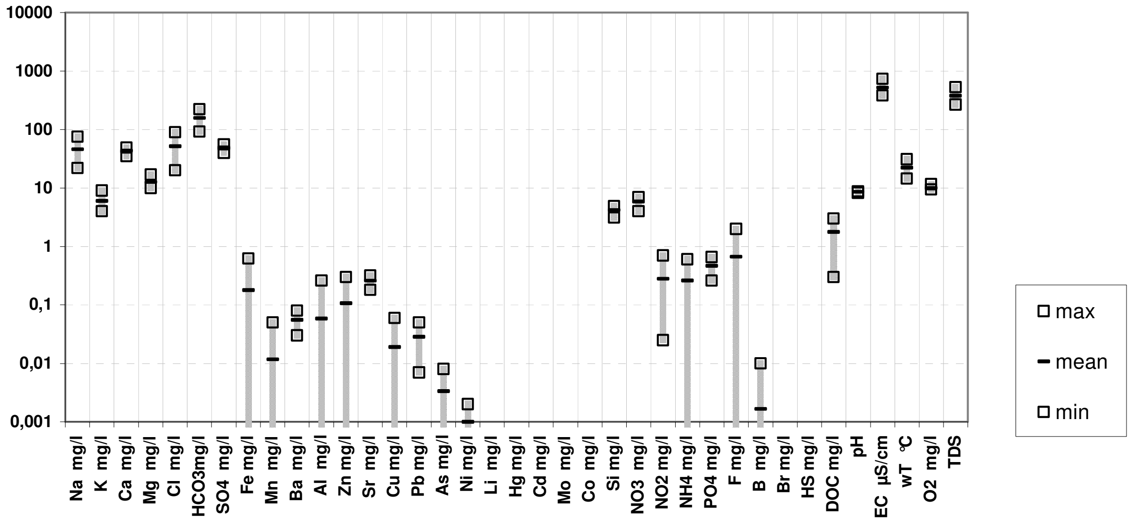

Figure 2: Palla surface water quality (2006 – 2007, data from (Pekdeger et al. 2008)).

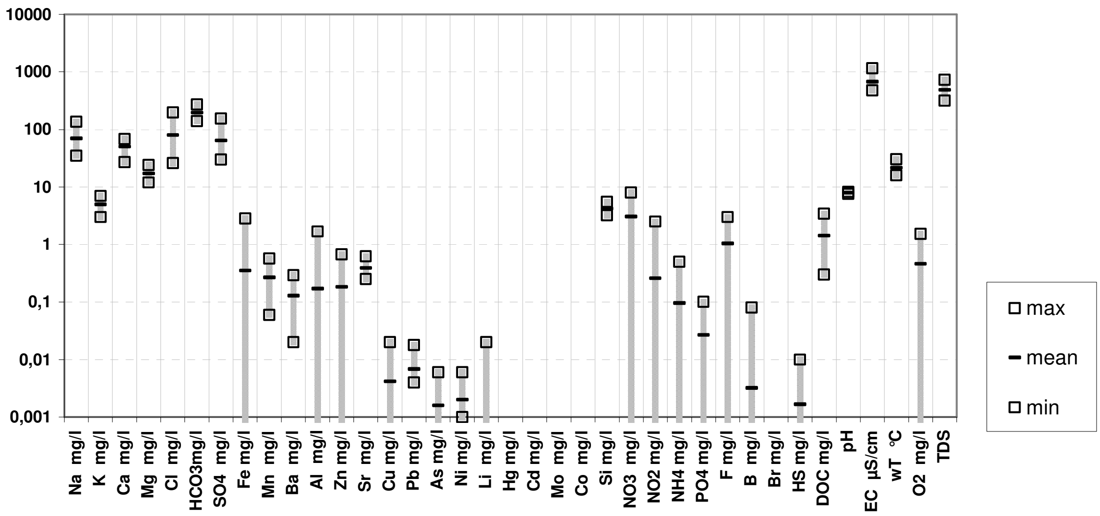

Figure 3: Palla bankfiltrate quality (2006 – 2007, data from (Pekdeger et al. 2008)).

Most investigated parameters lie well below the Indian standard for drinking water – in surface water, groundwater and bank filtrate. Moreover, based on the microbial investigations, no faecal contamination is identified in the tube well in Palla. Only Fluoride exceeds the threshold for drinking water standard and must be considered as critical criterion (Table 1).

Table 1 - Concentrations in fluoride in the tube well (30-60% of bank filtrate) in Palla.

	Average	Maximum	Indian standard (desirable)	Indian standard (permissible)	German standard
F (mg/L)	1.7	3	1	1.5	1.5

2.2.2 *Nizamuddin field site:*

Figure 4 and Figure 5 respectively present the surface water quality and the bankfiltrate quality in Nizamuddin, which is downstream the centre of Delhi and therefore it is directly exposed to contamination by treated and poorly treated waste water.

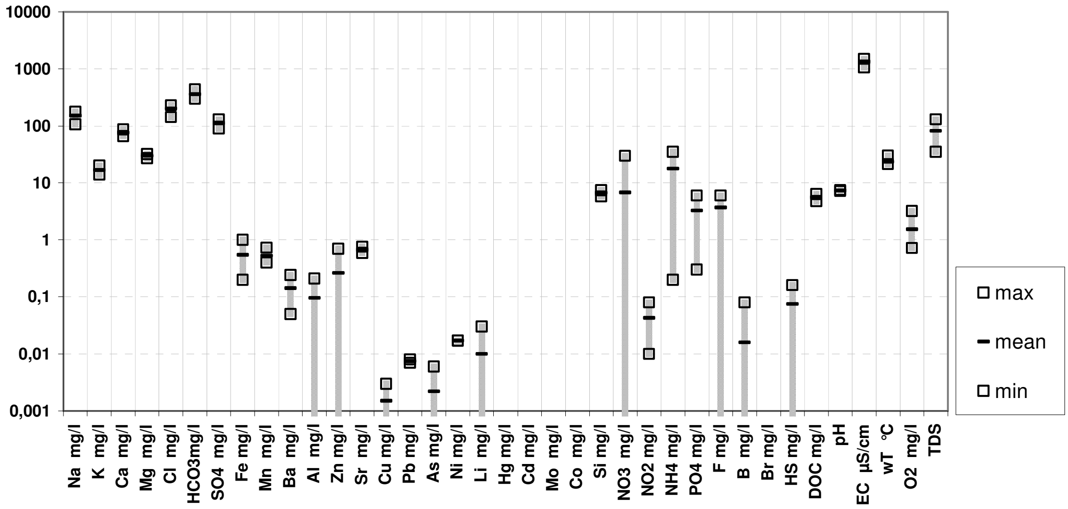

Figure 4: Nizamuddin surface water quality (2006 – 2007, data from (Pekdeger et al. 2008)).

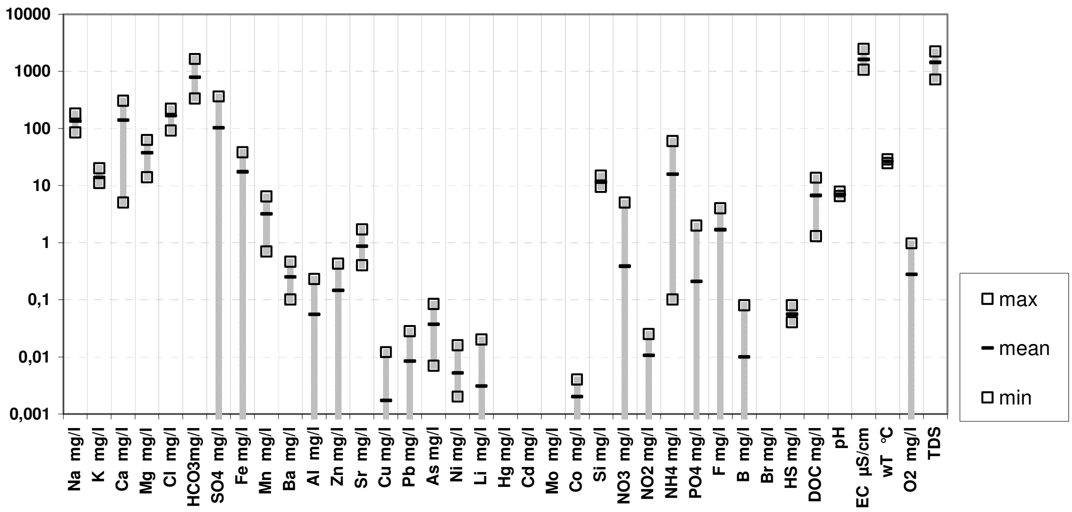

Figure 5: Nizamuddin bankfiltrate quality (2006 – 2007, data from (Pekdeger et al. 2008)).

An increase in concentration during infiltration can be observed for Fe, Mn, As, F and Ammonium, all of which reach concentrations critical for use as potable water. Therefore, post-treatment will need to target a wide range of substances.

Table 2 presents the expected levels for those critical compounds in 2 reference mixtures, which, based on theoretical considerations, could be relevant for the implementation of a pumping well. In a preliminary approach, mixture 1 offers an equivalent share of river bank filtrate and shallow ambient groundwater whereas mixture 2 is composed of 20% of deep groundwater and 80% of shallow groundwater – which is in fact believed to be highly correlated with river bank filtrates. In both cases, post-treatment options appear necessary.

Table 2 - Critical parameters in Nizamuddin (n.r : not regulated)

	Mixture 1 (50% SW + 50% shallow GW)	Mixture 2 (20% deep GW + 80% shallow GW)	Indian standard (desirable)	Indian standard (permissible)	German standard
As (mg/L)	0.019	0.028	0.01	0.01	0.01
Fe (mg/L)	10	15	0.3	1	0.5
Mn (mg/L)	1.7	2.5	0.1	0.3	0.05
F (mg/L)	2.2	2.1	1	1.5	1.5
NH_4 (mg/L)	15	14	n.r.	n.r.	0.5

2.2.3 *Najafgarh field site:*

Figure 6 and Figure 7 present the surface water quality and the bankfiltrate quality, respectively, in Najafgarh, which is located upstream of Delhi and is therefore not intensely exposed to human contamination.

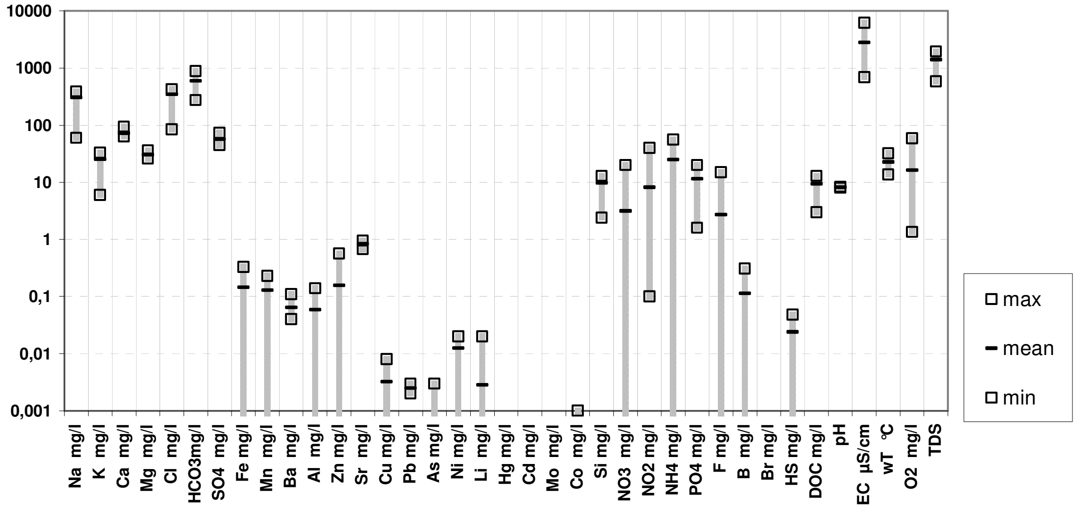

Figure 6: Najafgarh surface water quality (2006 – 2007, data from (Pekdeger et al. 2008)).

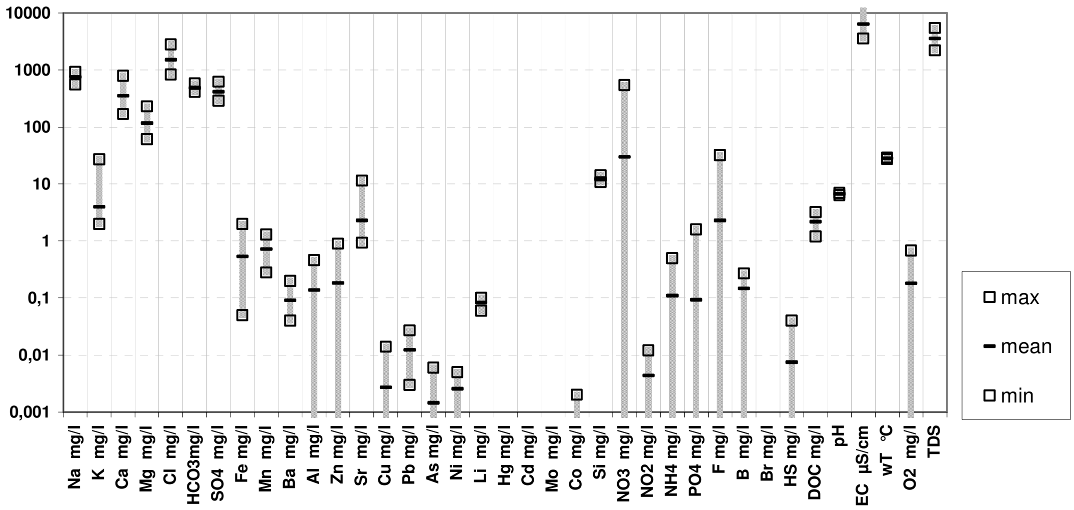

Figure 7: Najafgarh bankfiltrate quality (2006 – 2007, data from (Pekdeger et al. 2008)).

In this rural site, the main constraints are the high salinity of the groundwater and the seasonal availability of fresh surface water. Due to the high mineralization of the groundwater a possible RBF site must be optimized to reach a high share of bank filtrate. The design and the capabilities of RBF facilities are subject to ongoing work. Additionally, nitrogen species - ammonia, nitrite or nitrate – may be problematic substances due to a load with untreated sewage.

Table 3 – Mean values for electrical conductivity in Najafgarh and salinity-classification.

Surface Water	Shallow Groundwater	Medium Groundwater	Deep Groundwater
1,500 µS/cm	5,800 µS/cm	11,500 µS/cm	18,300 µS/cm
marginal river to brackish	saline	saline	Saline

3 Conventional post-treatment methods for river bank filtration (RBF)

RBF is a natural (pre-) treatment process that is commonly used in many regions of the world. However, the setup of RBF in combination with additional treatment techniques is strongly site specific (DVGW 2007). In Berlin for example, bank filtration is operated with only aeration and rapid sand filtration as post-treatment. Disinfection is usually not applied (SenStadt 2008). A schematic overview on different complementary treatment options is shown in Figure 8.

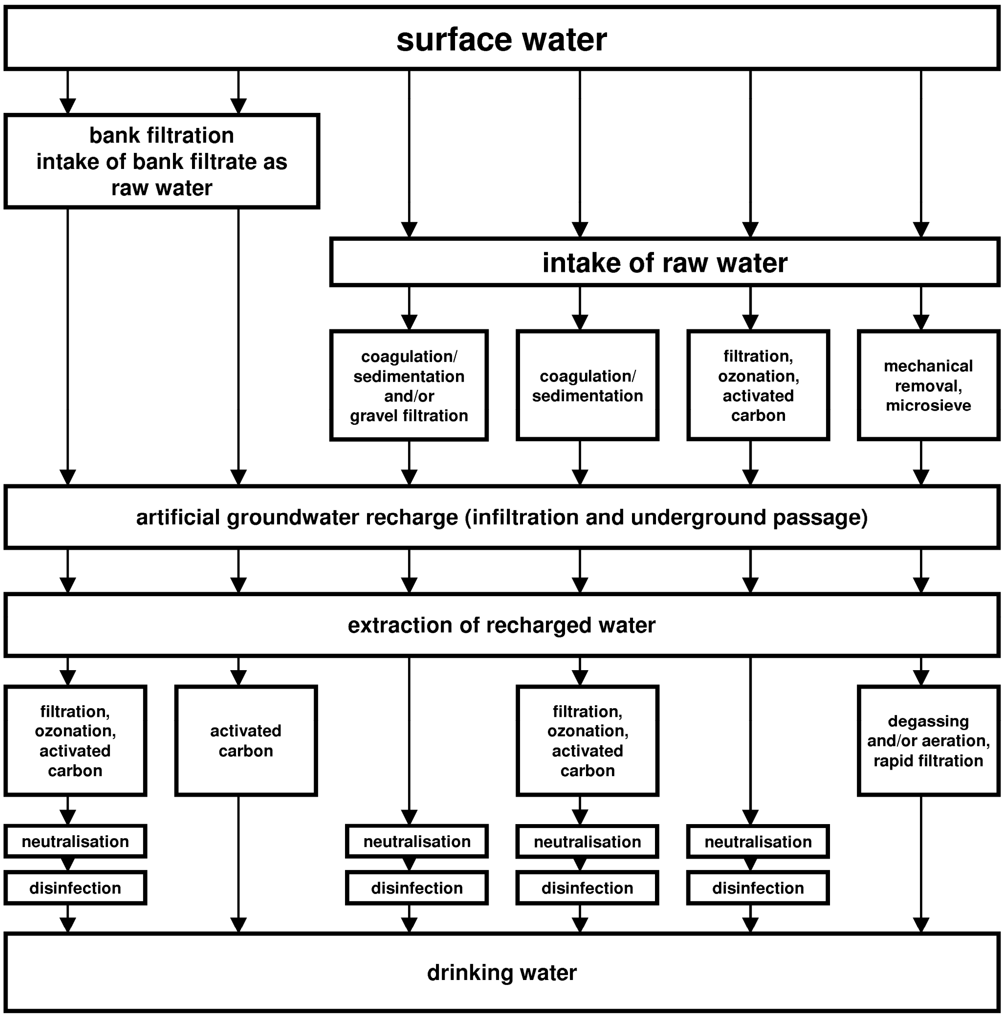

Figure 8 - Possible application of subsurface passage in combination with other treatment techniques (DVGW 2007).

3.1 Neutralisation

Neutralisation is carried out in order to reduce the concentration of carbon dioxide. It is connected with an increase of pH and usually applied prior to disinfection at the end of the treatment chain. An overview on different neutralisation techniques and their impact on water quality is given in Table 4, further details are described in the DVGW Arbeitsblatt W214-1 (DVGW 2005).

Table 4 - Overview on different neutralisation methods and their impact on water quality. Source: DVGW Arbeitsblatt W 214-1 (DVGW 2005)

Technique		Change of *:							
		pH	pH_c **	$K_{S4.3}$ +	$K_{B8.2}$ ++	$c_{(DIC)}$ °	$c_{(Ca^{2+})}$ °	$c_{(Mg^{2+})}$ °	$c_{(Na^{+})}$ °
Aeration		+	+	0	-	-	0	0	0
Filtration through:	$CaCO_3$	+	0	+	-	+	+	0	0
	$CaCO_3$· MgO	+	+	+	-	+	+	+	0
Dosage of:	$Ca(OH)_2$	+	+	+	-	0	+	0	0
	NaOH	+	+	+	-	0	0	0	+
	$Na_2(CO_3)$	+	+	+	-	+	0	0	+

* "+" = increase; "0" = no change; "-" = decrease
** pH_c : saturation pH after reaction with $CaCO_3$
\+ $K_{S4.3}$: acid capacity
++ $K_{B8,2}$: base capacity
° c(x) is the concentration of the respective substance.

3.2 Aeration

Aeration is used to equilibrate the water with the atmospheric gas composition. In drinking water treatment plants this method applies to oxygen, carbon dioxide, methane, hydrogen sulphide, chlorine and volatile organic compounds (Gimbel et al. 2004) . The exchange can be described with Henry's law and depends on the partial pressure of the respective compound in the water and the atmosphere (Atkins 1984). To some extent, ammonia is also stripped from the water but higher removal rates are obtained in rapid sand filters due to the microbial catalysis.

In closed aeration the water is sprayed, in open aeration it flows gravity-driven. Aeration schemes include:

- Diffused aeration: Air bubbles through water.
- Spray aeration: Water is sprayed through air.
- Multiple-tray aeration: Water flows through several trays to mix with air.
- Cascade aeration: Water flows downwards over many steps
- Air stripping: A combination of multiple tray and cascade techniques.

In water treatment plants, non-mechanical aerators are generally used e.g. different stair-types and perforated trays (Mutschmann & Stimmelmayr 1995).

Aeration also enables the oxidation of iron and manganese, which are mobilized in anaerobic aquifers. That is why it is commonly used after subsurface passage. Further details to aeration are given in the DVGW Arbeitsblatt W 214-3 (DVGW 2005).

3.3 Ozonation /Advanced Oxidation Process

Ozone is one of the most powerful disinfectants and oxidants available for water treatment. It has been used in Europe since the early 1900s (Langlais et al. 1991). Ozone should be generated onsite and used immediately as it is rather an instable compound: it has a very short half-life (<30 min) under normal conditions encountered in water treatment (Rice & Netzer 1982).

A high potential (from 10 000 to 30 000 Volts) is applied across some electrodes and converts oxygen to ozone. The generators can be fed from dried air from the atmosphere or from a liquid oxygen system.

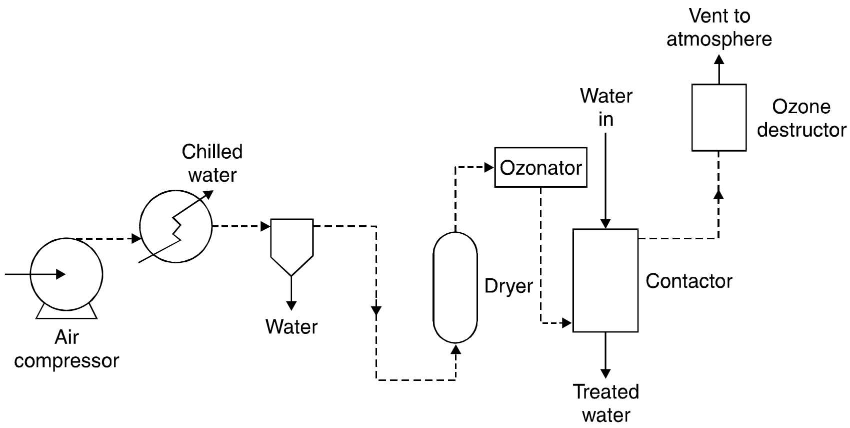

Figure 9 - Scheme of ozone production for drinking water application

Ozone has a disinfecting action against bacteria, viruses and protozoa which is not significantly affected by pH or temperature conditions. Standard doses vary from 1.0 to 2.0 mg O_3/L (Gimbel et al. 2004). Thus, compared to chlorine and chloramines, the contact time and dose required by ozone are lower.

Due to its oxidant action, ozone can also be used for iron and manganese reduction, taste and odor removal, removal of color and reduction of disinfection by-products precursors. Ozonation also converts both, suspended and dissolved natural organic matter (NOM) into smaller compounds, which can be more easily degraded by bacteria (Gilbert 1988). Pre- or posttreatment are required to ensure low particle concentration. Therefore it is an appropriate process to combine with riverbank filtration.

One main disadvantage of ozonation is the formation of brominated DBPs and bromate in water containing bromide (van Gunten & Hoigné 1994). As the ozone dose needs to be much higher (5 to 20 times) for the inactivation of Cryptosporidium than for Giardia, Cryptosporidium is often the limiting parameter. When high ozone exposures are required large amounts of bromate are a possibe consequence. The second main disadvantage is that in contrast to chlorine, the process does not provide any residual disinfectant.

3.4 Filtration systems

3.4.1 Sand filters

In BF & AR systems sand filtration is usually set after aeration or advanced oxidation processes (Grützmacher et al. in prep). In biologically active sand filters methane and hydrogen sulfide are oxidized at the top of the filter, followed by iron oxidation, ammonium oxidation (nitrification) and finally manganese oxidation (Gimbel et al. 2004). Easily biodegradable organic substances can be degraded at the top of the filter, whereas the natural organic material – which is mainly composed of slowly biodegradable humic and fulvic acid – are removed to a very small degree throughout the filter. Sand filters are also used to filter suspended matter, e.g. for removal of colloidal Fe and Mn after aeration.

Down-flow rapid sand filters are the most common types of filters on the market. Typical filtration velocities are in the range of 2 m/h to 10 m/h and they should be backwashed with water with a high velocity (30 m/h) and/or air (Mutschmann & Stimmelmayr 1995). The frequency of the backwashing depends on the influent water quality and the size of the sand material. It is usually in the range of a few days. With insufficient backwashing, progressive clogging of the pore takes place and it leads to a decrease of the hydraulic retention time and the treatment efficiency of the system.

Slow sand filters are operated at filtration velocity below 0.5 m/h (Graham 1988). Such filters are cleaned by mechanical removal and replacement of some centimeters of the top layers. The periodicity of this manual maintenance is in the range of months.

3.4.2 Activated Carbon

The base material of activated carbon can be organic (wood, peat, coconuts, etc.) or fossil (lignite, antracite). The activation is carried out by heating the carbon raw material to 800 – 1000°C in an atmosphere of water vapour and carbon dioxide (Gimgel et al. 2004, Najm et al. 1991). This leads to partial oxidation of the carbon and the development of a fine pore structure. The pore characteristics of activated carbon are presented in Table 5.

Table 5 - Pore characteristics of activated carbon (Arvin et al. 2002)

	Pore diameter (nm)	Pore volume (cm^3/g)	Surface Area (m^2/g)
Micropores	0-2	0.2-0.6	400-900
Mesopores	2-50	0.02-0.1	20-70
Macropores	>50	0.2-0.8	0.5-2

The typical organic chemical contaminant fits into the micropores. Substances with an affinity to absorption in lipid materials are particularly targeted. Activated carbon filtration is an effective process to remove oil and gasoline compounds, chlorinated solvents and a range of pesticides found in groundwater and surface waters (Sontheimer et al. 1988). However, organic colloidal material (humic matter) and inorganic colloidal material (iron and manganese oxides), proteins, carbohydrates and bacteria only fit in the macrospores. Extensive build-up of material in the macropores can plug the entrance to the smaller pores and therefore decrease the adsorption capacity of the system.

Activated carbon also hosts a variety of microorganisms, bacteria and protozoa (Wilcox et al. 1983). This significant biological activity in activated carbon filters reflects the ability to partly degrade some of the organic substances that are adsorbed in the carbon and thereby the bacteria perform a certain regeneration of the carbon.

Activated carbon is used for the adsorption of persistent pollutants, for which no significant degradation through riverbank filtration can be observed. It is commonly used in reactors as granular activated carbon (GAC). Biologically activated carbon is generally required after ozonation to remove ozone by-products and ensure the biostability of the effluent. Powdered activated carbon (PAC) is applied discontinuously if peak loads are detected. It is added directly to the water and has to be removed by filtration.

3.4.3 *Membrane Systems*

Membrane filtration using microfiltration or ultrafiltration (Figure 10) enables the rejection of particles and pathogens but it can not be used for the removal of Total Dissolved Solids (TDS) or salts. Nanofiltration in use for drinking water could be used for softening purposes (Gimbel et al. 2004).

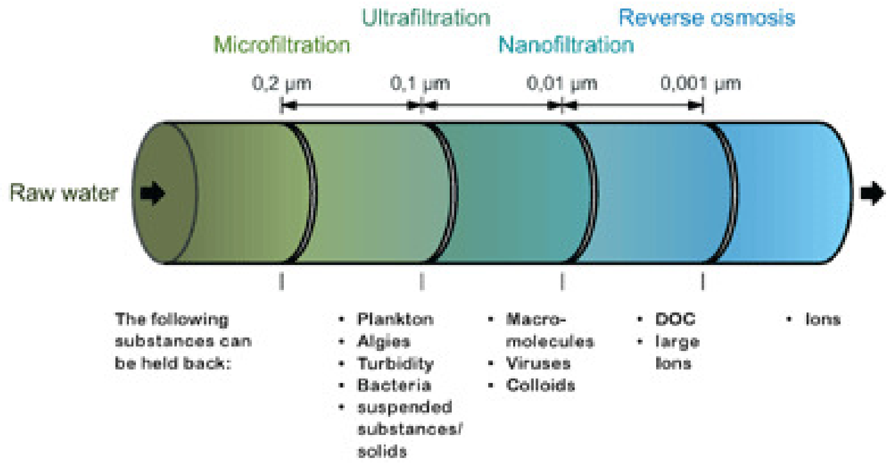

Figure 10: Pore sizes of different membrane systems (RWT GmbH 2010).

Main advantages of this technology include the reliability of consistent effluent quality, the ease of automation of the treatment system and the flexibility in being able to meet future water quality requirements. However, the membrane integrity can still be an issue as well as the cleaning/maintenance requirements and the handling of a concentrated backwash stream (Mulder 1990).

UF and MF membranes have a similar effect to riverbank filtration as they target suspended solids and pathogen. However, subsurface passage as a pre-treatment step would ease the operation and the maintenance of the membrane systems as some fouling materials would be avoided.

3.5 Chlorination

Chlorination has been used in water treatment since the early 1900s as an effective disinfectant for the protection of public health against waterborne diseases (Darnall 1911). It is comparatively inexpensive (C3 & Cfour 2003). Usually a residual concentration is discharged into the distribution system and inhibits regrowth of bacteria.

Chlorine compounds offer good bactericidal and viricidal effects. Three chlorination methods are usually applied:

- Chlorine (as liquefied chlorine gas or as a sodium hypochlorite solution)
- Chloramines
- Chlorine dioxide

Although the use of chlorine is the best known and most widely used method for disinfection, high concentrations lead to taste and odor concerns for the treated water. Moreover, chlorination produces halogenated disinfection by-products, typically chlorinated methanes which show toxic effects to liver and nerves and are potentially genotoxic (Sander et al. 1977).

Those inconveniences are less important when chloramines are used although they are less efficient against microorganisms. Chlorine dioxide can also be used as a disinfecting agent with higher effectiveness regarding inactivation of pathogens and absence of halogenated by-products but its main disadvantage is the higher cost for operation and maintenance. That is why a simple chlorination is usually set after underground passage (Grützmacher et al. in prep.).

Though the previously described treatment techniques, such as underground passage or ozonation provide sufficient removal of microorganisms, usually chlorination is provided as last treatment step in order to inhibit regrowth in the distribution system.

Chlorination is sometimes used as water pre-treatment for artificial ground water recharge. It decreases microbial activity and clogging and thus leads to more infiltration. Many disinfection byproducts are removed during subsurface passage (Grützmacher et al. in prep).

4 Post-Treatment Recommendations for the Delhi Field Sites

The water quality encountered at the three field sites renders post-treatment necessary, if bank filtrate is to be used for drinking water purposes. In the following chapters we present some recommendations for the different sites.

4.1 Palla Field Site

During drinking water production fluoride is usually removed by activated alumina filters – which are manufactured from aluminium hydroxide by dehydroxylating them into highly porous materials. They can efficiently reduce fluoride levels due to their adsorption properties. The amount of fluoride leached from the filtered water depends on how long the water is in contact with the alumina filter media (Figure 11). Enhanced efficiency is observed at lower temperatures and pH. Activated alumina, when used as a fluoride filter, can be regenerated by a solution of lye (sodium hydroxide; NaOH), sulfuric acid (H_2SO_4), or alum ($KAl(SO_4)_2$).

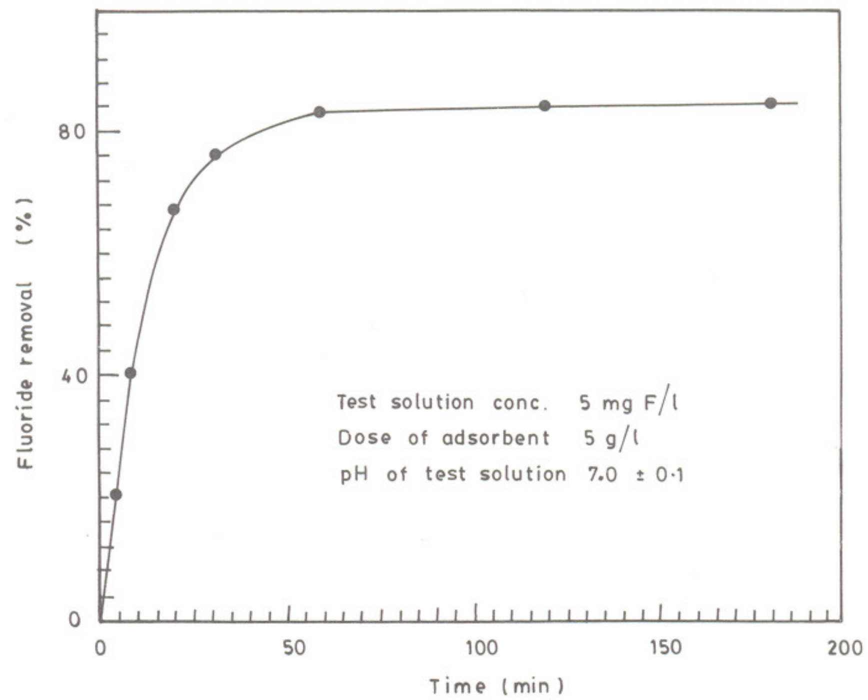

Figure 11- Removal of fluoride by activated alumina (M. Srimurali 2008)

4.2 Nizamuddin Field Site

4.2.1 Extensive conventional wastewater treatment

Due to its high concentration in ammonia, the water at Nizamuddin field site would normally not be used for water treatment purposes. Thus, considering any post-treatment option in Nizamuddin would require adequate wastewater technologies. Different options are here envisaged.

Biological treatment with aeration (+ polishing step)

In conventional wastewater schemes, nitrogen is removed through nitrification/denitrification processes. This 2-step removal is based on biological activity under aerobic/anaerobic conditions.

1st Step: Nitrification (aerobic):

$NH_3 + CO_2 + 1.5\ O_2 + \text{Nitrosomonas} \rightarrow NO_2^- + H_2O + H^+$

$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$

$NO_2^- + CO_2 + 0.5\ O_2 + \text{Nitrobacter} \rightarrow NO_3^-$

$NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$

2nd Step: Denitrification (anaerobic):

Denitrification occurs in anaerobic conditions as micro-organisms use nitrate as substrate for respiration.

A polishing step such as activated carbon or membrane filtration (UF/NF) might be necessary to optimise and reduce the NH_4 content.

Biofiltration with aeration

New techniques have been developed in order to combine nitrification/denitrification processes in one step, such as the BIOSTYR® process which consists of upflow filtration through a submerged and floating fine granular medial called BIOSTYRENE. Air is injected either to the base of the bed or into the media itself (Figure 12). In the latter case, the filter can simultaneously nitrify and denitrify. It is capable of eliminating different biodegradable pollutants: BDOC, suspended solids (SS), ammonium (NH_4) and nitrate (NO_3). The bacteria present in the effluent to be treated attach themselves to the BIOSTYRENE that acts as a filter. The pollution is broken down into cellular material, which is retained in the filtering bed by physical retention.

Filtration takes place in a direction that compacts the media rather than expanding it, thus enhancing the capture of the suspended material.

Periodic counter-current washing eliminates excess biomass and suspended solids filtered, without passing it through the whole bed. Downward flushing evacuates residues by the shortest route out of the bed, and the direction that the particles fall.

The BIOSTYRENE media is retained by the cell roof, which is fitted with nozzles (removable from the top face) that are only in contact with purified water and easy to access.

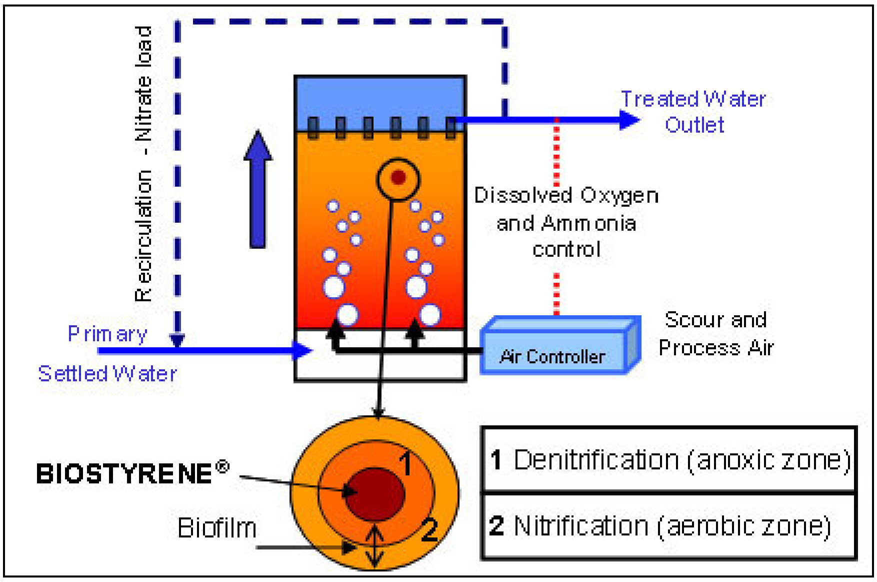

Figure 12: Biostyr Process (VEOLIA WATER Solutions&Technology 2010).

4.2.2 OBM Process

Based on the development of multi-barrier treatment trains, new possibilities are envisaged to target the removal of NH_4. As previously mentioned, a biological treatment/filtration with a follow-up polishing step could be designed for the Nizamuddin case. Within the framework of TECHNEAU WA2 the so-called OBM process was developed, comprising "chemical oxidation + biological oxidation + membrane filtration". This process could be applied as post-treatment to the Nizamuddin field site. Figure 13 presents the concept of this multi-barrier treatment and possible effects.

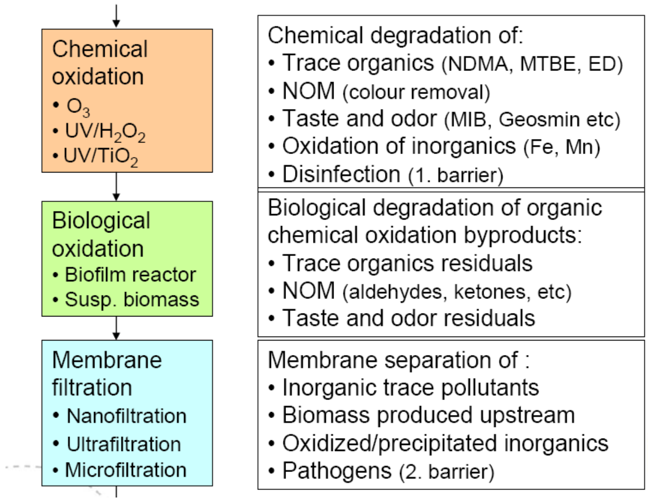

Figure 13 - The concept of OBM (Azrague et al. 2008).

The removal of ammonium could take place at 2 different stages (Figure 14):

- during the oxidation/ozonation step, depending on the pH and the bromide content, ammonia could be eliminated.
- during the bioreactor step, ammonium is to be removed once the organic load is degraded.

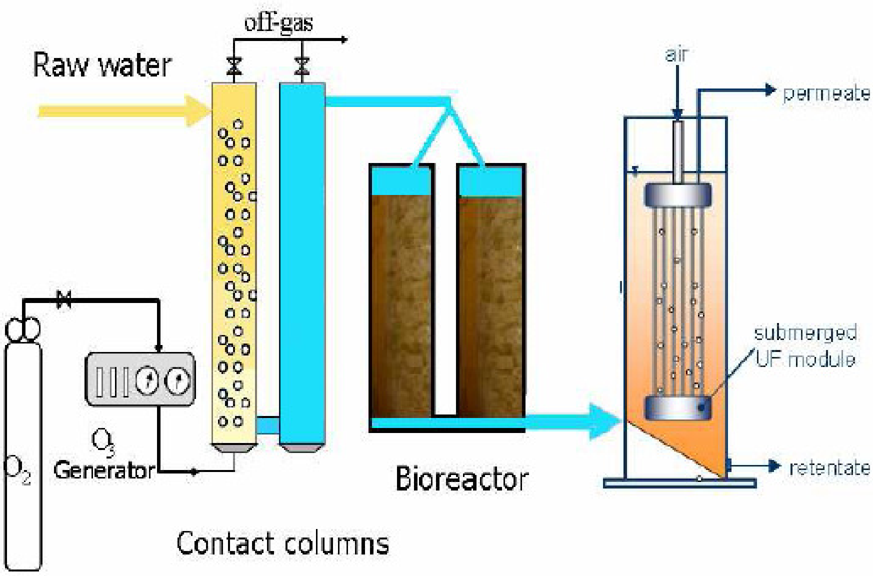

Figure 14 - OBM Scheme (Azrague et al. 2008)

As the OBM process is currently being developed within TECHNEAU WA2 (Water Treatment). A more detailed study on its application to Delhi / Nizamuddin is planned within TECHNEAU WA7 (Case Studies) in the frame of applying the different tools and technologies of the project to practice.

4.3 Najarfgarh Field Site

In order to deal with the water salinity in Najafgarh, a reverse osmosis unit would be necessary. This membrane process is very energy-intensive as it forces the raw water at high pressure through a membrane with small pores eliminating larger molecules (see Figure 10). However, using bankfiltrate instead of usual seawater as raw water may require a lower pressure – i.e. less energy.

The management of the resulting brine would also be an important issue. A serious integrated water resources management would be necessary if desalination processes have to be implemented in Najafgarh.

5 Perspectives and Conclusion

The three investigated RBF sites in Delhi have distinctive geographical locations and contamination exposures. For each of them, critical water parameters were identified that present a challenge with regards to drinking water production. As shown in Table 6, different treatment technologies are envisaged. For Palla and Najafgarh, one specific water component (fluoride and salinity, respectively) require targeted treatment. However, for Nizamuddin, whose surface water is highly exposed to contamination from poorly treated waste water, theoretical post-treatment options (presented in chap 3) are no longer efficient and extensive conventional wastewater treatment is recommended.
One other possible option for Nizamuddin is the Oxidation / Biofiltration / Membrane technology (OBM process) developed by NTNU and SINTEF within the TECHNEAU project and a specific report on its application to Delhi is planned within TECHNEAU WP7.9.

Table 6: Summary of critical parameters and possible treatment schemes for the three field sites in Delhi.

Palla	uncritical (except F-)	■ (Activated Alumina)
Nizamuddin	As, Fe, Mn, F and NH4 critical in shallow wells	■ Extensive conventional treatment necessary ■ Oxidation + Biofilter + Membrane (OBM)
Najafgarh	groundwater salinity	■ Desalination via Reverse Osmosis

This report shows the theoretical post-treatment options for river bank filtration sites in Delhi. The strong technological requirements for Nizamuddin and Najafgarh seem inadequate to be currently implemented. The priority in Delhi would be to develop an integrated water and wastewater management, in order to reduce contamination in the surface water and thereby lower the technological requirements for drinking water production.

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