Testing protocol for safe water solutions (D4.3 Updated)

Authors: Patrick Smeets (KWR)
Contributor (s): Adva Zach Maor (Amiad), Yehuda Shiva (ADIN), Benedikt Aumeier (RWTH), Alexander Wolf (SSP)
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CONTENTS

TERMINOLOGY AND ABBREVIATIONS

AC	Activated Carbon
BIS	Bureau of Indian Standards (refers to Drinking Water Specification)
BOD	Biological Oxygen Demand
CFU	Colony Forming Units (measure for number of bacteria)
COD	Chemical Oxygen Demand
DSS	Decision Support System
DALY	Disability Adjusted Life years
FIB	Faecal Indicator Bacteria
HCH	Hexachlorocyclohexane
HWT	Household Water Treatment
MPN	Most Probable Number (estimate of number of bacteria)
NSF	NSF International
NTU	Normalised Turbidity Units
OD	Optical Density
PAH	Polycyclic Aromatic Hydrocarbon
PFU	Plaque Forming Units (measure for number of viruses)
POE	Point Of Entry system
POP	Persistent Organic Pollutant
POU	Point Of Use system
QMRA	Quantitative Microbial Risk Assessment
RO	Reverse Osmosis (membrane filtration)
SOC	Synthetic Organic Compounds
SAC	Specific Absorption Coefficients
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UF	Ultra Filtration (membrane filtration)
USEPA	United States Environmental Protection Agency
UV	Ultra Violet
VOC	Volatile Organic Compounds
WHO	World Health Organisation
WSP	Water Safety Plan

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1 PUBLISHABLE EXECUTIVE SUMMARY

This report discusses the water quality testing of the Water4India solutions that will be pilot tested. Based on existing protocols for testing water treatment technologies a systematic approach was developed for testing solutions in the Water4India project. This approach was applied to the two planned pilot plant tests and resulted in sampling plans. In addition the methods for testing existing commercial home treatment systems are described. The report forms the basis for water quality monitoring in work package 7 *Technological deployment and validation of the selected solutions in India* of the Water4India project.

The frameworks for testing water treatment systems are available from USEPA, WHO and NSF focus on commercially available systems for point of use (POU) or point of entry (POE) to be tested in a controlled environment. They require (and allow for) artificially created challenge waters with defined levels of contaminants. The pilot testing in Water4India will be on natural water sources and therefore the source water quality is less controlled. The challenge water quality in the protocols provides a reference to check if natural water is providing the same level of challenge. The protocol for QMRA of full scale drinking water systems in the Netherlands was used as a basis for testing microbial efficacy of the solutions in a real world environment. The protocol and the experiences with implementation provided a basis for the types of analysis, the number of samples and their sensitivity to get meaningful results from the tests.

Water quality monitoring will address both the contaminant challenges and the operational water quality challenges of the pilot system. Contaminant challenges are those parameters defined in Indian BIS water quality standards that need to be met. Operational water quality challenges are the parameters that can impact treatment efficacy and stability even though they may not be regulated. Both the contaminant and operational challenges were determined based on the raw water source and the types of treatment processes. Already existing data on raw water quality or treatment efficacy was used to predict expected water quality results and to set treatment targets that are needed to reach BIS requirements.

Besides long term monitoring, a short intensive monitoring period was proposed in which samples will be collected for more advanced analysis that are too complex and costly to perform over a longer period. The monitoring of pathogenic microorganisms during a short period provides essential data to better interpret the long term monitoring of indicator organisms for health risk assessment. Also treatment may remove pathogens to a different extend than the indicator organisms.

The Amiad pilot will treat river water pre-treated by aeration, alum dosing and coagulation. The pilot will consist of shallow granular media pre-filters, fiber filtration and in-line chlorine dosing. Monitoring will focus on the effect of fiber filtration for removal of particles and pathogenic protozoa like *Cryptosporidium* and *Giardia*. These pathogens are expected to be present in river water and are highly resistant to chlorine disinfection. Fiber filtration is potentially more effective for removing these pathogens than conventional rapid sand filtration. This assessment will require advanced water quality analyses that can only be performed for a short period. Combined with the long term monitoring of indicator bacteria in the raw water as a proxy for the level of pathogens, the findings can be translated

to long term effect on treated water quality and health. The performance of particle removal will be assessed by continuous on-line monitoring of turbidity and testing particle removal.

The Solarspring pilot will treat water from a shallow bore well with pre-filtration, ultrafiltration, activated carbon filtration and UV disinfection. High iron content and turbidity shown in initial samples will need to be removed by the pilot. This will be monitored by sample analysis on site. Initial water quality analysis shows a high level of faecal contamination. This may be caused by the drilling of the well. If weekly sampling for indicator bacteria confirms the presence of continuous faecal contamination, an intensive advanced microbial water quality analysis will also be performed for this system. Integrity of the membrane filtration and consistent performance of the UV disinfection will be essential for validating microbial performance of the system on the long term. Membrane integrity tests will be performed monthly. UV irradiation will be monitored on-line with a UV sensor.

In the updated version of the report, feedback from the testing in work package 7 was included. This showed that various planned monitoring strategies could not be performed due to technical, logistic and administrative issues, which are inherent to working in rural India. However through flexibility and creativity much of the intended monitoring outcomes were achieved. In addition, knowledge exchange and capacity building was achieved through working with the Bhavan laboratory for *Cryptosporidium* and *Giardia* analysis. Innovative challenge testing using fluorescent beads in the field were also successful.

Results from monitoring the pilots are presented in report D7.2 and evaluated in report D7.3. This evaluation of the results will feed into the risk assessment described in Water4India deliverable 4.4 and into the decision support system developed in work package 6.

2 INTRODUCTION

2.1 Purpose of this document

Within the Water4India project several technologies for water treatment will be studied. In WP7 *Technological deployment and validation of the selected solutions in India*, two pilot systems will be deployed and validated in India. This document is basis for the water quality aspects in T7.3 *Monitoring and overall performance evaluation of the solutions*. Goal is to demonstrate if the solutions contribute to providing drinking water that complies with the BIS standards and could provide additional benefits with respect to health and consumer satisfaction. Water quality standards in India (BIS) and the current drinking water quality situation were discussed in Water4India deliverables D2.2 *Application of framework for selected region*, D3.5 *Report on feasibility of the proposed technological solutions in case studies* and D4.2 *Monitoring plans*. Based on evaluation the health relevance of specific contaminants in D4.2 key criteria for water quality was selected. Apart from direct health significance, parameters that for the acceptability of the water for consumption, such as colour, turbidity, odour and taste, will also be evaluated. By making safe water attractive, consumers will tend to select the safely treated water for drinking.

The goal of the document is to provide testing protocols that allow testing of the solutions for these aspects within the constraints of the practical pilot situations in India.

2.2 Structure of the deliverable

In Chapter 3 an inventory of existing treatment evaluation frameworks is provided as a basis for the Water4India framework presented in Chapter 4. There the general water quality challenges of treating water in India are presented and target performances of treatment technologies are set. Chapters 5, 6 and 7 discuss the Water4India pilot systems and tested home treatment systems. The general Water4India water treatment testing framework was applied to develop actual testing protocols for each of these specific conditions. Finally general conclusions are drawn in Chapter 8.

2.3 Relationship to the project objectives

The objective of the Water4India project is to provide solutions to improve drinking water quality and to support decisions on technology selection with a decision support system (DSS). Several water treatment solutions are tested in pilots to determine their feasibility in the Indian rural conditions. Evaluation of water treatment performance is an important aspect of the pilot systems. This report provides testing protocols to assess this performance and the conditions under which this was achieved. Contribution to specific project objectives as numbered in the DoW:

Objective 2: *Assess and quantify currently applied technologies to produce drinking water at small scale level. Its integration with different solutions directed to address water shortage will be considered. The technology evaluation will include all relevant factors, i.e. efficiency, robustness (to cope with climate change impacts), operability, social, environmental and economic factors.* **Contribution**: The testing protocols in this report were developed to assess and quantify the efficiency of the technologies to produce drinking water at small scale level.

Objective 4: *Assess and quantify existing technologies for water quality monitoring to evaluate the quality of raw and treated water, and also the composition of waste water. Special attention will be given to pathogens, studying the quality of water by state-of-the-art methods such as Quantitative Microbial Risk Assessment within the framework of Water Cycle Safety Plans based on good housekeeping*. **Contribution**: The testing protocols developed in this report take into account the required removal of pathogens in the framework of QMRA, rather than just the removal of faecal indicator organisms.

Objective 6: *Demonstrate the selected technologies in sites showing different scenarios. The test sites will be selected according to their anticipated water scarcity, but an assessment on their hydrological situation and water availability will be also demonstrated. These will assess the efficiency of the DSS applied at the selected region.* **Contribution**: This report provides protocols to assess the improvement of water quality by the demonstrated technologies.

2.4 Relationship to other deliverables and tasks

The protocols were developed to be used in T7.3 *Implementation of technologies*. The results will feed into T6.2 where appropriate technologies are evaluated. The results also provide valuable experience to improve the work in T4.2 *Monitoring plans for India*. Monitoring of the performance of actual full-scale treatment plants should be part of a national monitoring strategy, next to monitoring of the produced water. Monitoring each barrier in a supply system is more in line with the Water Safety Plan approach for drinking water and helps to protect against risks that cannot directly be monitored in the drinking water at relevant levels, such as pathogen occurrence. Ideally this is done in a quantitative framework. The monitoring results therefore also feed into T4.4.*A Quantitative microbial risk assessment approach for India*. Lessons from the pilot systems can thus be incorporated in a broader QMRA framework.

2.5 Contributions of partners

KWR had the responsibility to prepare this document and has performed much of the research into testing protocols for water treatment technologies. KWR was also assessed the water quality challenges at the pilot sites. Amiad has provided detailed information about the fiber filtration pilot, the local conditions and performance of the treatment process in previous tests as a basis for Chapter 5. Adin has contributed by collecting additional water quality data and information about performance of various water treatment processes in Chapter 4. Both Amiad and Adin contributed to development of the testing framework in Chapter 4. RWTH and Solarspring provided detailed information about their pilot and home treatment systems for Chapter 6 and Chapter 7, although they were not officially involved in this task according to the DoW.

2.6 Changes in the udated version

The original report D4.3 was updated as a part of Task 4.6 (D4.5 Updated versions of D4.1, D4.2 and D4.3). Goal of the update is to include feedback from the field testing of Water4India solutions in work package 7 and possibly new scientific insights. We have updated the document by including the actually performed monitoring and tests in WP7. We also updated the estimation of raw water quality based on newly acquired data in India and the Netherlands. The results of monitoring are reported in D7.2.

3 TREATMENT EVALUATION FRAMEWORKS

3.1 Existing frameworks for testing water treatment

3.1.1 WHO Evaluating household water treatment options

The World Health Organisation (WHO) has developed a framework for testing household water treatment systems with respect to microbial water quality (WHO 2011). The document provides a basis to evaluate treatment performance by setting health based performance targets as a basis for treatment evaluation. A level of 10^{-6} DALY (Disability adjusted life year) is used as a reference level for tolerable risk. Based on assumed raw water concentrations, the required removal of pathogens to achieve this risk target was determined using QMRA (quantitative microbial risk assessment). This was performed for *Campylobacter* jejuni, *Cryptosporidium* parvum and rotavirus as representatives of pathogenic bacteria, protozoa and viruses. Since these organisms occur in different concentrations in source water and their health impact varies, this resulted in different levels of treatment efficacy required to achieve the health target. Treatments that achieve this are considered 'highly protective'. A treatment that achieves 10^{-4} DALY is considered protective, and a good way forward to achieving the end goal. If this is only achieved for two of the three organisms, the treatment can be considered as an 'interim' option to improve water safety. The approach and required treatment efficacies are summarised in Figure 3.1.

This WHO approach cannot be used directly for evaluation of the solutions in the Water4India project. The document only addresses microbial risk, whereas several chemical risks and aesthetic issues also need to be addressed. Secondly it is focussed on household water treatment (HWT). A HWT is typically a 'one step solution' (which may contain a combination of processes) that needs to provide drinking water from any source. The solutions in Water4India are generally just one of many barriers in a treatment system. Therefore it is not designed to achieve the total removal in just one step. Therefore these solutions will be evaluated in the context that they are meant to operate. Still the WHO line of thinking will be applied for the evaluation.

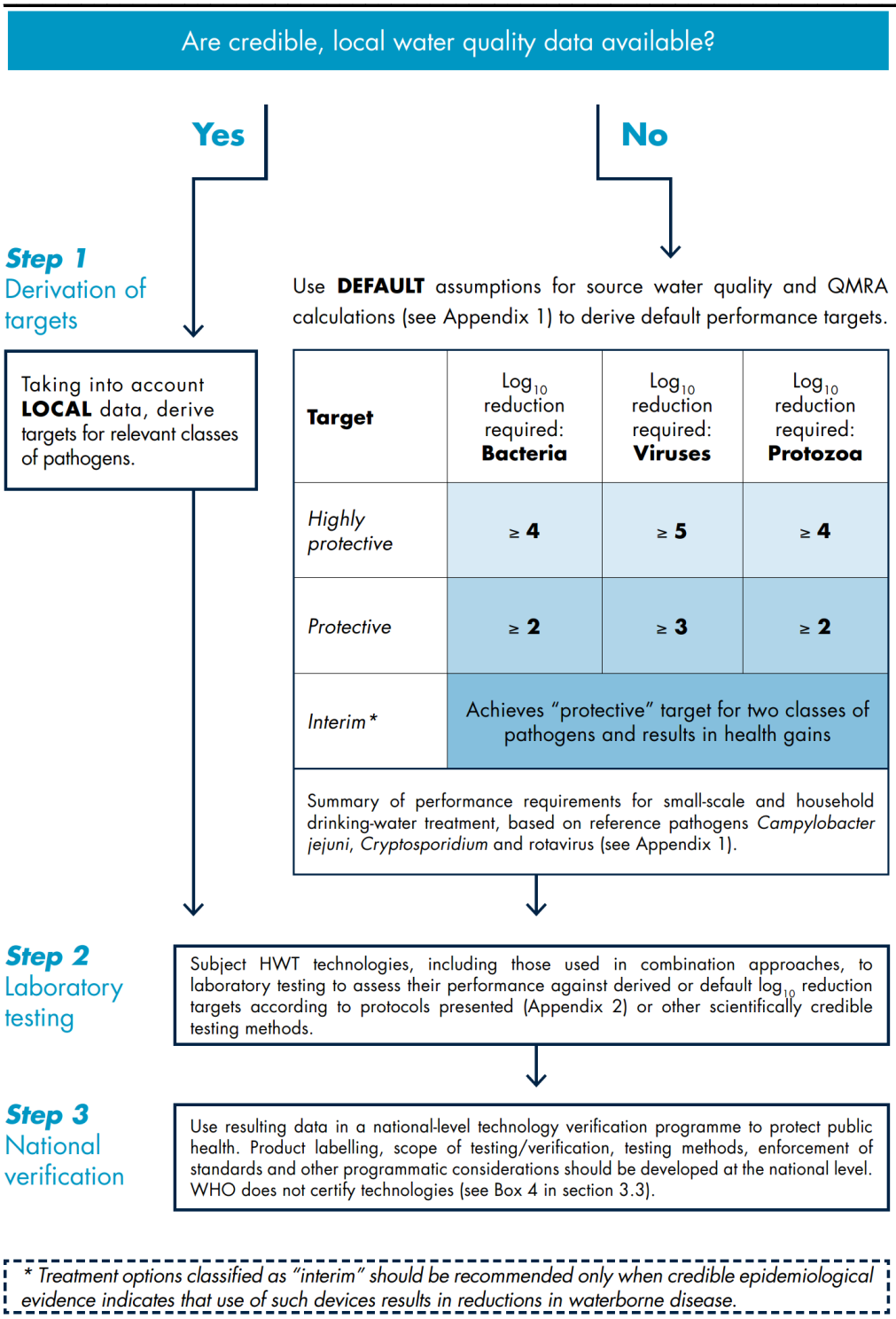


Figure 3.1 WHO approach to assess household water treatment systems

3.1.2 USEPA 1987 Guide standard and protocol for testing microbiological water purifiers

The protocol is aimed at small scale filters for use in homes, campers, boats etcetera. The protocol does not address removal of chemicals but does address the release of chemicals by the treatment, such as silver or a disinfectant residual. The required treatment efficacy is shown in Figure 3.2. The treatment targets were based on the provisional targets for absence of indicator bacteria in 100 ml and pathogens in 100 l and the limited data available on the occurrence of these organisms in the source waters. The challenge concentrations were selected such that the required treatment efficacy could be assessed in smaller volumes.

The protocol describes the culturing methods and testing procedures for filtration, chemical disinfection and UV disinfection processes. Typically one challenge sample and four treated samples are required.

Organism	Influent Challenge	Minimum Required Reduction	
		Log	%
Bacteria: *Klebsiella terrigena* (ATCC-33257	10^7/100 mL	6	99.9999
Virus: a. Poliovirus 1 (LSc) (ATCC-VR-59 and, b. Rotavirus (Wa or SA-11) (ATCC-VR-899 or VR-2018)	1 x 10^7/L; 1 x 10^7/L	4	99.99**
Cyst (Protozoan): *Giardia**** a: *Giardia muris* or *Giardia lamblia* or	10^6/L	3	99.9
b. As an option for units or components based on occlusion filtration: particles or spheres, 4-6 microns	10^7/L	3	99.9

Figure 3.2 Challenge concentrations and required log reduction according to USEPA (1987)

3.1.3 Netherlands Inspectorate guideline Assessment of the microbial safety of drinking water

The Dutch Inspectorate guideline Assessment of the microbial safety of drinking water (VROM 2005) is a protocol to assess drinking water systems in practice. The quantification of pathogens in the source water and the health based target for pathogens in drinking water result in site-specific requirements for treatment efficacy. Treatment efficacy is assessed by monitoring indicator organisms before and after treatment steps. No spiking for challenge testing is performed at the full scale. Figure 3.3 provides an overview of the required treatment efficacy at various surface water treatment systems to achieve the health target of 1 infection per 10.000 persons per year (Smeets et al. 2009).

The guideline requires 6 to 26 pathogen measurements in source water, depending on system size. In additions 3 to 9 samples during critical conditions that could lead to peak concentrations are required.

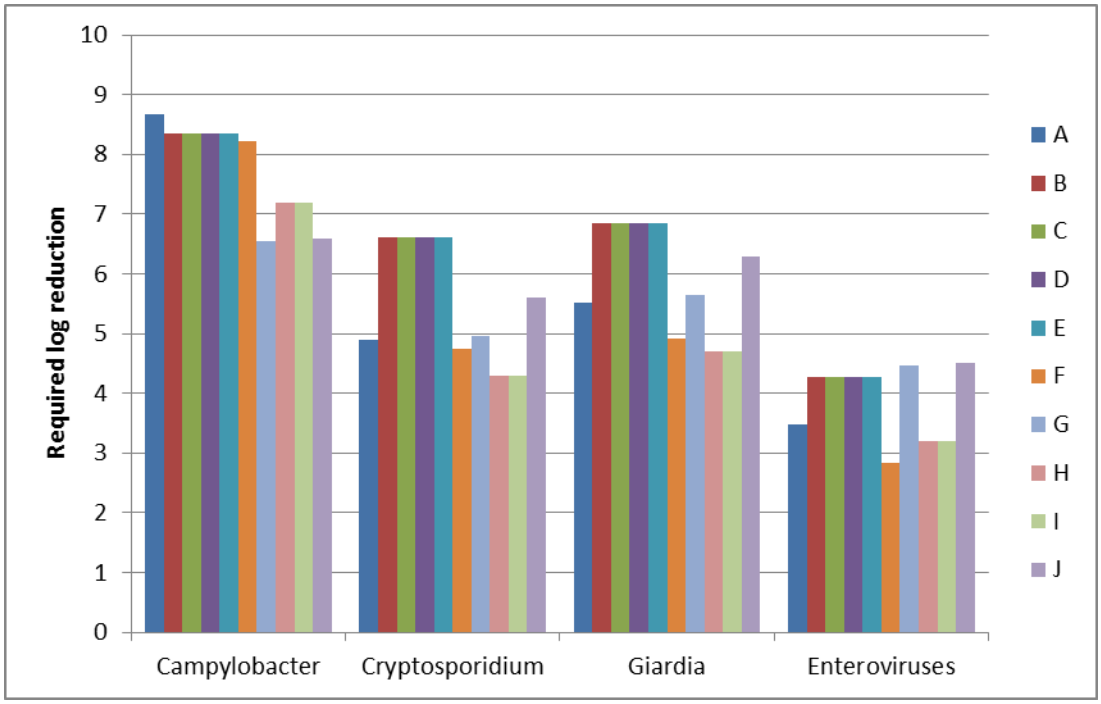


Figure 3.3 Required log reduction at treatment sites A to J to achieve health based target in The Netherlands (Smeets et al. 2009)

The guidelines have defined the indicator organisms in Table 3-1 to represent the removal of relevant pathogens. Sufficient samples are required for treatment monitoring, however numbers are not specified. Generally weekly to monthly samples are used for this.

Table 3-1 Indicator organisms to assess treatment efficacy for index pathogens (VROM 2005)

	Bacteria	Protozoan parasites	Viruses
Index pathogens	*Campylobacter*	*Cryptosporidium* and *Giardia*	Enteroviruses
Indicator organisms	*E. coli*	SSRC	Somatic coliphages and F+ RNA phage

3.1.4 NSF/ANSI 53: Drinking Water Treatment Units - Health Effects

Description according to USEPA (2006): "*This standard applies to both POU and POE units. The substances covered by this standard include asbestos, cysts (based on the use of microspheres or Cryptosporidium parvum oocysts), barium, cadmium, hexavalent and trivalent chromium, copper, fluoride, lead, mercury, nitrate, nitrite, selenium, radon, turbidity, and total trihalomethanes. A number of volatile organic compounds (VOCs), such as synthetic organic compounds (SOCs), chlordane, toxaphene, and polychlorinated biphenyls (PCBs), are also covered. Typically, the testing done by NSF International requires that to be certified, the device must reduce the influent challenge concentrations to below the maximum permissible concentration of a contaminant in drinking water as established by a recognized regulatory agency, such as the EPA or Health Canada. A given product may be certified*

under this standard for removal of some of the challenge substances. For example, activated carbon filters covered by this standard are not intended to be used with water that is microbiologically unsafe or of unknown quality unless there is adequate disinfection before and after the carbon treatment component. Products that use activated carbon adsorption would be certified in a way that indicates it has achieved acceptable reduction regarding a partial list of the substances cited above. In other words, a product may be certified under this standard to remove lead and asbestos, but not VOCs." Table 3-2 provides an overview of the substances that are tested and the (minimum) challenge concentrations applied in tests. It is not feasible to test for all these parameters within the scope of the Water4India project, but they provide a reference for the key contaminants identified in the project.

Table 3-2 Challenge and target contaminant level in NSF/ANSI 52 test (Multipure.com 2015, AquaRO)

Substance	Percent Reduction**	Influent challenge concentration (mg/L unless specified)	Maximum permissible product water concentration (mg/L unless specified)
ALACHLOR*	>98%	0.050	0.001
ARSENIC (pentavalent As (V); As (+5); arsenate @ 6.5 pH***	>99.9%	0.050 +/- 10%	0.010
ARSENIC (pentavalent As (V); As (+5); arsenate @ 8.5 pH***	>95.8%	0.050 +/- 10%	0.010
ASBESTOS	>99.9%	10^7 to 10^8 fibers/L; fibers greater than 10 micrometers in length	99% reduction requirement
ATRAZINE*	>97%	0.100	0.003
BENZENE*	>99%	0.081	0.001
BROMODICHLOROMETHANE (TTHM)*	>99.8%	0.300	0.015
BROMOFORM (TTHM)*	>99.8%	0.300	0.015
CARBOFURAN (Furadan)*	>99%	0.19	0.001
CARBON TETRACHLORIDE*	98%	0.078	0.0018
CHLORDANE	>99.5%	0.04 +/-10%	0.002
CHLOROBENZENE (Monochlorobenzene)*	>99%	0.077	0.001
CHLOROPICRIN*	99%	0.015	0.0002
CHLOROFORM (TTHM)* (surrogate chemical)	>99.8%	0.300	0.015
Cryptosporidium (CYST)	99.95%	minimum 50,000/L	99.95% reduction requirement
CYST (Giardia; Cryptosporidium; Entamoeba; Toxoplasma)	99.95%	minimum 50,000/L	99.95% reduction requirement
2, 4-D*	98%	0.110	0.0017

DBCP (see Dibromochloropropane)*	>99%	0.052	0.00002
1,2-DCA (see 1,2-DICHLOROETHANE)*	95%	0.088	0.0048
1,1-DCE (see 1,1-DICHLOROETHYLENE)*	>99%	0.083	0.001
DIBROMOCHLOROMETHANE (TTHM; Chlorodibromomethane)*	>99.8%	0.300	0.015
DIBROMOCHLOROPROPANE (DBCP)*	>99%	0.052	0.00002
o-DICHLOROBENZENE (1,2 Dichlorobenzene)*	>99%	0.080	0.001
p-DICHLOROBENZENE (para-Dichlorobenzene)*	>98%	0.040	0.001
1,2-DICHLOROETHANE (1,2-DCA)*	95%	0.088	0.0048
1,1-DICHLOROETHYLENE (1,1-DCE)*	>99%	0.083	0.001
CIS-1,2-DICHLOROETHYLENE*	>99%	0.170	0.0005
TRANS-1,2- DICHLOROETHYLENE*	>99%	0.086	0.001
1,2-DICHLOROPROPANE (Propylene Dichloride)*	>99%	0.080	0.001
CIS-1,3- DICHLOROPROPYLENE*	>99%	0.079	0.001
DINOSEB*	99%	0.170	0.0002
EDB (see ETHYLENE DIBROMIDE)*	>99%	0.044	0.00002
ENDRIN*	99%	0.053	0.00059
Entamoeba (see CYSTS)	99.95%	minimum 50,000/L	99.95% reduction requirement
ETHYLBENZENE*	>99%	0.088	0.001
ETHYLENE DIBROMIDE (EDB)*	>99%	0.044	0.00002
Furadan (see CARBOFURAN)*	>99%	0.19	0.001
Giardia Lamblia (see CYST)	>99.95%	minimum 50,000/L	99.95% reduction requirement
HALOACETONITRILES (HAN)*			
BROMOCHLOROACETONITRILE	98%	0.022	0.0005
DIBROMOACETONITRILE	98%	0.024	0.0006
DICHLOROACETONITRILE	98%	0.0096	0.0002
TRICHLOROACETONITRILE	98%	0.015	0.0003
HALOKETONES (HK):*			
1,1-DICHLORO-2-PROPANONE	99%	0.0072	0.0001
1,1,1-TRICHLORO-2-PROPANONE	96%	0.0082	0.0003
HEPTACHLOR*	>99%	0.25	0.00001
HEPTACHLOR EPOXIDE*	98%	0.0107	0.0002
HEXACHLOROBUTADIENE (Perchlorobutadiene)*	>98%	0.044	0.001
HEXACHLOROCYCLOPENTADIENE*	>99%	0.060	0.000002
LEAD (pH 6.5)	>99.3%	0.15 +/- 10%	0.010
LEAD (pH 8.5)	>99.3%	0.15 +/- 10%	0.010
LINDANE*	>99%	0.055	0.00001
MERCURY (pH 6.5)	>99%	0.006 +/- 10%	0.002
MERCURY (pH 8.5)	>99%	0.006 +/- 10%	0.002
METHOXYCHLOR*	>99%	0.050	0.0001
Methylbenzene (see TOLUENE)*	>99%	0.078	0.001
Monochlorobenzene (see CHLOROBENZENE)*	>99%	0.077	0.001
MTBE (methyl tert-butyl ether)	>96.6%	0.015 +/- 20%	0.005
POLYCHLORINATED BIPHENYLS (PCBs , Aroclor 1260)	>99.9%	0.01 +/- 10%	0.0005
PCE (see TETRACHLOROETHYLENE)*	>99%	0.081	0.001
PENTACHLOROPHENOL*	>99%	0.096	0.001
Perchlorobutadiene (see HEXACHLOROBUTADIENE)*	>98%	0.044	0.001
Propylene Dichloride (see 1,2 -DICHLOROPROPANE)*	>99%	0.080	0.001
RADON	>94.9%	4000 ± 1000 pCi/L	300 pCi/L
SIMAZINE*	>97%	0.120	0.004

Silvex (see 2,4,5-TP)*	99%	0.270	0.0016
STYRENE (Vinylbenzene)*	>99%	0.150	0.0005
1,1,1-TCA (see 1,1,1 - TRICHLOROETHANE)*	95%	0.084	0.0046
TCE (see TRICHLOROETHYLENE)*	>99%	0.180	0.0010
1,1,2,2- TETRACHLOROETHANE*	>99%	0.081	0.001
TETRACHLOROETHYLENE*	>99%	0.081	0.001
TOLUENE (Methylbenzene)*	>99%	0.078	0.001
TOXAPHENE	>92.9%	0.015 +/- 10%	0.003
Toxoplasma (see CYSTS)	99.95%	minimum 50,000/L	99.95% reduction requirement
2,4,5-TP (Silvex)*	99%	0.270	0.0016
TRIBROMOACETIC ACID*		0.042	0.001
1,2,4 TRICHLOROBENZENE (Unsymtrichlorobenzene)*	>99%	0.160	0.0005
1,1,1-TRICHLOROETHANE (1,1,1-TCA)*	95%	0.084	0.0046
1,1,2-TRICHLOROETHANE*	>99%	0.150	0.0005
TRICHLOROETHYLENE (TCE)*	>99%	0.180	0.0010
TRIHALOMETHANES (TTHM) (Chloroform; Bromoform; Bromodichloromethane; Dibromochloromethane)	>99.8%	0.300	0.015
TURBIDITY	>99%	11 +/- 1 NTU	0.5 NTU
Unsym-Trichlorobenzene (see 1,2,4-TRICHLOROBENZENE)*	>99%	0.160	0.0005
Vinylbenzene (see STYRENE)*	>99%	0.150	0.0005
XYLENES (TOTAL)*	>99%	0.070	0.001

3.1.5 NSF/ANSI 42: Drinking Water Treatment Units - Aesthetic Effects

Description according to NSF (2015) "*NSF/ANSI 42 establishes the minimum requirements for the certification of POU/POE filtration systems designed to reduce specific aesthetic or non-health-related contaminants (chlorine, taste, odour and particulates) that may be present in public or private drinking water. The scope of NSF/ANSI 42 includes material safety, structural integrity and aesthetic, non-health-related contaminant reduction performance claims. The most common technology addressed by this standard is carbon filtration.*" In the Water4India project the removal of disinfectants will not be a goal, the particle removal goal is relevant for treatment solutions. The protocol was developed for testing technologies in a controlled environment where all facilities for testing and laboratory analysis are available. For the Water4India pilot systems the challenge level of 10,000 particles/ml provides a reference for to compare with the naturally occurring particle concentrations in the source water.

Table 3-3 Challenge and target contaminant level in NSF/ANSI 42 test (Multipure 2015, AquaRO)

Substance	Percent Reduction**	Influent challenge concentration (mg/L unless specified)	Maximum permissible product water concentration (mg/L unless specified)
CHLORAMINE as Aesthetic Effect (As Monochloramine)	>97%	3.0 mg/L +/- 10%	0.5 mg/L
CHLORAMINE as Aesthetic Effect (As Monochloramine)***	>98.3%	3.0 mg/L +/- 10%	0.001
CHLORINE as Aesthetic Effect	99%	2.0 mg/L +/- 10%	> or = 50%
PARTICULATE, (Nominal Particulate Reduction, Class I, Particles 0.5 TO <1 µm	Class I > 99%	At Least 10,000 particles/mL	> or = 85%

NSF also provides standards for specific technologies including RO membrane filtration, UV disinfection, ion exchange and arsenic removal..

3.1.6 USEPA/NSF Protocol for equipment verification testing for arsenic removal

The USEPA/NSF protocol for equipment verification testing for arsenic removal (2003) describes the requirements for testing technologies for arsenic removal. Apart from the general requirements for technology testing, the protocol addresses specific issues for the various technologies for arsenic removal. The protocol was developed for testing technologies in a controlled environment where all facilities for testing and laboratory analysis are available. The pilot systems in Water4India will not test arsenic removal, but the protocol can be a basis for testing new absorbents in WP3.

3.2 Applicability of existing testing protocols in Water4India project

The fore mentioned protocols and guidelines for testing drinking water solutions cannot be applied directly in the Water4India project for several reasons:

- Most of the listed protocols assess a full treatment that needs to produce drinking water quality. Water4India solutions also include single treatment steps that only contribute to the total treatment system
- Some of the listed protocols only focus on single contaminants.
- The USEPA and NSF protocols and the Netherlands guideline assume a developed context, different from India in terms of water quality challenges and targets
- The protocols require advanced water quality analysis of parameters which are often not feasible in India
- Most protocols use spiked challenge testing. Since the pilots in India supply drinking water spiking would introduce an increased risk to the population. This is not acceptable.

Still the protocols and guidelines provide references that can be used to develop testing protocols for the solutions in the Water4India project. Strong points of the existing protocols are:

- Reference of important parameters for evaluation in relation to the type of treatment technology (USEPA, NSF)
- Reference for challenge testing both in terms of contaminant level and operational conditions (USEPA, NSF, WHO). At the pilot systems the naturally occurring challenges can be compared to the dosed challenges proposed in these protocols.
- References for how to set treatment targets
- Example of how to test in real practical situations to sufficiently assess source water quality and treatment performance (Netherlands)

4 FRAMEWORK FOR TREATMENT EVALUATION

4.1 General approach

The testing protocols will be different for each technology and can also differ for the context in which they are applied. To arrive at a testing protocol for the Water4India solutions a series of steps must be undertaken to develop a water quality testing protocol.

1. Define the context of the solution and place it in the water supply concept and treatment train
2. Determine water quality challenges, both contaminant and operational
3. Determine water quality primary and secondary treatment targets
4. Assess water quality analysis options
5. Design water quality testing protocol

4.2 Defining the context of the solution

The Water4India deliverable 3.3 (Aumeier and Yüce, 2014) provided the framework for evaluation of water treatment solutions in the Water4India project. Figure 4.1 illustrates how a solution can be part of a treatment train which in turn is part of a water supply. Therefore the water quality coming into the solution and leaving the solution doesn't need to be the same as the raw water and the drinking water quality respectively. This both affects the challenge with regard to the contaminants and the operational water quality conditions.

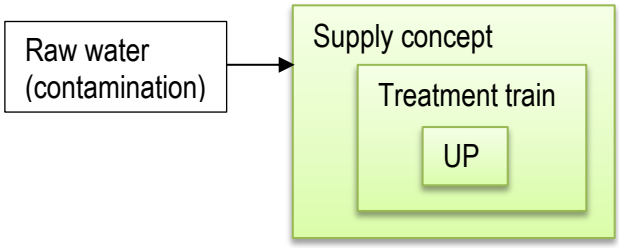


Figure 4.1 Hierarchy in drinking water supply (Aumeier and Yüce. 2014, Water4India deliverable 3.3)

Most technologies have very specific objectives in the multiple barrier system, targeting specific contaminants. Roughly they can be divided in pre-treatment and post-treatment processes. Pre-treatment processes target high and variable contaminations to reduce them to a much lower level, but not necessarily drinking water levels. Their main goal may be to prepare the water for post-treatment. They are characterized by very robust operation, but less strict performance requirements. Post-treatment steps need to remove contaminants to a very low level and provide drinking water that complies with the standards. These processes can be much more sensitive to disturbances by changing water quality. Some processes can fulfil different objectives, depending on the combination with other process steps. For example pre-chlorination has the objective to improve coagulation-sedimentation whereas post-chlorination has the objective to inactivate pathogens. For the current testing framework, the objectives will be linked to the intended implementation in the demonstration. If there are multiple implementations of one technology, separate testing protocols will be developed for each implementation.

4.3 Determining water quality challenges

4.3.1 Contaminant challenges

Although the tested technologies contribute to the drinking water production, they cannot simply be evaluated by testing the treated water according to drinking water standards (BIS 2012). Most technologies will not produce drinking water from any kind of water source, but only contribute to the multi-barrier process. Therefore a different strategy is needed to evaluate the performance of technologies. Following the WHO Water Safety Plan (WSP) concept, the solution can be regarded as one of barriers in a multi barrier system (Bartram et al. 2009). The total efficiency of the water supply system is determined by the combined effect of all the barriers. So the effect of the treatment solution on water quality contaminants can be evaluated in different ways:

- Does the total system, including the solution provide water that complies to BIS?
    - How effective should the solution be to achieve compliance to BIS in this system?
- What is the contribution of the solution to this achievement for the various parameters?
- Is the solution as effective as the conventional solution that it replaces?
- Can the solution meet even higher challenges typical for this situation?

In order to answer these questions water needs to be monitored for relevant parameters at least at the following points:

- Raw water
- Influent of the solution
- Effluent of the solution
- Drinking water

With this monitoring the pilot system can be tested. To translate that to more general conclusions for application in other locations some issues need to be resolved. The raw water quality at the pilot system during the testing period will have a specific combination of water quality parameters. This water quality needs to be compared to typical situations elsewhere in India. Raw water quality in India has been discussed in the Water4India deliverables D2.2, D3.2 and D3.3 in general terms. This information is compiled in Water4India deliverable 4.2 to provide a background overview of contaminant levels and their health impact in Indian situations using available monitoring data and studies from India. Lacking data, such as actual pathogen concentrations in water sources, will be estimated based on data from other countries. This information will be used to place the pilot conditions in a broader spectrum in India to assess the applicability of the solution in India.

Based on the working principle of the solution, relevant water quality parameters can be selected. Table 4-1 provides an overview of the most relevant contaminants identified in Water4India deliverable 3.3 (Aumeier and Yüce 2014) and the potential effect of treatment solutions on these parameters as described in Water4India deliverable 3.1 (Adin et al. 2014). For microbial contaminants the Watershare Treatment Calculator (KWR 2015) was used as a reference for potential efficacy of existing treatment processes. This tool compiles current scientific knowledge based on review publications (LeChevallier and Au 2004, Hijnen et al. 2006, Hijnen and Medema 2010) and provides the best estimate of the potential treatment efficacy under specific conditions. Fiber filtration will only be tested on surface water so groundwater parameters will not be relevant. The UF, UV and GAC will be tested on shallow groundwater which doesn't contain all groundwater contaminants, but may contain pathogens.

Table 4-1 Expected contaminant removal by treatment solutions

n°	Water source	Major contaminant(s) / characteristic parameter(s)	Fiber filtration	Ultrafiltration	Activated carbon filtration	UV Disinfection 40 mJ/cm²
1	GW	Fluoride	-	-	+?	-
2	GW	Iron	+	++	-	-
3	GW	Arsenic	-	-	+?	-
4	GW	Salinity (TDS)	-	-	-	-
		Salinity (conductivity)	-	-	-	-
5	GW	Nitrate	-	-	-	-
6	GW	POPs (DDT)	-	-	++	-
		POPs (HCH)	-	-	++	-
7	GW	Organics (BOD)	-	-	++	-
		Organics (COD)	-	-	++	-
8	GW	Petrochemicals (PAH)	-	-	++	-
9	GW	Trace Metals (Lead)	-	-	-	-
		Trace Metals (Zinc)	-	-	-	-
		Trace Metals (Chromium)	-	-	-	-
		Trace Metals (Nickel)	-	-	-	-
10	RW	Variable turbidity (TSS)	+	++	-	-
11	RW	Nitrate	-	-	-	-
12	RW	POPs (DDT)	-	-	++	-
		POPs (HCH)	-	-	++	-
13	RW	Organics (BOD)	-	-	++	-
		Organics (COD)	-	-	++	-
14	RW	Petrochemicals (PAH)	-	-	++	-
15	RW	Pathogens (E. coli/total coliforms)	0.5-1.5	3-6 log	0.7 log	>5.3 log
		Pathogens (viruses)	0.5-1 log	2-6 log	-	2.2 log
		Pathogens (protozoa)	3-4.5 log	6 log	1.3 log	>3 log
		Pathogens (helminths)	4-5 log	6 log	1?	-
16	RW	Trace metals	-	-	-	-
17	PW	Organics (algae) (BOD)	+	+	+	-
		Organics (algae) (COD)	+	+	+	-

4.3.2 Operational challenges

Operational water quality challenges are those water quality aspects that are not directly contaminants considering their health effect, BIS standards or acceptability, but parameters that can affect the functioning of the treatment solution. Based on the testing protocols in Chapter **Error! Reference ource not found.** and experiences of the technology developers, the water quality challenge parameters summarized in Table 4-2 will be addressed in the water quality testing protocol of the Water4India solutions.

Table 4-2 Expected operational water quality challenges for treatment solutions

	Fiber filtration	Ultrafiltration	Activated carbon filtration	UV disinfection
Particles (turbidity)	Clogging of filter, increased backflush	(Irreversible) clogging of filter (backwash, cleaning), increase wear of membrane (leakage, replacement)	Shortened run time of filter	Ineffective at high turbidity
Algae	Clogging of filter, increased backflush	(Irreversible) clogging of filter (backwash, cleaning), increase wear of membrane (leakage, replacement)	Shortened run time of filter	Ineffective at high turbidity
Organics			Shortened run time of filter	Ineffective at low UV transmission
Low temperature	-	Increased pressure, leading to leakage	Less efficient	-
pH	Poor pre-treatment, increased particles			

4.4 Determine water quality primary and secondary treatment targets

4.4.1 Primary water quality treatment targets

The primary water quality targets are the BIS standards that are related to health. Primary goal of treatment is to provide drinking water that always complies with these targets. Given the monitored water quality at the pilot system and the BIS standards, the maximum required treatment efficacy can be calculated for the pilot situation. Based on the overview of raw water quality in India in Water4India deliverable 4.2 more general targets can be set for drinking water treatment in typical situations. If the solution is a 'full treatment' this directly defines the treatment target. When the solution is part of a multi barrier system the total efficacy also depends on the other steps in the treatment system. If these steps are operated sub-optimal, this may affect the treatment so that the BIS standard isn't met for the produced water even if the solution is performing as expected. Therefore also other treatment steps need to be evaluated for their potential efficacy. For microbial aspects the Watershare QMRA Treatment Calculator (KWR 2015) will be used as a reference for potential efficacy of existing treatment processes. This tool compiles current scientific knowledge based on review publications (LeChevallier and Au 2004, Hijnen et al. 2006, Hijnen and Medema 2010) and provides the best estimate of the potential treatment efficacy under specific conditions. Thus the potential water quality of the solution in an optimized

treatment system can be estimated. If the solution replaces a specific traditional treatment process, their performances can also be compared using the same approach.

In general a technology performs better when it removes more contamination. However, the level of removal that is beneficial to final water quality needs to be regarded in respect to the type of contaminant, the raw water quality and the position that the technology takes in the multiple barrier water treatment system. For example, reducing Fluoride by a factor 2 (50% removal) is already beneficial to health, but for pathogenic microbes a factor of 100,000 removal (99.999% or 5 log) is regarded as highly protective. Other goals may not require a certain percentage removal, but only removal of high contamination peaks. For example, turbidity may be normally be at acceptable levels requiring only 50% reduction, but during monsoon 99% reduction may be required to achieve acceptable water quality.

4.4.2 Secondary water quality treatment targets

Apart from the main objective, a technology may have additional benefits. The additional benefits may not be necessary to achieve BIS standards, but still contribute to water quality aspects of the produced drinking water. For example additional lowering of the turbidity, colour, odour and taste of the water beyond the BIS maximum permissible limit does provide a benefit. Especially since this can encourage people to drink the treated water instead of alternative sources such as contaminated spring that may seem more attractive from the consumers view. The additional benefits need to be weighted differently from the main objective when evaluating or comparing solutions.

4.4.3 Variability

Besides the contamination or operational challenge level, the variability of source water quality may pose specific problems. Especially river water sources may be prone to rapid changes during the monsoon period, characterized by short peaks. This can have the following effect on the treatment solutions:

- Treatment stays in operation and effectively addresses the water change either by robustness or by adapting settings
- Treatment stays in operation but temporarily does not meet treated water quality targets
- Treatment stays in operation but is damaged/contaminated by the peak, reducing its efficacy on the long term
- Treatment needs to be stopped during peaks, and temporarily no water is produced.

The required strategy will generally be determined beforehand by the treatment supplier. In the first and second case the robustness of the treatment should be tested by making sure the peak load has occurred and was monitored. For bench scale tests the peak load must be simulated.

4.5 Assess water quality analysis options

Water quality assessment can be performed in various ways. Since conditions can be challenging in India, the options for water quality monitoring during the pilots can be limited. Monitoring options were discussed in report Water4India deliverable 4.1 and conclusions for monitoring the solutions are summarized in Table 4-3. The options will be discussed in more detail for each pilot since the location can affect the possibilities.

Table 4-3 Summary of monitoring options for Water4India solutions (From Water4India deliverable 4.1 Updated)

			Accuracy / precision	Robustness / stability	Sensitivity	Specificity / selectivity	Interpretation	Ease-of-use	Cost	Availability	Infrastructure & logistics	Acceptability	Risk of use	Environmental impact	Options
W4I solutions															
	Source														
		Turbidity	-	+	-	-	-	-	-	-	-	-	-	-	Field kit/on-line
		Arsenic	+	+	+	+	-	-	-	-	-	-	-	-	Field kit/lab
		Fluor	+	+	+	+	-	-	-	-	-	-	-	-	Field kit/lab
	Filtration														
		Turbidity	+	+	+	-	-	-	-	-	-	-	-	-	Field kit/on-line
		Temperature	-	+	-	-	-	-	-	-	-	-	-	-	Thermometer/on-line
		Indicator organisms	+	+	+	+	-	-	-	-	+	-	-	-	Field lab/lab
		Pathogens	+	+	+	+	-	-	-	-	+	-	-	-	Lab
	UV Disinfection														
		Turbidity	-	+	-	-	-	-	-	-	-	-	-	-	Field kit/on-line
		UV transmission	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/on-line
		Indicator organisms	+	+	+	+	-	-	-	-	+	-	-	-	Field lab/lab
		Pathogens	+	+	+	+	-	-	-	-	+	-	-	-	Lab
	Membrane filtr.														
		Turbidity	+	+	+	-	-	-	-	-	-	-	-	-	Field kit/on-line
		Arsenic	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/lab
		Fluor	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/lab
		Temperature	-	+	-	-	-	-	-	-	-	-	-	-	Thermometer/on-line
		Indicator organisms	+	+	+	+	-	-	-	-	+	-	-	-	Field lab/lab
		Pathogens	+	+	+	+	-	-	-	-	+	-	-	-	Lab
	New Adsorbents														
		Turbidity	-	+	-	-	-	-	-	-	-	-	-	-	Field kit/on-line
		Arsenic	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/lab
		Fluor	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/lab
		DOC	+	+	+	+	-	-	-	-	+	-	-	-	Field kit/lab

4.6 Design water quality testing protocol

The water quality testing protocol describes the required water quality monitoring before and after drinking water treatment in order to evaluate the performance of Water4India solutions. In this report we focus on demonstrating the effect of Water4India treatment solutions, however in Water4India deliverable 4.2 we also discuss the need to test full scale treatment performance on the long term. Verifying full scale treatment performance is needed because direct testing of the produced drinking water is generally insufficient to demonstrate compliance to health based targets in the framework of QMRA.

Table 4-4highlights the components of the water quality testing protocol and the factors that determine the choices made. Assumptions on contamination level, treatment performance and variability need to be made to design the water quality testing protocol. Higher variability will require more frequent

monitoring and low contamination levels will require more sensitive techniques and larger sample volumes followed by sample concentration before analysis.

Table 4-4 Aspects that impact the water quality testing protocol

	Aspect	Example
General	Method availability, Complexity Safety Costs	pH strip versus HPLC
Parameter	Contaminants present Treatment principle	Turbidity, arsenic, viruses
Specificity	BIS requirement Treatment efficacy for sub-parameters	Coliforms versus *E. coli* versus viruses
Sample volume (sensitivity)	Contamination level BIS level Treatment target Method limit of quantification or detection	1 ml up to 1000 litre
Sample frequency	Variability raw water conditions Variability treatment operation Fouling, loading, wearing of treatment Executable (manpower)	On-line Hourly (one day) Daily Monthly

4.6.1 General

Method availability is an important limiting factor and involves also the complexity, safety and costs of analysis. Advanced laboratories can analyse any water quality parameter without limitation. However such a laboratory will not be available on site, and thus transportation to such a lab would be needed. For many parameters this would require controlled conditions (cooling) and limited time between sampling and analysis in the lab. Regular transportation to a major lab in India, or even abroad, would soon lead to high costs. Alternatively samples could be prepared on site (filtration) stored over a period of time (cooled or frozen) and then collectively be transported and analysed to reduce costs. This may be feasible for some parameters and will be explored for the specific pilot.

Many important parameters are available as field test kits as described in Water4India report Water4India deliverable 4.1 (Smeets et al. 2014). The complexity of the tests can vary per parameter and test system and needs to be in line with the training and skill of the person performing analysis. For the pilot we will distinguish between very basic skills, for example a local operator or technician, and medium skilled, for example a student in environmental science. Tests that require laboratory training will not be included. Water testing may involve risks such as handling dangerous chemicals or culturing potential pathogenic microbes. Only methods that allow sufficient protection of the analyst and the environment will be selected.

Costs in general are an important restriction for the monitoring activities. Field kit costs consist of a fixed fee for the equipment and costs of reagents and materials per sample, generally bought per batch . When designing monitoring program this will be taken into account. The total number of samples will

relate to typical batch sizes per parameter (e.g. 10, 25, 50, 100 samples) and the onetime costs for equipment. Laboratory analysis by a third party laboratory will generally be a fixed price per sample for a batch of related parameters, possibly with some additional costs per batch of samples for administration. Project partner laboratories will generally apply a bulk cost for a batch of specialty analysis since these costs depend strongly on number of samples per batch and the complexity of the analysis. On-line equipment will be installed by technology suppliers and costs are part of the installation.

4.6.2 Parameter

The BIS describe a large range of parameters and source waters can contain a large range of contaminants. However the study will focus on parameters of relevance for the specific pilot. Requirements are that the parameters is (expected to be) present in the source water and that it is affected by the treatment solution, or may impact the solution. Table 3.1, Table 3.2 and Table 3.3 already indicated the relevant parameters for the various pilots.

4.6.3 Specificity

Different methods can be used to analyse water quality that differ in specificity for the parameter under study. For example turbidity, total suspended solids (TSS) and particle counting all analyse the presence of particles in the water. Although they are strongly related, there is no fixed relationship between these parameters. Higher TSS will generally coincide with higher turbidity. However if only the source of particles in the water changes, this could also affect the turbidity since different materials have different light scattering characteristics. Specificity of microbiological parameters is especially important. Coliform bacteria can be from a faecal or environmental source, whereas *E. coli* (a sub-population of coliforms) has a faecal origin. *E. coli* in general are not pathogenic, but *E. coli* O157:H7 is. So the more specific a microbial analysis is, the better it can be related to health impact. However, more specific analysis often requires more resources and skill. The specificity of a analysis method will be considered for each pilot and sampling point.

4.6.4 Sample volume (sensitivity and accuracy)

BIS standards generally define target concentrations for chemicals or absence of microorganisms in specific volumes. For treated water samples this provides the basis for the sampling volume. Some parameters in BIS are described as ‘absence in drinking water’, so without a specified volume. In report D 4.2 these parameters are discussed and quantified by linking them to health based targets. The resulting volumes may not always be achievable in practice however. A more general approach for these parameters is discussed in Water4India deliverable 4.2 and this will be applied in the pilot monitoring. Water quality variability may also affect the required volume. When a BIS parameter is close to the detection limit in practice, it may be beneficial to sample a larger volume than prescribed by BIS. Insight in the variation of the concentration below detection limit aids the estimation of occurrence of higher concentration.

4.6.5 Sample frequency

The required sample frequency is strongly determined by variation in source water quality and in treatment variability. Both short term and long term variability may occur. Short term variability can be caused by incidents, such as rainfall events or backflushing of a filter. Such events can lead to spikes of concentrations of a few hours. Long term variation can be caused by seasonal changes, for example

monsoon time, or degradation of the treatment, for example UV lamp fouling. The monitoring program will apply several strategies to address variability:

- On-line monitoring of proxy-parameters that indicate changes and variations in the system
- A short term sampling program, taking several samples on a single day
- Long term sampling, taking samples over a period of several months
- Event sampling, taking samples at a moment when peak concentrations or poor treatment performance are expected.

Special attention is needed to address the variability of microbial water quality. Monitoring surface waters in various settings has shown that concentrations of microbes vary over several orders of magnitude in time. This leads to two issues. First sufficient water samples are needed to characterise raw water quality and determine the average concentration for risk estimations. Depending on the source water variability 20 to 100 samples are needed to sufficiently capture the high concentrations that dominate the average concentrations. The QMRAidit tool (Smeets et al. 2013) can be used to predict sample programme outcomes based on assumptions about raw water quality. These assumptions are constantly improved when new sampling results become available. Thus the sampling frequency and volume can be optimised based on intermediate results.

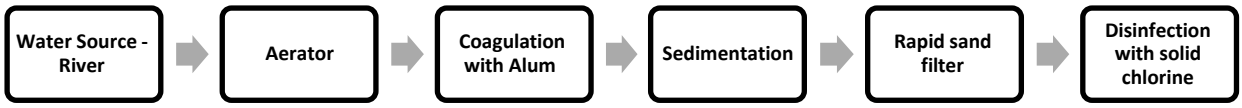
Secondly the variability can obscure the assessment of treatment efficacy in the pilots. The momentary sample at the inlet is not the same water that is tested at the outlet. Additionally build-up and release of contaminants can occur in the treatment system, for example in filtration cycles. Thus simply comparing two individual samples can lead to over- or under estimation of treatment efficacy. A series of samples from influent and effluent will therefore be used to estimate treatment efficacy using the QMRAspot software (Schijven et al. 2011).

The expected variability of water quality was assessed in report Water4India deliverable 4.2 based on currently available data. This forms the starting point for the sampling programs.

5 FIBER FILTRATION PILOT (AMIAD)

5.1 Pilot description

The fiber filtration system will be tested at a drinking water treatment plant. The current water flow scheme at water the treatment plant is as follows:



During the dry season, river water has relatively low turbidity (5-10 NTU). No Alum dosing is needed, and the product water of the sand filter has a turbidity of 3-5 NTU, which is satisfactory.
During Monsoon season (June-September) high turbidity (20-50 NTU) is expected in the river water.

The pilot is designed to replace the rapid sand filters .The intake water comes from the sedimentation pond at 90 m^3/hr. The pilot is composed out of low bed media filters followed by a 7um AMF 370K filter and proportional disinfection with liquid chlorine. It is equipped with high end monitoring analysers and on-line monitoring system.

5.2 Water quality challenges

5.2.1 Contaminant challenges

The fiber filtration technology is designed to remove particles from water. The direct effect is a clearer water that is more attractive, but there are additional benefits to be expected. As can be seen from Table 4-1 microbial pathogens and algae are also particles or are associated with particles that are (partially) removed by fiber filtration. So by removing particles, other contaminants may also be removed. Secondly, by removing particles, subsequent processes can perform better. In the current pilot system, particle removal is followed by disinfection with chlorine. Presence of particles is known to inhibit chlorine disinfection. Pathogenic organisms inside particles may be protected by the particles, so removing them makes the total system more effective. Particles can also contain organic matter that consumes chlorine, increasing chlorine demand. If chlorine dosing is not adjusted accordingly, the required chlorine exposure may not be reached. In new applications, other processes may be considered after fiber filtration, such as activated carbon filtration or UV disinfection. Particle removal also has a potential positive effect on these processes. Figure 5.1 shows the monitored levels of turbidity, TSS and faecal coliforms in the river sampling point from 2004 to 2010 (CPCB 2015).

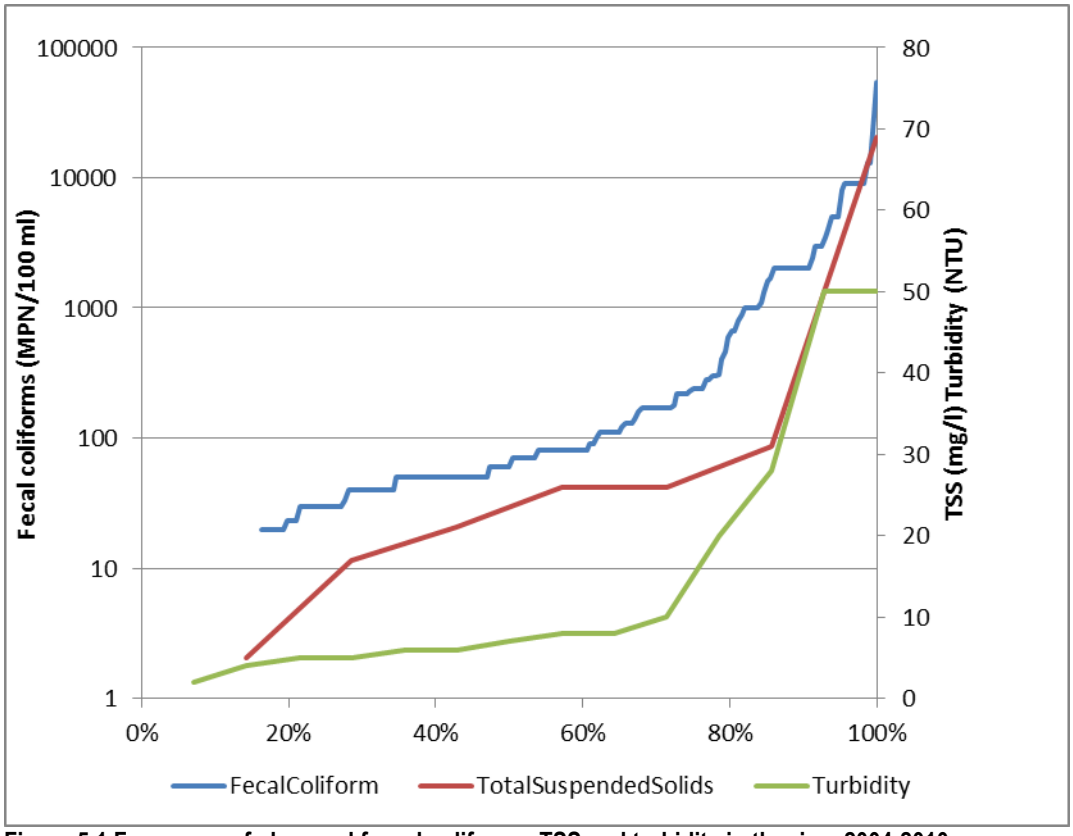


Figure 5.1 Frequency of observed faecal coliforms, TSS and turbidity in the river 2004-2010

Figure 5.1 shows that turbidity of the river water can be as high as 50 NTU, and TSS levels up to 70 mg/l. The data is insufficient to analyse when these high concentrations occur since only a limited number of data exist. The faecal coliform data is much more extensive. The concentration varies from <20 MPN/100 ml up to 50,000 MPN/100 ml resulting in an average concentration of 1,100 MPN/100 ml.

This is the same level of faecal indicator bacteria (FIB) as observed in Dutch surface water (see Water4India deliverable 4.2). The level of pathogens was estimated using the empirical equations defined in D4.2 resulting in the estimations in Table 5-1.

Table 5-1 Mean faecal indicator bacteria (FIB) and pathogens in rivers assumed for the river based on relationships found in the Netherlands (D4.2)

	Mean n/l	Max n/l	BIS Standard	Log removal for BIS compliance
E. coli, faecal coliforms (CFU or MPN/l)	11,000	500,000	<1/100 ml	3.0-4.7
Enterovirus (PFU/l)	0.11	1.5	<1/100 l*	1.0-2.2
Cryptosporidium (oocysts/l)	0.66	4.5	<1/10 l	0.8-1.7
Giardia (cysts/l)	5.3	35	<1/10 l	1.7-2.5

* BIS requires viruses to be "absent" and the method described samples 100 l
** Not defined

During the update of this report a second database with data from the same sampling point in the river was found (CPCB-ENVIS, 2016). Although both datasets refer to the CPCB and the national water quality monitoring programme (NWMP), the reported concentrations of faecal coliform bacteria are much lower in the CPCB-ENVIS database, resulting in 60 to 273 MPN/100 ml annual average concentrations (Table 5-2). At that time the CPCB database (CPCB 2015) could no longer be accessed to find a possible explanation for this order of magnitude difference. As a result, the estimated pathogen concentrations are also lower, although less than an order of magnitude lower because the indicator to pathogen ratio is concentration dependant (see Water4India deliverable 4.2) . Estimated concentrations based on 273 MPN/100ml (2014) would be 0.04, 0.33 and 2.6 enterovirus, *Cryptosporidium* and *Giardia* per liter. This doesn't impact the required sensitivity of analysis methods for pathogens in source water.

Table 5-2 CPCB-ENVIS water quality report of fecal indicator data (CPCB-ENVIS, 2016)

	FECAL COLIFORM (MPN/100ml)			TOTAL COLIFORM (MPN/100ml)		
	Min	Max	Mean	Min	Max	Mean
2014	50	500	273	110	900	734
2013	30	350	214	140	900	599
2012	30	220	88	130	500	228
2011	50	140	60	140	350	228
2010	50	240	118	700	3000	1577
2009	50	500	233	70	9000	3147
2008	70	170	89	90	200	114
2007	30	130	75	50	170	98

Seasonal variations may affect the level of faecal contamination in river water. Therefore all data from the river from 2004-2010 was plotted as day of the year in Figure 5.2. There is no clear temporal pattern in FIB concentrations indicating that both high and low concentrations can occur throughout the year. Therefore it is not possible to select the period for monitoring when peaks are likely to occur.

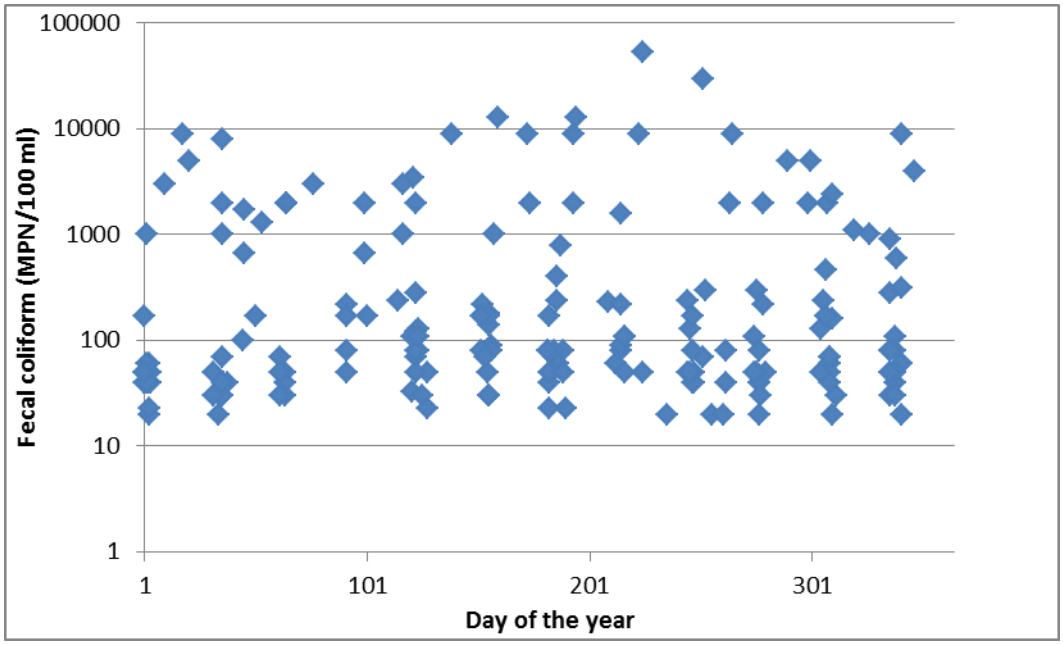


Figure 5.2 Observed faecal coliforms in the river 2004-2010 grouped per day of the year

5.2.2 Operational challenges

The operational challenge for the fiber filtration unit is the variable TSS level which may cause (irreversible) clogging of the filters. The challenge is increased by the lack of control of the current coagulant dosing, which may result in an increase of the already high turbidity and coagulation occurring inside or after the filter.

5.3 Water quality targets

The pilot treatment needs to provide water of at least equal quality as the traditional treatment. The challenge for the fiber filtration unit will be to reduce the turbidity to below 5 NTU when river turbidity is high, or 90% removal of turbidity. Secondly the fiber filtration may provide additional benefit for the removal of microbial pathogens. First by effectively removing particles, the chlorination will be more effective for disinfecting bacteria and viruses. Secondly the fiber filtration may remove protozoan pathogens *Cryptosporidium* and *Giardia*, and helminths from the water by filtration more efficient than sand filtration. To achieve the BIS standard of absence in 10 litres up to 3.4 log removal is needed. Traditional rapid sand filtration achieves a maximum of 1 log, or 2 log when optimized coagulation is achieved. The fiber filtration system has achieved 3 to 5 log removal of protozoa in laboratory experiments. The level of removal that can be shown will be limited by the concentration in the source water. Since the faecal contamination level doesn't vary with seasons, there is no indication when sufficient levels of pathogens will occur to validate the efficacy in the pilot.

5.4 Water quality analysis options

The pilot plant is located in a rural area about 8 hour drive from a laboratory in Bangalore. Frequent laboratory analysis is therefore not feasible. The system is operated by staff with technical training but no water quality analysis experience. Therefore basic analysis using field kits or user friendly methods can be performed on site. The pilot is equipped with advanced on-line monitoring equipment for the most relevant water quality parameters, turbidity and particles.

5.4.1 On-line monitoring

On-line monitoring will be performed for operational purposes, but will also support other goals. It provides insight in the operational window on a very detailed time scale beyond the conventional approach with water samples. It especially provides information about variability of conditions and peaks or sudden changes in water quality and how the treatment deals with this. Data feed into automatic operation, remote access for analysis and response and stored for later analyses and reporting. Table 5-3 summarizes the on-line measurements and their approximate monitoring interval.

Table 5-3 On-line monitoring at fiber filtration pilot

Parameter	Sample point	Interval	Comment
Turbidity	After shallow media filter	10 min	
Turbidity	After microfiber filter	10 min	
Flow	Inlet	1 min	
Free chlorine	After chlorine dosing	10 min	
Temperature	After chlorine dosing	10 min	Included in free chlorine
Pressure difference	Over filtration unit	1 min	
Particles	Various	10 min	Particle monitor is placed temporary

Turbidity monitoring will indicate the main performance of the filtration unit. Free chlorine concentration, flow and temperature will be used to calculate CT values and estimate effect of chlorination on pathogenic bacteria and viruses. On-line monitoring supports the constant effectiveness of this barrier.

5.4.2 Field test kit water analysis

Water quality analysis with a field test kits will be performed during a specific testing period by a visiting researcher. When this monitoring is successful, the pilot plant technician will be trained to perform the analysis and continue monitoring over the operational period. The use of FTK eliminates logistic problems to get samples to the laboratory, provides consistent results and saves costs. It can also provide rapid feedback to the water supply operators, helping to build trust in the supplied water quality. Table 5-4 summarizes the assessments to be performed with the on-site field test kit. As reported in D7.2, the field test kit was not supplied in time and the *E. coli* monitoring wasn't implemented on site, nor could the operator be trained to use it. Tests were performed with fluorescent beads instead to assess the effect of media filtration, see description below. The effect of chlorination was assessed by calculating inactivation efficacy based on monitored chlorine concentration, pH and temperature as described in D7.3. Executing *E. coli* monitoring is recommended for other studies as it provides a reference level of faecal source contamination and treatment performance.

Table 5-4 Field test kit water samples at fiber filtration pilot

Parameter	Sample point	Interval	Comment
E. coli	Raw water	Daily Weekly	Study period of one week Normal operations
E. coli	After shallow media filtration	Daily Weekly	Study period of one week Normal operations
E. coli	After fiber filtration	Daily Weekly	Study period of one week Normal operations
E. coli	After chlorination	Daily Weekly	Study period of one week Normal operations

In addition AMIAD performed field tests during its quarterly visits to the pilot, for which results are presented in report D7.3. This included:

- Turbidity [NTU],
- Particle size distribution [mg],
- Total suspended solids [mg/L],
- Fixed and volatile solids [mg/L],
- Aluminium [mg/L],
- pH Value [-],
- Electrical conductivity [µS/cm]

5.4.3 Laboratory analysis in India

Laboratory tests in India will be performed to support evidence of compliance to BIS standards. This also serves to 'validate' the FTK results. At least one sample per season is needed to substantiate performance under those conditions. At this moment it is unclear if standard water quality parameters will be tested in Indian NRDWP monitoring framework. Table 5-5 and Table 5-6 summarize the proposed samples to be analysed in a laboratory. The minimum BIS parameters don't include lead, however this has been identified as a health issue. Due to practical challenges, the laboratory analysis were not performed (see D7.2). The treated water was not considered a drinking water source that needed monitoring under the NRDWP.

Table 5-5 Laboratory analysis in India of fiber filtration pilot

Parameter	Sample point	Interval	Comment
Turbidity	After fiber filtration	4 times	One per season
TSS	After fiber filtration	4 times	One per season
E. coli	After chlorination	4 times	One per season

Table 5-6 Laboratory analysis in India of 'general parameters' for fiber filtration pilot

	BIS minimum parameters	W4I technology performance In DSS
pH	X	X
Turbidity	X	X
TDS	X	X
Total Hardness	X	X
Alkalinity	X	
Fluoride	X	X
Chloride	X	
Sulphate	X	
Nitrate	X	X
Arsenic	X	X
Iron	X	X
Lead		X
total coliforms and	X	*
E. coli	X	X**

* Total coliforms is part of faecal coliform testing, however not used for DSS
**Defined as faecal coliforms

5.4.4 Laboratory analysis at Bhavan laboratory and KWR

An important water quality benefit of the fiber filtration system is the potential removal of protozoa and helminths from the water which are not disinfected by chlorine. At the time of designing the water monitoring plan, there was no laboratory in Bangalore that can perform *Cryptosporidium* and *Giardia* analyses. Therefore samples were planned to be stored and transported to the KWR laboratory for this type of analysis. This would also provide the opportunity to collect information about other pathogens and human faecal markers in raw water and their removal by treatment in India. The proposed sampling program for pathogens is summarized in Table 5-7. When preparing the sampling mission, it became clear that transportation of these samples from India to KWR in the Netherlands would not be feasible within the time frame, the budget and the administrative requirements in India. Meanwhile we came in contact with the Bhavan laboratory in Mumbai that had the capability of *Cryptosporidium* and *Giardia* analysis, but had no experience with environmental samples. It was decided to perform the analysis in the Bhavan lab with support from an experienced KWR analyst. Thus we achieved knowledge exchange and capacity building in India and were able to reduce transport time. The processed samples were also analysed for *Cryptosporidium* and *Giardia* at KWR for a second opinion (other parameters were not feasible with the processed samples). The analysis of SSRC (spores of sulphite reducing Clostridia) was added to the program as a surrogate for the removal of protozoa. Results are described in report D7.3. The analysed parameters are summarised in Table 5-7 Laboratory analysis at Bhavan laboratory and KWR of fiber filtration pilot samples.

Table 5-7 Laboratory analysis at Bhavan laboratory and KWR of fiber filtration pilot samples

Parameter	Sample point	Interval	Comment
Cryptosporidium and *Giardia*	Raw water	daily	Study period of one week
Cryptosporidium and *Giardia*	After shallow media filtration	daily	Study period of one week
Cryptosporidium and *Giardia*	After fiber filtration	daily	Study period of one week
SSRC	Raw water	daily	Study period of one week
SSRC	After shallow media filtration	daily	Study period of one week
SSRC	After fiber filtration	daily	Study period of one week

[1] During one day, hourly samples will be taken to assess the short term variability of the source water and treatment efficacy. If short term variability is high, this will be repeated including the other microbial parameters.

5.5 Challenge testing with fluorescent beads

Amiad had obtained fluorescent beads (microspheres) of sizes that represent the protozoan pathogens, to perform challenge testing on a parallel test cassette at the pilot installation. The required equipment to count these beads in samples is similar to the equipment needed for protozoan analysis. Therefore the Bhavan laboratory was capable to perform this analysis. These challenge tests proved to be very successful, as described in report D7.2. However it can only be performed at small scale and not in a full scale system that provides drinking water.

6 SOLAR SPRING PILOT

6.1 Pilot description

The pilot installation will treat water from a shallow well (around 20m deep) at Kanabargi village in Belgaum, Karnataka. Currently the well water is not treated. The Solar Spring pilot system will consist of a solar powered unit that contains several automated treatment steps with a capacity of 1000 l/h resulting in 10 m^3/d.

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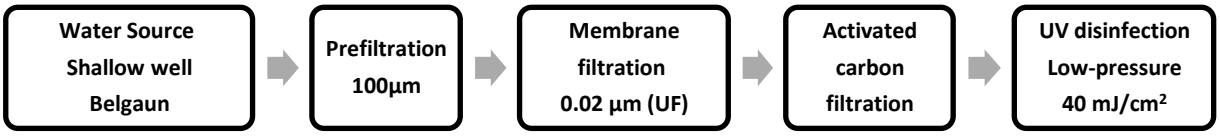

Figure 6.1 Solarspring pilot system process scheme and photo

6.2 Water quality challenges

6.2.1 Contaminants challenges

A shallow well can contain the groundwater contaminants mentioned in Table 3.1, but it can also be influenced by contaminants from the surface. Especially microbial pathogens can form a contaminant of concern for shallow wells (see Water4India deliverable 4.2). Non-compliance to BIS standards in the Belgaum area is mainly due to iron, turbidity, hardness and high pH, and in some cases nitrate. Two samples from the pilot well have been analysed in laboratory. The main results are summarized in Table 6-1.

Table 6-1 Results from water quality testing

S. NO.	PARAMETERS	TEST RESULT
	Chemical	
1	Turbidity,NTU	129.0
2	Total Hardness as $CaCO_3$,mg/l	270.6
3	Fluoride as F,mg/l	0.2
4	Total Dissolved Solids,mg/l	1042.0
5	Sulphates as SO_4,mg/l	142.0
6	pH,@ 25°C	7.06
7	Total Organic Carbon,mg/l	Not Detected (DL : 0.1)
8	Total Suspended Solids,mg/l	22.0
9	COD,mg/l	2529.6
10	Nitrate (as NO_3),mg/l	2.2
11	Alkalinity as $CaCO_3$,mg/l	286.9
	Microbiology	
12	E.coli,MPN/100ml	Present
13	Total Coliform Count,MPN/100ml	> 161
	Metals & Minerals	
14	Iron as Fe,mg/l	12.7

TEST	COLIFORM COUNTS	BIOLOGICAL REFERENCE RANGE
WATER CULTURE	>1,100 MPN/100mL	<10 MPN/100 mL

The test results show that the shallow well water contains microbial contamination. Turbidity is very high compared to the desirable limit of 5 NTU, which may be caused by the very high iron content (desirable

limit of 0.3 mg/l). Dissolved solids exceed the desirable limit of 300 mg/l but are below the permissible limit of 2000. The ultrafiltration and UV disinfection will form the main barriers against microbial contaminants. Pre-filtration and ultrafiltration will need to remove iron and turbidity to a large extent. The COD level is extremely high and suggests a significant amount of organic contamination, which is contradicted by the low TOC level. These measurements seem to be incorrect. The water testing didn't address persistent organic pollutants (POP). POP include pesticides like DDT and HCH and are contaminants of concern for Indian groundwater (Water4India deliverable 3.2). Activated carbon will likely remove organic pollutants if they are present. Since the presence of POP at the pilot site is not known, targets for removal cannot be set.

6.2.2 Operational challenges

High turbidity and iron levels can lead to rapid clogging of the pre-filtration and fouling of the UF membrane. The hardness of the water may also cause (irreversible) fouling of the UF membrane.

6.3 Water quality targets

The alternative for the pilot system is no treatment and direct consumption of the raw water. Therefore the pilot cannot be compared to the 'current' treatment. The pilot treatment will improve the water quality, striving to reach the BIS standards and to reduce health impact from water contaminants. The pilot system is expected to remove microbial pathogens to a large extend. Microbial indicator bacteria need to be reduced by >99.9% (> 3 log units) according to the initial water quality samples. According to the estimated efficacy in Table 4-1 the pilot could achieve over 9 log removal of bacteria. *Cryptosporidium* and *Giardia* are expected to be removed more than 9 log units. Helminths are less affected by UV disinfection and therefore removal largely relies on UF membrane filtration to achieve 6 log removal. Virus removal is the most critical since this might only be 4.2 log removal, which is just below the "highly protective" WHO classification. Pathogen removal will largely depend on membrane integrity. Testing membrane integrity is therefore one way to validate the effectiveness of the treatment. The level of removal that can be shown will be limited by the concentration in the source water. The initial samples suggest substantial faecal contamination, however this may be due to drilling of the well and concentrations may go down when the well is in operation for a longer duration of time. Possibly contamination with indicators and pathogens will only occur under specific conditions.
An important challenge for the pilot unit will be to reduce the turbidity to below 5 NTU, so 96% removal of turbidity. The system will also need to reduce iron content by 98% to achieve BIS standards. UF membrane filtration will be the main barrier for iron in the pilot system.

6.4 Water quality analysis options

6.4.1 On-line monitoring

The pilot system has on-line monitoring of pressure and flows for operation, but no water quality sensors. A UV irradiation sensor will be installed to monitor the UV disinfection system. The sensor will show short term fluctuations caused by water quality variations of UV transmittance. It will also show long-term effects of lamp aging and fouling. Together the flow and UV monitoring can be used to model the efficacy of UV disinfection for the various pathogens, especially the consistent performance of the UV system.

6.4.2 Field test kit water analysis

Water quality analysis with a field test kits will be performed during a specific testing period by a visiting researcher. When successful this might be adopted and continued by the pilot plant technician. The use of FTK eliminates logistic problems to get samples to the laboratory, provides consistent results and saves costs. It can also provide rapid feedback to the water supply operator, helping to build trust in the supplied water quality. The Solarspring pilot will be studied for two months by a student capable of doing basic field sample testing. The results of this monitoring are presented in report D7.3.

Table 6-2 Field test kit water samples at fiber filtration pilot

Parameter	Sample point	Interval	Comment
E. coli	Raw water	weekly[1]	Study period of four months
	After UF membrane	weekly[1]	Study period of four months
	After GAC	weekly[1]	Study period of four months
	Treated water	weekly[1]	Study period of four months
Iron	Raw water	weekly[1]	Study period of two months
	After UF membrane or treated water	weekly[1]	Study period of two months
Turbidity	Raw water	weekly[1]	Study period of two months
	After UF membrane or treated water	weekly[1]	Study period of two months

[1] During or following special events such as heavy rainfall extra sampling is performed

6.4.3 Laboratory analysis in India

Laboratory tests in India will be performed to support evidence of compliance to BIS standards. This also serves to 'validate' the FTK results. At least one sample per season is needed to substantiate performance under those conditions. The minimum required BIS parameters in Table 5-5 will be analysed in the produced drinking water.

Table 6-3 Laboratory analysis in India of fiber filtration pilot

Parameter	Sample point	Interval	Comment
Turbidity	Treated water	4 times	One per season
TSS	Treated water	4 times	One per season
Iron	Treated water	4 times	One per season
E. coli	Treated water	4 times	One per season

6.4.4 Laboratory analysis at KWR

The initial samples suggest substantial faecal contamination of the groundwater. If this is confirmed by regular FTK samples, the risk from pathogens is probably the most significant risk at this pilot. In that case sampling for actual pathogens and human faecal indicators is suggested to quantify the actual health risk from this type of source. Currently there is no laboratory in Bangalore that can perform *Cryptosporidium* and *Giardia* analyses. Therefore samples need to be stored and transported to the KWR laboratory for this type of analysis. Table 6-4 shows the proposed monitoring program if faecal contamination is confirmed over a longer period of time by FTK analysis of *E. coli*. When preparing the sampling mission, it became clear that transportation of these samples from India to KWR in the Netherlands would not be feasible within the time frame, the budget and the administrative requirements in India. Due to practical difficulties at the pilot site, it was also not feasible to include the advanced sampling needed in the sampling mission, since the pilot was not running at that time. Moreover, more

recent samples from the bore well water (source of the pilot) no longer contained indicator bacteria, so the analysis was unlikely to detect any pathogens. Instead more extensive analysis of the pilot system and the existing piped supply was performed with a field kit (see report D7.3).

Table 6-4 FTK analysis of Solarspring pilot

Parameter	Sample point	Interval	Comment
E. coli	Raw water	daily[1]	Study period of one week
E. coli	Treated water	daily[1]	Study period of one week
E. coli	Piped water	daily[1]	Study period of one week

[1] If a special event such as heavy rainfall occurs during the sampling period, extra samples should be taken.

7 HOUSEHOLD WATER TREATMENT SYSTEMS RWTH

7.1 Test description

Commercial household water treatment systems are commonly used in Indian household. There is a vast range of manufactures that apply various treatment principles, often in combinations, to provide treatment systems that can be used by consumers. The goal of this test is not to pilot the technologies in practice, but to gain insight in the functioning of such systems under normal and stressed conditions. Results are not intended as a grading or certification of the technology and cannot be used in that fashion by any party.

Two different types of household systems for drinking water treatment were tested under general and challenge conditions (flow diagrams in Figure 1)):

a) Eureka Forbes Aqua acid (AS) Xpert: electrically operated feed pressure from 0.6 to 2.0 bar, required; Water sources: Bore, water pipe and tank cars; Purpose: Desalination of brackish water (TDS ≤ 2000 mg / l), reduction of bacteria, viruses, protozoa, taste and smell; nominal filtration capacity: not specified, depending on the salinity of the influent; Retail price: 20999 rupees (300 euros). Life span: 6000 l

b) Hindustan Unilever limited (HUL) Pureit classic: gravity operated (maximum driving water column 0.15 m); Water source: unspecified; Purpose: Reduction of bacteria, viruses, protozoa, taste and smell; nominal filtration capacity: 2-9 l / h; Price: 1550 rupees (approx. 20 euro); Life span: 1250 l

7.2 Water quality challenge

Following the WHO guidelines the main objective of the investigation is to determine whether a microbiologically safe drinking water can be produced significant at all times even with significant organic and physical pollution. The challenge test described in the following protocol was derived from the guidelines for household systems for drinking water treatment U.S. EPA (1987) and the WHO (2011) and adapted to Indian conditions. The challenges included physical (turbidity/suspended solids and temperature), chemical (inorganic and salinity) and microbiological (bacteria and viruses) parameters. Since the tests are performed in a lab, challenge water of poor quality needs to be made artificially.

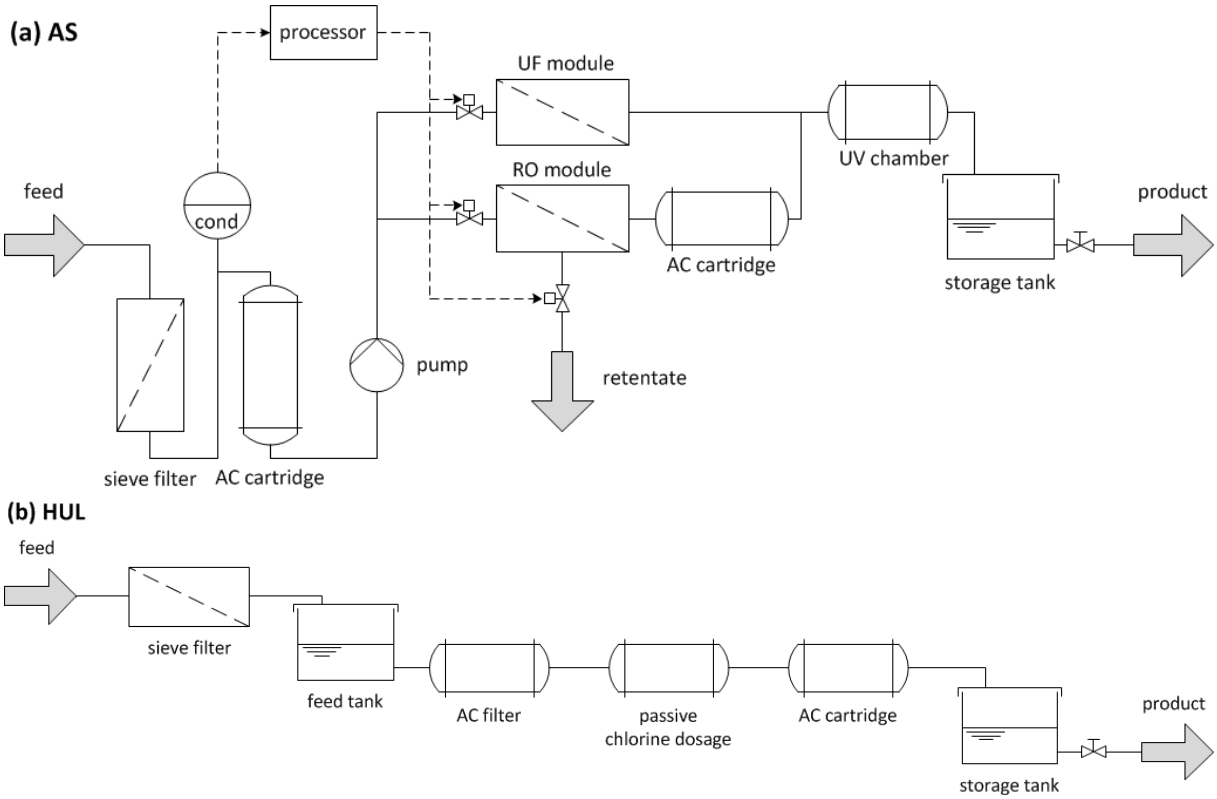

Figure 7.1 Flow schemes of investigated systems (a) Aquasure Xpert and (b) HUL Pureit

In each phase of the test 150 l of water is treated according to manufacturer's instructions. Depending on the filtration performance of the system, up to 30 l of water was produced every day, which is approximately the minimum drinking water requirements of a 4-person household (Ray and Jain, 2014).

7.3 Methods

Every day the feed water container is filled with fresh tap water and residual chlorine content was eliminated with 1.55 mg/l sodium thioglycolate (Sigma-Aldrich) and 2.26 mg/l sodium thiosulphate (Sigma-Aldrich). Subsequently a microbiological load of ~ 10^5 CFU/ml *E. coli* (DSM-613) and ~ 2 * 10^4 PFU/ml MS2 phage (DSM-13767) is added to the water. The *E. coli* are cultured overnight in 250 ml shake flasks at 37 ° C, 300 min^{-1} and 5 cm diameter of shaking in DSMZ liquid media 1. The MS2 phage are cultured in advance according to the instructions of the DSMZ in *E. coli* (DSM-5695 optical density by 0.1 from log phase) on double layer agar, the soft agar that is formed around the plaques is transferred to the phage buffer (0.05 M TRIS/HCl, 0.2% $MgSO_4$, 0.01% gelatin, pH 7.4), centrifuged (14000 min^{-1} / 10 min) and then filtered (0.2 µm cellulose acetate), allocated and frozen in 10% glycerin. Before each filtration cycle an appropriate quantity (calibrated with dilution series) is added to the feed tank. MS2 phages are not, however, able to infect *E. coli* strain DSM-613. In the first test phase (General), this feed water is fed to the investigated systems. In the second test phase (Challenge phase), the pH value in the feed water is increased with 1 M sodium hydroxide solution (Carl Roth), the temperature is set to 10 ± 2 ° C, salinity is increased to ~ 1500 mg / l with sea salt (Sigma-Aldrich), the total organic carbon (TOC) is increased with humic acid sodium salt (Sigma-Aldrich) and turbidity is created with Arizona test dust A2 (Ellis Components) according to Table 7-1 and verified before use.

Table 7-1 Physicochemical and microbiological values in the feed water in the challenge test (*: limit of the German drinking water Ordinance)

		General phase	Challenge phase
Turbidity	(NTU)	< 1 *.	74 ± 17
TOC	(mg/l)	2.6 ± 0.4	25.1 ± 2.5
SAC254	(m^{-1})	1.9 ± 0.5	49.5 ± 12.5
SAC436	(m^{-1})	0.3 ± 0.2	40.9 ± 11.5
Conductivity	(µS/cm)	286 ± 3	2518 ± 176
pH	(-)	7.7 ± 0.1	8.5 ± 0.1
E. coli	(CFU/ml)	$9.4 \cdot 10^4$ ... $2.2 \cdot 10^5$	$6.4\ 10 \cdot ^4$ ... $9.9 \cdot 10^4$
MS2	(PFU/ml)	$9.5\ 10 \cdot ^0$ ... $2.5 \cdot 10^4$	$1.1\ 10 \cdot ^5$ ... $3.1 \cdot 10^6$

The product flow is determined volumetrically with a flask and timer. The TOC is determined with a TOC-TN_b Analyser (DIMATOC® 2000) according to DIN EN 1484. The specific absorption coefficients (SAC) are measured at wavelengths of 254 nm and 436 nm with a Kontron UVIKON 922 double beam spectrometer or Thermo Fisher Genesys 20 vis spectrometer: $SAC(\lambda) = E(\lambda) / d$. The SAC254 and SAC436 are a measure for aromaticity (typically double bonded organic compounds) and the colour of the sample. Free chlorine determination is performed with Hach LCK310 cuvette tests. The microbe concentrations in the overnight- and spiking liquids are determined by optical density (OD) with the Thermo Fisher Genesys 20 vis spectrometer (λ = 600 nm) which is previously calibrated with dilution series. The *E. coli* samples are analysed with dilutions on agar plates in duplicate after 20 h of incubation at 37 °C (analogous to U.S. EPA method 1602, DSMZ medium 1). Additionally, to improve the detection limit in the product water, the presence / absence of *E. coli* in 100 ml sample is determined analogue EN ISO 9308-1 DIN. The MS2 phage samples are also quantified using dilution series in duplicate after 20 h at 37 °C as plaques on agar plates (analogue to U.S. EPA method 1602, host *E. coli* DSM-5695, DSMZ medium 544).

8 CONCLUSIONS

The water quality testing protocol was developed to provide water quality data that can be used to evaluate the treatment systems and to provide input to other tasks in the Water4India project. It focuses on the most essential parameters in order to get as much information possible within the limited budget availability. The actual execution of the monitoring required flexible to adapt to changes and challenges but also opportunities during the execution of the pilot testing. The project partners involved in the pilot used their available equipment, people and contacts to get the most out of sampling. This experience has shown that it can be challenging to achieve exactly the planned activities in India due to logistiscs, reliability of poser supply, availability of skilled laboratories and variable water conditions. Intermediate results lead to new insights that required adaptation of sampling strategies. Challenging filtration by dosing fluorescent beads provided clear and valuable data to evaluate the system, although this can only be done in small scale test setup that doesn't provide drinking water.

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ANNEX 1 ON-LINE MONITORING IN THE AMIAD PILOT

To: ADVA ZACH MAOR, ADVER ADIN, RAANAN ADIN, HAIM CICUREL, YEHUDA SHIVA
Subject: On-line monitoring AMIAD pilot DRAFT
CC: CHRISTIAN KAZNER, ARTURO MARQUINA
From: Patrick Smeets
Date: 22 May 2014

Introduction

The AMIAD pilot will soon be shipped to India. Some on-line monitoring equipment is foreseen, however additional monitoring could add value to the research. From a logistical point AMIAD prefers to ship the monitoring equipment together with the pilot. This memo evaluates the various goals and options for on-line monitoring as a starting point for discussion and decision.

AMIAD pilot

The location of the AMIAD pilot is uncertain and may have some impact on the process chain. For now we assume the following:

- The pilot uses pre-treated surface water from the existing plant. Pre-treatment consists of intake, coagulant dosing mixing aeration and sedimentation. If Alum is used as coagulant, an extra step op alum removal by shallow media filters will be implemented in the pilot.
- The pilot consists of Microfiber filters. Initially a 7 micron size cartridge will be used, this may be adapted during the testing period.
- A separate chlorination unit is added to the pilot to provide disinfected water (concentration, contact time (Ct), temperature and pH conditions)
- On-line monitoring that is already planned:
    - Turbidity of influent (after pre-treatment)
    - Turbidity after microfiber filtration (care is needed not to include fine air bubbles)
    - Flow
    - Pressure inlet & outlet (dP)
    - Free chlorine

The water quality goals for the microfiber filtration pilot are:

- Removal of turbidity and total suspended solids (TSS) to improve acceptability
- High removal (3-5 log) of large pathogenic micro-organisms (*Cryptosporidium , Giardia , helminths)* was goal, other and some removal (0.5-1.5 log) of smaller pathogens (bacteria, viruses)

The water quality goals for the disinfection are:

- Inactivation of pathogenic micro-organisms (*Giardia* , bacteria, viruses, no effect on *Cryptosporidium*), theoretical reduction can be calculated (1 log for *Giardia* , many logs for bacteria and viruses)
- Improve color? Odor?
- Provide residual disinfectant to disinfect recontamination during piped and secondary distribution and storage.

Goals of on-line water quality monitoring

On-line monitoring can provide advantages over sampling especially when conditions vary over short periods of time. This may be variations is source water quality e.g. due to rainfall, seasonality or contamination events (industrial, life stock bathing, manure or pesticide run-off). On-line monitoring can also detect failures, e.g. leakage of filters or failure of dosing. The monitoring can simply register the variations or it can lead to action to respond to deviations from the desired situation. Where conditions are constant, an infrequent water sample is generally more efficient. The on-line monitoring at the pilot can serve several goals:

- (Automatically) Adjust the operation of the pilot (operational monitoring), e.g. backwashing, filtration rate etc.
- Assess the performance of the pilot for the project (under variable conditions)
- Assess how changes in water quality affect the performance of the pilot
- Assess the quality and variability of the source water for other pilot-treatment technology testing (to define test conditions)
- Assess the quality and variability of the treated water and how this affects health
- Assess how on-line monitoring for operation (as part of WSP) reduces health risks (include in QMRA), this could include the potential effect of increased turbidity of the effect of chlorination.

Possible on-line monitors

Besides the planned on-line monitoring there are several options that are discussed here for the value they add. Only ‘off the shelf’ solutions are discussed since they need to be readily available and work reliable under remote conditions.

Turbidity (TSS sensor or particle counter as an alternative?)

Turbidity provides a basic indication of the water quality and variability of source water (especially the occurrence of peak events) and the efficiency of particle removal processes like filtration. Although some researchers suggest turbidity removal as a surrogate for pathogen removal, other researchers did not find such a relation. Especially since turbidity is a bulk parameter that is influenced by many factors including particle size and material, it does not provide information about actual particle removal. The particles measured after a treatment process may not actually be particles that entered and passed the process since particles can be formed or transformed during treatment, affecting their impact on turbidity. Besides monitoring turbidity before and after the microfiber filtration process, turbidity monitoring can be considered:

- Measure turbidity in the source water, to monitor water quality variability and to assess the effect of the existing pre-treatment.
- Measure turbidity before and after microfiber filtration to assess efficacy of filtration
- Measure turbidity in the distribution system to assess the aesthetic water quality of the water received and how it varies.

- Correlate between turbidity peaks and chlorine demand – to try and simulate an early detection of possible contamination

Temperature

Temperature affects many aspects of water quality and treatment such as die-off rate of pathogens, growth rate of micro-organisms, efficacy of chlorination, chlorine consumption rate, transmissibility of (membrane)filters and coagulation-sedimentation. It is not expected that temperature will be affected by treatment, therefore a single temperature monitoring point can be sufficient. Temperature can also be an indication of sudden water quality changes e.g. due to rainfall.

- Measure temperature after filtration or chlorine injection, since that is a clean and controlled environment. This could be combined in the pH sensor.

pH+ORP

The pH of the water affects treatment processes of coagulation and disinfection with chlorine and the pH can also be changed by the processes. The pH of the river Caucery seasonally varies between 7.5 and 8.3. The effect of short term events (rainfall, spill) on pH is unknown.

A pH sensor often also measures ORP/redox, which can be used to monitor disinfection potential of chlorination directly.

- Measure pH in raw water (river/intake before coagulation) to adjust coagulant dosing and assess river water quality and variability in general. The added value of on-line monitoring versus sampling (strips or test kit) needs to be evaluated.
- Measure pH after filtration, this will also indicate stability of pH during coagulation and the conditions during disinfection (needed to calculate disinfection based on Ct. Given the pH range on river water the effect is limited, unclear what the effect of coagulation is)
- Measure ORP (Oxidation Reduction Potential) after chlorine injection to assess disinfection potential of chlorination. Some studies suggest a better correlation with inactivation than free chlorine measurements.

Oxygen

Sufficient oxygen is required in drinking water to prevent odor and taste problems (BIS tolerance level 5 mg/l according to Basavaraddi 2012). Source waters can have low dissolved oxygen levels (D2.1 par.4.4.1) and are generally aerated during treatment. Since contaminated waters can have high BOD content and BOD is not removed to a great extent by treatment, oxygen levels in drinking water may decrease in time during storage and distribution. So far no information is available about the occurrence of this problem. Best point to measure would be after the distribution system, when oxygen may be depleted. Oxygen has been identified as an indicator of level of groundwater pollution (Basavaraddi 2012) but currently no information about relevance in surface water. This parameter requires further study for its relevance for health monitoring in T4.1. The microfiber filtration pilot will not affect the oxygen level and therefore on-line monitoring in the AMIAD pilot does not seem appropriate at this time.

Electrical Conductivity (EC)/TDS

EC can be measured relatively easy and is sometimes combined with other sensors. In some areas salinity of groundwater exceeds the 500 mg/l guideline, which roughly corresponds to a conductivity of 500 to 1000 µS/cm. For surface water concentrations ranges of 50 to 50,000 have been reported within one river (See presentation WP4 14 May 2014 Israel), however it is unclear if this is actual variation at one point. The microfiber filter will not have an effect on salinity. Salinity can be of interest to assess the

general health from salinity and to identify the frequency and magnitude of water quality variations from rainfall or contamination events

Free chlorine
On-line free chlorine monitoring allows an accurate control of chlorine dosing. Free chlorine measured after chlorine injection provides insight in the chlorine dose. Additional measurement after the clear water tank, in combination with the flow, provides insight in the chlorine demand/decay and can be used to calculate the Ct. From this and the temperature and the pH the expected disinfection of the produced water can be calculated. Measuring chlorine after distribution at the tap provides insight in the level of protection during distribution, however this may be done more efficiently by sampling.

s::can spectro::lyserTM
The s::can spectro::lyserTM is a UV absorbance instrument that measures absorbance at 256 discrete wavelengths ranging from 200 to 700 nm. Each absorbance values is assembled in a broad-band spectral absorption curve for the sample water, which results in greater analytical capability compared to single wavelength UV254 instruments. Analysis of the absorption curve can provide equivalent measurements of several water surrogate parameters including TOC, dissolved organic carbon (DOC), nitrate, and turbidity, among others. Based on experience AMIAD would not recommend to use it in this remote location since it is too unique and too complicated to calibrate and to find spare parts.

***E. coli* 'sensor'**
Several systems for 'on-line' monitoring of *E. coli* exist. In fact these system automatically sample and process the water to get results within several hours. The current stage of development is such that they cannot operate stand-alone in the expected conditions in India since they will need regular maintenance and refilling. Use of this technology will be assessed either on location or in the laboratory over a short period as described in T4.5 (to be decided later). Sampling kits will be used to evaluate the technology as described in T4.3.

Nitrate
Nitrate is a contaminant that regularly exceeds guideline values. The concentration can be variable, indicating the variable level of contamination by human activities. This provides information for the general assessment of water quality and health risk in WP4. If samples (described in T4.2) indicate a rapid variability of nitrate concentrations it may be interesting to monitor nitrate on-line over a period of time. The microfiber filtration pilot will not affect the nitrate level and therefore on-line monitoring in the AMIAD pilot does not seem appropriate at this time.

Toxicity monitoring
Test kits that use fluorescent bacteria to assess general toxicity according to ISO 11348 exist and may be used (e.g. Checklight, Toxcontrol, decision in in T4.2). This procedure has also been automated to be used 'on-line'. At this time the system is too specific to be used in the remote circumstances. Toxcontrol on-line is available from Techspan India who is contacted for more information. It is not expected that the microfiber filtration will have a significant effect on general toxicity. At this stage it is not appropriate to install this in the AMIAD pilot.

Fluoride monitoring
Fluoride contamination above the guideline value of 1 mg/l occurs in groundwater supplies. Fluoride concentrations in surface water are generally low, for example 0.4 mg/l in the river Cauvery

(Venkatesharaju et al. 2010). Fluoride concentrations in groundwater are not expected to vary rapidly, and peaks of fluoride don't lead to acute health impact. So there is no need for on-line fluoride monitoring either in the AMIAD pilot or the groundwater pilot.

Arsenic monitoring

Arsenic contamination above the 10 µg/l guideline value occurs regularly in groundwater supplies. Arsenic contamination in river waters is generally low (<1 µg/l), but recharge from bedrocks and human contamination can lead to higher arsenic levels exceeding the guideline value (Smedley and Kinniburgh 2005). No data on Indian rivers is available at this time. At this stage it is not appropriate to install on-line arsenic monitoring in the AMIAD pilot.

Conclusions

AMIAD will install the following on-line sensors before shipping the pilot installation:

- Flow meter before filter
- Turbidity meter before filter
- dP (pressure difference) before-after the filter
- Turbidity meter after filter
- Free chlorine meter after chlorine injectors
- pH/ORP/temperature after chlorine injection
- UV spectrolyser is under consideration to gain experience

Suitable analysis techniques for samples will be identified in T4.1 and sampling programs will be designed in T4.2 and T4.3. These programs will consider additional on-line measurements either from the start or after initial sampling. Plan is to only use these temporarily e.g. during a study visit of days or weeks. Integration with the AMIAD pilot will only be implemented if this is convenient (e.g. for housing, power supply, data processing and storage). Potentially useful meters are show in red in Figure 1.

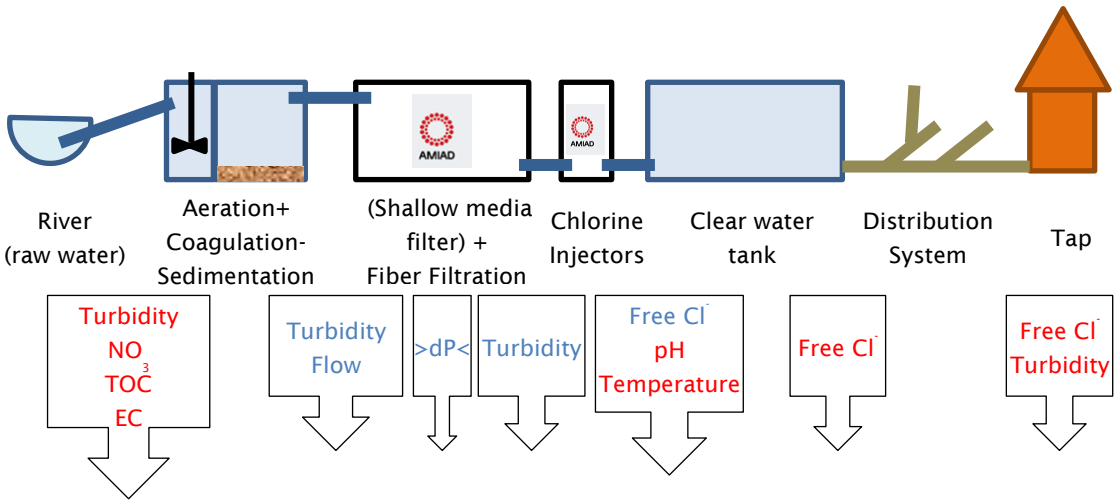

Figure 0.1 ***Illustration of integrated pilot test system and the planned (blue) and optional or temporary (red) on-line water quality monitors***