Inventory of water quality monitoring techniques suitable for Indian communities (D4.1 updated)

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CONTENTS

TERMINOLOGY AND ABBREVIATIONS

ADI	Acceptable Daily Intake
ADI	Acceptable Daily Unit
BIS	Bureau of Indian Standards
BOD	Biological oxygen demand
DALY	Disability-Adjusted Life-Years
FAO	Food and Agriculture Organisation
GC	Gas Chromatography
GC	Gas Chromatography
GV	Guideline Value
HPLC	High Pressure Liquid Chromatography
IEC	Education and Communication
ISO	International Organization for Standardization
NRDWP	Narional Rural Drinking Water Programme
NRDWQMSP	National Rural Drinking Water Quality Monitoring and Surveillance Programme
PCR	Polymerase Chain Reaction
QAQC	Quality Assurance & Quality Control
RGNDWM	Rajiv Gandhi National Drinking Water Mission(RGNDWM).
TDI	Tolerable Daily Intake
TDS	Total Dissolved Solids
TTC	Thermo-Tolerant Coliforms
UDWQMP	Uniform Drinking Water Quality Monitoring Protocol
UV	Ultraviolet
WHO	World Health Organisation
WQM	Water quality Monitoring
WSP	Water Safety Plan
YLD	Years of healthy life lost in states of less than full health (i.e. Years Lived with a Disability)
YLL	Years of Life Lost by premature mortality
WQM	Water quality Monitoring

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1 PUBLISHABLE EXECUTIVE SUMMARY

The overall objective of the Water4India project is to optimize drinking water treatment and supply in Indian communities facing challenges in terms of available water quantity and quality. Water quality monitoring contributes in several ways to this objective. This document describes how the various objectives of water quality monitoring described in report D4.2 lead to the requirements of monitoring techniques to meet these objectives within the project and within India. Objectives of monitoring can be awareness raising, operational, compliance, health risk assessment and assessment of treatment efficacy. The characteristics of various monitoring techniques were linked to the various objectives. Monitoring techniques need to be sufficiently sensitive to assess the health impact. However, there are also other technical and socio-economic criteria such as accuracy, specificity, cost, safety and ease of use. These needs may vary with the different objectives. Although microbial health risk emerging at the household level is highly relevant in rural India, routine monitoring at the household level isn't feasible due to costs, safety and complexity of methods. However, tests can be used as part of education and awareness raising at the household level. For awareness raising, accuracy is less important than safety, ease of use and costs, whereas accuracy is very important for evaluating treatment and costs are less of an issue. These considerations were brought together in a framework to evaluate monitoring techniques. The framework was applied to a range of microbial and chemical field test kits and laboratory techniques. Feedback from experience with some of the monitoring techniques to assess the performance of the Water4India solutions highlights the need for capacity building and an adequate supply chain for equipment and materials. This document can be used to select evaluated techniques and to evaluate alternative techniques that may be introduced during the project.

Current monitoring in India is focussed on compliance monitoring. The current Indian approach and the issues involved are described in the document. One important issue is the lack of a logical and systematic reporting and communication structure for water quality data. Results don't reach the person that needs to act on them, making monitoring obsolete. This issue cannot be resolved by the monitoring technique itself and needs organisational changes. This is beyond the scope of this report, but needs to be addressed in the project for monitoring to have an effect on water quality.

2 INTRODUCTION

2.1 Purpose of this document

Goal of the Water4India project is to provide solutions to improve drinking water supply in rural India. Improvements should lead to sufficient water of sufficient quality. This document focuses on the characteristics of available monitoring technologies to assess drinking water quality. Water quality assessment is needed to identify water quality issues that need to be solved, and to evaluate the improvement achieved by suggested technologies. Goal of the study was to provide an overview of various water quality monitoring techniques and their characteristics. Second goal was to develop a general framework to link these to the requirements of various monitoring goals and strategies identified. Thus the most appropriate monitoring technique can be selected in relation to the specific context.

2.2 Structure of the deliverable

The deliverable first introduces the various water quality monitoring techniques in Chapter 3. In Chapter 4 a framework is developed to evaluate monitoring techniques based on various criteria like the monitoring objective (D4.2) and the local situation (D2.2). This framework is applied to available techniques in Chapter 5. This includes feedback on application of selected techniques in the Water4India project. Conclusions are summarised in Chapter 6.

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). In order to assess the impact of improvements, both the current and the improved water quality need to be monitored. At the pilot scale this provides insight in the specific effect of the solution on water quality. Water quality monitoring is needed to identify the problems and feed them into the DSS in order to find optimized solutions for specific situations. At the regional or national scale water quality monitoring can help to identify priority areas or contaminants to which solutions can be applied. Contribution to specific project objectives as numbered in the DoW:

Objective 1: *Identify the main vulnerable areas suffering from water scarcity taking into account different factors such as current and future water availability, supply from centralised or decentralised sources, and qualitative and quantitative requirements of communities in the light of available sources and their quality.* **Contribution**: The inventory of water quality monitoring techniques provides the first step to assess the water quality of the available sources.

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 house keeping.* **Contribution**: Assessment of existing water quality monitoring technologies is the main subject of this report. The framework for selection of technologies allows the selection of the most

appropriate monitoring technology that will provide data for quantitative microbial risk assessment and water safety planning in the specific context of rural India.

2.4 Relationship to other deliverables and tasks

This document is closely related to the other deliverables in work package 4. The water quality monitoring techniques in task 4.1 (Water4India deliverable 4.1) need to be related the various objectives of water quality monitoring as described in task 4.2 (Water4India deliverable 4.2). These objectives lead to specific demands for analysed parameters, costs, sensitivity, specificity and complexity. The Water4India deliverables 4.1 and 4.2 are therefore closely related. Similarly, the testing of the pilot systems, described in Water4India report 4.3 required an assessment of available technologies and how they can be applied in rural India.

Water quality issues in India play a role in most tasks in the Water4India project. Although work package 2 focuses on water quantity, this cannot be separated from water quality, since sufficient water of poor quality doesn't lead to significant health improvement. The initial inventory of water quality issues in D2.1 and the focus on health related issues in D4.2 provided a background for the discussion on monitoring techniques and the parameters that are most relevant in the current report. Work package 5 provides insight in the stakeholders that can potentially benefit from the advice on improvement of water quality monitoring. Work package 5 also provides insight in the water quality parameters that are of interest to the community, which may be different from only the health related parameters. These insights were discussed in this document with respect to how they impact the monitoring technique requirements.

2.5 Contributions of partners

KWR had the responsibility to prepare this document and has performed much of the research into water quality monitoring in general and India specifically. Adin and Amiad have contributed by providing additional information on water quality monitoring in Chapter 4 and contributed to the discussion on monitoring technique selection. They also provided feedback on the use of these techniques during the pilot testing. Vertech contributed to the section on socio-economic aspects of monitoring.

2.6 Aims and objectives Task 4.1 in W4I

The aim of work package 4 (WP4) in the Water4India project was defined in the description of work (DoW): *The aim of Work Package 4 is to develop methods to assess current health risks from drinking water, to identify the important causes of risk in the water cycle and to assess the impact of the solutions developed in this project on health risks from drinking water. Chemical/toxic risks will be addressed by smart water quality monitoring and comparing outcomes to water quality standards. Microbial contaminants in drinking water and drinking water sources are highly variable and water quality analysis cannot provide full verification of drinking water safety. Microbial monitoring will therefore be combined with water cycle safety planning and quantitative microbial risk assessment.*

The aim of Task 4.1 in the Water4India project was defined in the DoW: *Suitable monitoring techniques for chemical/toxic and microbial parameters will be identified from contacts and literature study. The suitability for the Indian situation will be assessed by technical criteria (complexity, specificity, sensitivity,*

interpretation of the outcome) and socio-economic aspects (costs, ecological impact, social acceptance).

The task builds on the information and situation description in deliverables D2.1 and D3.1. More detailed information about the current water quality monitoring practice, water quality results and health impact in D4.2 were also used in the current study. The collection of information led to a slight adjustment of the focus of this document from the techniques to the interpretation and use of the data.

2.7 Changes in updated version (Task 4.6)

The original version of this deliverable was developed in August 2014 in Task 4.1. In Task 4.6 this deliverable was updated in August 2016 to include feedback from the activities in WP7 and to include most recent scientific insights. Due to the timing of the original document early in the project, it already contained elements of D4.2 Monitoring programs that were needed to develop 4.1. In the updated version the relevant chapters (chapter 3, 4 and 5 of the original D4.1 document) were moved to D4.2. Monitoring at the household level was included in the discussion on socio-economic aspects in paragraph 4.3, since task 4.4 highlighted the importance of safe treatment, handling and storage at the household level. The feedback from demonstration of the Water4India solutions in WP7 was included in Chapter 5 in the evaluation of the technologies.

3 MONITORING TECHNIQUES

3.1 Introduction

Monitoring can be performed in many ways. This chapter introduces the various types of monitoring and how they can be used. This is done in general terms, more specific evaluation of application is discussed in Chapter 5. There are no uniform definitions for the various types of monitoring, therefore the types and terminologies are based on their general use in the field or publications. Some monitoring technologies could fit under multiple described types, depending on the context.

3.2 Observations

Regular observation of a water supply system is an important way to detect potential deterioration of water quality. The WHO sanitary inspection guidelines in WHO (1997) provide a list of checks that can be made regularly. Examples of observations that indicate water quality deterioration are:

- breaches in fences to keep animals or humans away from water sources or stored water
- leakage of drinking water infrastructure
- chemical waste dumped near water sources or storage
- failing or missing water treatment equipment
- dead animals in water sources or storage

Regular inspections by trained staff that are aware of water related risks are essential preventive measures that will generally provide an alarm before deteriorated water quality is detected by other monitoring techniques.

3.3 Organoleptic water quality assessment

The color, turbidity, odor and taste of drinking water provide a first indication of the water quality. Increase of turbidity or color can indicate a deteriorated raw water quality, a failing treatment system or ingress of dirty water. Contaminants, especially pathogenic microorganisms, might be associated with increased turbidity in sources e.g. through run-off from agricultural land after rainfall. Decreased removal of turbidity by treatment is probably associated with reduced removal of pathogenic microorganisms and ingress of can also include chemical or microbial contaminants.

Odor and taste are not clear, absolute indicators of water quality. However, change of either parameter would indicate a change in the water supply system and therefore could lead to further investigations. The presence of chlorine, as a residual disinfectant, is easily detected by the odor and taste, and therefore also the lack of disinfectant.

3.4 Test strips and simple measurements

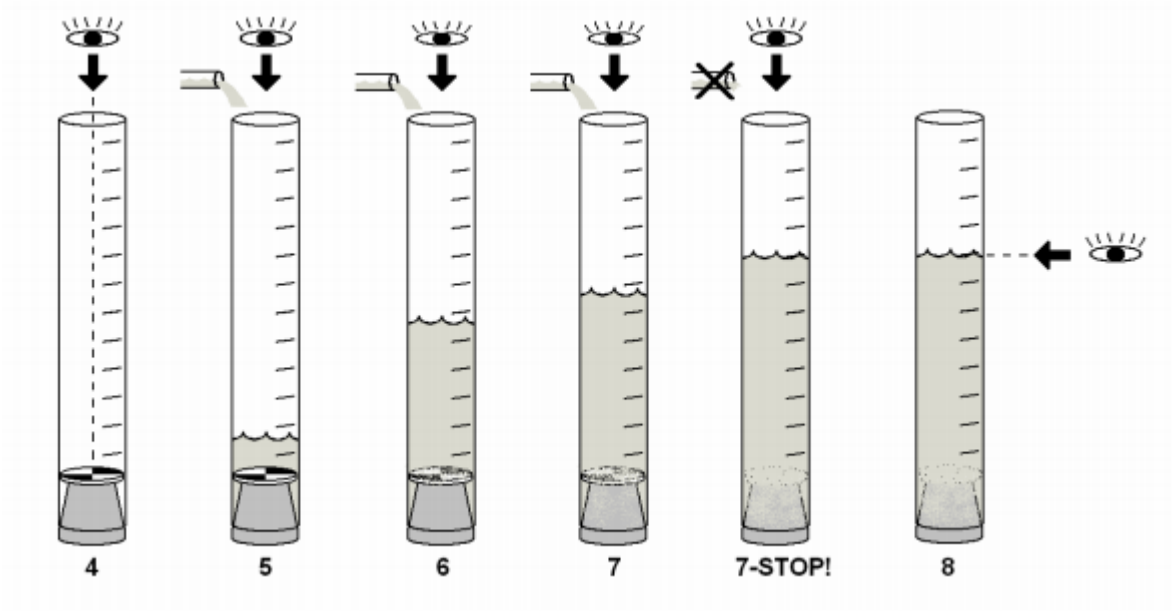
Test strips are available for various parameters and provide a first indication of water quality. Test strips for pH and chlorine content are typically used in low resource and emergency settings. The test strips are dipped into the water which causes a discoloration, which can be compared to a reference chart to estimate the value of the parameter. These tests are inaccurate, but cheap and easy to use. Nitrate testing strips are promoted to assess anthropogenic (agricultural) impact on water sources as part of water safety planning involving school children (Samwel and Möller 2009). Similar tests use droplets or

pills that cause a color change when added to water. Again the resulting color has to be compared to a reference chart.

Figure 3-1 Examples of test strips for pH and chlorine

Turbidity tubes are used to enhance the observation of water turbidity and get a more reproducible, quantitative scale than with observation in a glass. A turbidity tube is a transparent tube with a black and white pattern on the bottom. The tube is filled until the pattern can no longer be observed from the top of the tube (Figure 3-2). The number of centimeters of water in the tube is recorded and can be translated to a turbidity value (NTU) using a table. This method can be applied for turbidity values of 5 NTU and higher. Indian standards require 1 NTU with permissible relaxation to 5 NTU. Therefore, this method can only be applied to poor quality (raw) water. The secchi disk uses the same principle, but the black and white pattern is now printed on a disk attached to the end of a pole or line. The disk is submerged under water until the pattern is no longer visible, and the depth is read from a scale on the pole. This method is more suitable to assess turbidity in surface water.

Figure 3-2 Illustration how to use a turbidity tube



3.5 Field test kits

Field test kits can be regarded as small, portable laboratories that can be used to analyze specific parameters in the field. Typically, these are laboratory methods such as titration that have been miniaturized and standardized so that people with basic training can operate them. Reagents for specific parameters need to be obtained. A set amount of this reagent (pill, powder or drops) is added to the sample in a standard testing vessel (a cuvette). After allowing sufficient time for response, the cuvette is placed in a photometer which accurately reads the color and through an algorithm calculates and reports the corresponding concentration of the tested parameter. The accuracy can be close to a standard laboratory test, when the person operating it is well trained and experienced.

Some field test kits include basic microbiological parameters such as colony count, coliform bacteria and *E. coli*. These tests are based on culturing these bacteria, which requires time and the correct temperature. Tests therefore require energy, are more complicated and take more time. Also the sampling itself requires experienced staff since samples can easily be contaminated by hands or dirt. To increase sensitivity samples can be concentrated by filtration, or a larger testing volume is used. A whole range of technologies have been developed to overcome these difficulties in the field which will be discussed later.

Figure 3-3 Example of a water quality field test kit

3.6 Routine laboratory

A routine laboratory is capable of performing test of common water quality parameters according to standards. The context may have an impact on what can be considered a 'routine laboratory'. In highly developed context, a routine laboratory may be capable of more complex analysis than in a developing country. In India the sub-district laboratories can be considered routine laboratories, while the state labs can be considered research laboratories. The capabilities of Indian laboratories and their role in the Indian water quality monitoring program are discussed in more detail in report D4.2 Monitoring plans. Correct sampling, storage and transport and timely analysis are key issues when using laboratories for monitoring. Especially in rural India the time between sampling and analysis in a laboratory may take too long to obtain reliable results.

3.7 Research laboratory (advanced)

A research laboratory may have the facilities to perform very advanced analysis of parameters that require more expensive equipment and highly trained staff. Analysis can include heavy metals, toxic elements, pesticides and pathogenic viruses, bacteria and protozoa using microbial molecular techniques like PCR (polymerase chain reaction) or NGS (next generation sequencing). As a result, these analyses are generally expensive and transportation issues become more challenging since there are only a few research laboratories.

3.8 On-line monitoring

Some parameters can be measured by a sensor, making it possible to continuously monitor water quality. Commonly used on-line monitors for water quality monitoring or process control are

- turbidity,
- temperature
- conductivity (TDS)
- pH
- chlorine
- UV extinction

A small side-stream of the water is led along an electrode or through a measuring chamber where the actual measurement takes place. These measurements are used to trigger alarms, to adjust process conditions (manually or automatically) or to identify trends. More recently developed sensors that are applied in practice are UV-VIS (spectral UV measurement to assess various organic compounds including DOC) and particle counting. New measuring principles are continuously developed, tested and implemented. Typically on-line measurements cannot directly detect contaminants, only bulk water characteristics.

Bio-monitors have been developed to detect toxic compounds on-line. Algae, daphnia, mussels or fish are constantly fed with the water. When a contaminant occurs in the water, these organisms will respond by reducing fluorescence (algae), changing behavior (daphnia, fish) or closing their shells (mussels). Such a response generates an alarm to stop water intake or distribution and to start further investigation to identify the cause.

Development of on-line monitors for micro-organisms is ongoing. Some systems can measure total bacteria content, however that is not relevant since also safe, healthy water contains (harmless) micro-organisms. Some systems can detect indicator bacteria like *E. coli* to detect fecal contamination. These are not real on-line systems since the measurement takes some time for culturing bacteria or stimulating enzyme production. Systems can automatically sample and analyze the water at a fifteen minute to three hour interval, providing results at the end of each interval. Most of these systems are in the prototype or demonstration stage.

4 FRAMEWORK TO EVALUATE MONITORING TECHNIQUES

4.1 Evaluating monitoring techniques

This study set out to identify monitoring techniques that are suitable for the Indian context and the goals of the Water4India project. Monitoring techniques can be characterised by technical and social aspects. Some monitoring techniques can be qualified as not suitable based on these aspects. Examples are monitoring techniques that require expensive equipment (economic aspect) advanced equipment (technical aspect) or results that are hard to interpret (social aspect). To select only the relevant monitoring techniques for small Indian communities, criteria need to be set.

UNICEF (2005), the TECHNEAU project (Mons, 2008) and Bain et al., (2012) developed methods for evaluating monitoring techniques. From these evaluations we can learn about important test characteristics to select appropriate test methods for the required situation (Table 4-1). The Unicef (2005) evaluation method ranks monitoring techniques according to weighted impact factors (scale 1-10) of 4 parameters. The technical efficiency impact weighs heavier (6x) than safety impact (2x), adequacy impact (1x) and information impact (1x), shown in Table 0-1. Mons (2008) developed an evaluation form (Table 0-2) to rate technical specifications (sensitivity, robustness and time to result), operational specifications (ease-of-use, maintenance requirements) and costs (instrumentation and operation). The rating is on an arbitrary scale from 1-5 and indicates very low to very high and very poor to very good. Besides, each evaluation form includes a recommendation for use in small-scale systems (no, yes, strong). Bain et al. (2012) list important characteristics which should be considered when selecting a test for faecal indicator bacteria in drinking water. The characteristics include costs, time, technical staff & laboratory equipment and information provided (see Table 0-3). The information on the characteristics was compiled for 44 tests. According to monitoring requirements (resource availability and purposes of testing) the reader can select suitable tests to evaluate bacterial drinking water quality.

The examples of methods to evaluate monitoring techniques have in common that two factors are important (see Table 4-1): (1) required resources, such as costs, laboratory and personnel equipment and (2) the information provided, such as the test reliability and sensitivity. For the Indian situation, ideally the most relevant information to enable health improvement is retrieved at minimal costs and potential negative impact. Required resources can be expressed as the social-economic factors. The local situation and purpose of the test determine the requirements on the information provided by the monitoring technique. The information provided is determined by the technical aspects. The aspects are explained in the following paragraphs. Annex 1 provides more details from the other evaluation studies.

Table 4-1 Important characteristics for selecting relevant monitoring techniques in evaluation studies

	UNICEF (2005)	TECHNEAU (2008)	Bain et al. (2012)
Required resources / Socio-economic factors			
Costs		X	X
Availability			X
Laboratory equipment		X	X
Analysis time		X	X
Trained personnel		X	X
Infrastructure & logistics		X	
Ease of use & interpretation	X	X	
Risk of use	X		
Environmental impact	X		
Information provided / Technical factors			
Robustness	X	X	
Sensitivity	X	X	
Specificity	X		X

4.2 Technical Criteria

The technical characteristics of monitoring techniques determine the test performance. The test performance itself determines which information is generated. The required information is dependent on the purpose of testing. Especially, the requirements for test sensitivity or specificity are very dependent on the purpose of testing. The performance of a test method is determined by several analytical validation parameters, listed below:

1. accuracy (result close to true value),
2. precision (closeness of results of repeated individual measurements),
3. robustness (sensitivity to operational variations),
4. sensitivity (limit of detection/quantification),
5. specificity (reaction to a wide variety of chemicals) and
6. selectivity (measure for matrix interference),
7. sample stability (to test the influence of sample preparation).

The accuracy of a test method is a measure if the result is close to the true value. Generally, field test kits are available at relatively low prices, but their analytical accuracy is generally less than that of the analytical methods (WHO, 2008). For field kit test it is therefore necessary to check the validity of the field test kit before applying it. The precision of a test method is a measure of the closeness of the results (scatter) of repeated individual measurements. A good precision indicates that the test methods produces similar outcomes for similar measurements. The accuracy and precision are strongly related and will be regarded as one criterion in the framework for selecting monitoring methods.

The robustness of a test method is a measure for the sensitivity to operational variation. The test method should remain unaffected by variations in method parameters such as the water quality with respect to other parameters. A more robust method is generally more easy to use as it is less sensitive to small errors made by the analyst. The sample stability of a test method is a measure for the influence of sample preparation, for example quenching of residual chlorine to stop reactions in the sample. This is closely related to the robustness of a method and will be regarded as one criterion in the framework for selecting monitoring methods.

The sensitivity of a test method is a measure for at very low concentrations. The sensitivity can be expressed by the detection limit or the limit of quantification. The detection limit of an individual analytical procedure is the lowest amount of analyte in a sample which can be detected but not necessarily quantitated as an exact value. The quantitation limit of an individual analytical procedure is the lowest amount of analyte in a sample which can be quantitatively determined with suitable precision and accuracy. The sensitivity of a test method is dependent on test purposes.

The specificity of a test method is a measure for the reaction to a specific variety of chemicals. The specificity is very dependent on the purpose of testing. Test methods with low specificity can usually be accompanied by supporting techniques to obtain more specific results by further testing. The selectivity of a test method is a measure for matrix interference. Specificity and selectivity are closely related and will be regarded as one criterion in the framework for selecting monitoring methods.

Interpretation of the outcome evaluates how the test result can be translated to action. Tests can have various types of results (concentration, presence/absence etc.) and interpretation depends on the context. Field tests often come with a form of interpretation, e.g. "*if all test compartments turn green, boil the water to prevent diarrhoea*" versus "0.1 µg/l".

4.3 Evaluating socio-economic aspects

The selection of an appropriate monitoring technique is affected by some aspects such as: costs, ease of use, sensibility and timeliness. Socio-economic aspects are mainly the considerations that describe required resources: costs of infrastructure, equipment and consumables, level of training of technical staff and logistics. Besides, the consequences of testing such as human and environmental safety or impact are discussed.

The testing costs consist of the instrumentation and operational expenditures (Mons, 2007). The costs of field kits are often expressed as the costs per 400 or 500 kits. Field kits provide a sustainable and cost-effective water quality-monitoring tool, which can test the water source effectively and periodically. These kind of kits represent an useful management tool to decision-markers to decide about the sustainable and cost-effective tool in India (UNICEF, 2005) Besides, shipping and importation costs can enlarge this amount. The costs associated with required specific equipment or materials also influence the total costs related with the monitoring technique. Operational costs include manpower, consumables and maintenance of the equipment (Chilundo et al., 2008). The availability in India states that the specified monitoring equipment or field kits can be provided.

In order to carry out specific analysis, additional equipment and materials could be required. For instance, the requirement of ultraviolet light for the detection of fluorogenic substrates. Field kits

normally do not require extra equipment and/or materials. The required equipment and materials determine what sort of laboratory is needed for conducting the analysis. For example, only in the state laboratory in India the Gas Chromatography (GC) and High Pressure Liquid Chromatography (HPLC) can be performed (Government of India, Ministry of Drinking Water and Sanitation 2013).

Besides equipment, training of personnel could be required to perform specific analysis. Normally, field kits are easy to use and do not require specific training. However, the use of standard microbiological techniques require training, for instance.

In addition to the chemical or microbial analysis, monitoring includes the distribution of physical material (samples) and data logistics. The infrastructure needed for the transportation of products and information should function properly. This also includes the logistics on distribution and most important the feedback, in information cycles.

The ease-of-use is the measure for easy handling during measurements. The ease-of-use increases if instructions are clear, the number of actions is limited and actions are 'fail proof' (e.g. no measurements required, no risk of contamination).

The acceptability of methods used can be an issue in some particular cases. For instance, some microbial methods produce a strong odour, making the methodology quite unattractive.

On the other hand, there is the "risk of use" which is the human hazard during handling of monitoring equipment and materials. The safety impact by UNICEF (2005) includes the hazard involved in using techniques or field kits, leakage of chemicals or gases and the packaging of chemicals.

Another aspect to consider is the "environmental impact", wich is the ecosystem hazard due to usage of the monitoring equipment and materials. In this sense, the used materials and chemicals should be disposed of in a safe manner. Culture based microbial tests may also culture pathogens, and these products should be treated as faecal waste. In the case of excess reagents (hazardous chemicals) and packaging (plastic and glass) can end up in the environment.

These aspects combined influence the overall complexity of a test in terms of equipment and/or operation. WHO has ranked the complexity of analytical (laboratory) methods for inorganic and organic chemicals (see Annex 2). WHO ranks volumetric method colorimetric method and HPLC as the least complex methods (WHO, 2011). Nevertheless, in the case of HPLC requires expensive laboratory instruments with computer interfaces and, in some cases, several inputs (which represents the necessity of special training).

The socio-economic aspects are especially relevant at the household level. Microbial water safety in rural India largely relies on handling, storage and treatment of water in the household (see report D4.4). Routine monitoring at the household level could consist of weekly microbial samples. The overview in Annex 3 includes basic tests that cost around $1, amounting to $52 per year only for microbial testing. The economic assessment in report D2.2 indicated an annual income of approximately $600, so monitoring take up too much of this budget. In addition these tests introduce risks since bacteria are are cultured, and this could include pathogenic bacteria. Logistics, waste production, consistent execution of monitoring and interpretation of results also don't favour microbial water quality monitoring at the

household level. It is therefore not feasible to test microbial water quality in every household on a routine basis due to costs, complexity and risk. Basic tests could be used to educate people and create awareness of the need to treat and protect water in the household. Water quality testing could be a tool of educational program on water and hygiene in schools (Samwel and Möller, 2009). Adequate testing of the household treatment technologies through the WHO program is performed with advanced techniques in laboratories. This could be supplemented with simple, built-in, monitoring of the condition of the technology, e.g. to indicate depletion of chlorine or leakage of filters. Development and implementation of these concepts to verify performance in the field can improve water safety in the household.

4.4 Weighting various aspects

Since some aspects may be considered more important than others, weighting of scores is applied in some evaluations, for example by UNICEF (2005). This is important when a total score of a technique is determined in the evaluation. Other studies (Bain eta l. 2012) don't use weighting and don't calculate a total score. Instead they made a general evaluation whether a method is appropriate for a low resource setting.

Since the choice and number of criteria and their score are more qualitative than quantitative, applying weighting can lead to a false sense of accuracy. For the current framework no weighting was applied. Instead criteria are judged on a pass/no-pass basis. If one criteria does not fulfil the requirements for the evaluated objective and setting, the test is simply not suitable. This will be clarified when the framework is applied.

4.5 The framework for selecting water quality monitoring techniques

The examples of evaluating monitoring techniques (UNICEF 2005, TECHNEAU 2008 and Bain 2012) highlight the complexity of comparing tests and selecting the optimal test for a given situation and purpose. Given the fact that the government of India has already supplied most gram panchayats with field test monitoring kits and that a programme for setting up an network of laboratories is being implemented, the framework for selecting techniques will be directed towards that situation. The goal is not to redo the excellent work that is already available. The current framework will focus on how to use the existing information to make selections for the identified issues and situations in India.

4.5.1 Monitoring parameters

The framework focuses on monitoring parameters that can have a significant impact on health. This does not include all regulated parameters. By focussing on a limited number of parameters, resources are directed towards the maximum possible health gain. The previous discussions have indicated the following parameters:

- Nitrate: as indicator of human contamination or health issue
- BOD: as an indicator of human contamination or health issue
- *E. coli* : as indicator of faecal contamination or health issue
- Fluoride: as an important health issue in specific areas
- Arsenic: as an important health issue in specific areas
- Turbidity, colour, odour: as measure of organoleptic acceptability

- Pesticides: as a potential (future) health issue
- Heavy metals: as a potential (future) health issue
- Pharmaceuticals: as a potential (future) health issue
- Pathogens (V. Cholerae, *Giardia* , *Cryptosporidium* , enteroviruses, Hepatitis virus, ...): to assess microbial health risk
- Process conditions (temperature, pH, flow, chlorine levels): to assess the state of the treatment at the moment of sampling, possibly to model treatment efficacy

4.5.2 Monitoring objectives

Objectives of monitoring are discussed in D4.2 Monitoring programs. Five main goals of monitoring can be identified and summarised as:

- **Awareness raising**: to be performed at the grass root level. Monitoring needs to provide insight how the behaviour (e.g. open defecation) affects drinking water quality and ultimately how drinking water quality relates to health. Key aspects are low costs, simple test and interpretation, poor accuracy.
- **Operation**: to be performed by local responsible persons at habitation or gram panchayat level. Monitoring needs to provide key information about water quality variations that require operational actions. Key aspects: both influent (high contamination), effluent (low contamination) and process conditions measured with some quantification. 'Indicator' parameters are sufficient (actual hazardous contaminant not measured). Short time to result, so performed locally by people with basic skills but no lab.
- **Compliance monitoring**: this is described in the national monitoring program, includes current field test kits and laboratory analysis at different levels
- **Assess effect of W4I solutions**: analysis performed locally by personnel with additional training or student, sample conservation for later analysis in labs. Both indicators and actual hazardous parameters will be measured, and in addition process parameters. Quantitative an accurate, quantitative analysis is needed in influent (high concentration) and effluent (low concentration), therefore costs may be higher.
- **Health risk assessment**: performed at state or national level by highly skilled personnel. Requires accurate, quantitative measurement of the hazardous substances (chemicals, pathogens) and how they relate to the compliance monitoring parameters. This monitoring will be more costly. Lab analysis needs to be combined with field data from compliance monitoring.

4.5.3 Combining parameters, objectives and monitoring characteristics

The required characteristics of monitoring techniques are related to the monitoring objectives and the parameters. Table 4-2 provides an overview of the essential parameters for various objectives and the characteristics that are relevant for that application. For example, visual inspection of source water turbidity (e.g. in a 'standard' glass) may provide sufficient accuracy for a treatment operator to make decisions on treatment settings. Therefore accuracy and sensitivity are scored '-' meaning not important. However, turbidity after filtration should be quite low, and detection of sub-optimal performance therefore requires a more sensitive method, leading to '+' score. Since operation is a daily practice at each treatment site, it is important that costs are low, so costs score '+'. When the objective is to evaluate a W4I solution for particle removal, an accurate turbidity measurement of influent and effluent

is needed (accuracy='+'), however costs are less relevant since it is a temporary action at a single location (cost='-').

The column 'options' in Table 4-2 lists the type of analysis that would be possible, e.g. a visual observation, a field test kit or analysis in a laboratory. Table 4-2 forms the basis for selecting suitable field test kits in Chapter 5.

Table 4-2 Monitoring technique characteristics required for various objectives

			Accuracy / precision	Robustness / stability	Sensitivity	Specificity / selectivity	Interpretation	Ease-of-use	Cost	Availability	Infrastructure & logistics	Acceptability	Risk of use	Environmental impact	Options
Awareness															
	Human impact														
		Nitrate	-	+	-	-	++	++	++	++	++	+	+	++	Test strip/Field kit
		Indicator organisms	-	+	+	+	++	++	++	++	++	+	+	++	Field kit
Operation															
	Source														
		Turbidity	-	+	-	-	++	+	++	++	++	-	+	+	Visual/Field kit/on-line
		Arsenic	+	+	-	+	++	+	++	++	++	-	+	+	Field kit
		Fluor	+	+	-	+	++	+	++	++	++	-	+	+	Field kit
	Sedimentation														
		Turbidity	-	+	-	-	++	+	++	++	++	-	+	+	Visual/Field kit/on-line
		pH	+	+	-	-	++	+	++	++	++	-	+	+	Test strip/Field kit
		Alum	-	+	-	-	++	+	++	++	++	-	+	+	Field kit
	Filtration														
		Turbidity	-	+	+	-	++	+	++	++	++	-	+	+	Visual/Field kit/on-line
	Disinfection														
		Temperature	+	+	-	-	++	+	++	++	++	-	+	+	Thermometer/on-line
		pH	-	+	-	-	++	+	++	++	++	-	+	+	Test strip/Field kit
		Turbidity	-	+	-	-	++	+	++	++	++	-	+	+	Visual/Field kit/on-line
		Free chlorine	+	+	+	-	++	+	++	++	++	-	+	+	Field kit
		Indicator organisms	-	+	++	+	++	++	++	++	++	+	+	++	Field kit
Compliance	SEE GUIDELINES														Field kit + lab
	routine monitoring param.		+	+	+	+	+	+	++	++	++	-	+	+	Field kit/lab
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
Health risk assessment															
	Microbial														
		Indicator organisms	+	+	+	+	-	-	-	-	+	-	-	-	Field lab/lab
		Pathogens	+	+	+	+	-	-	-	-	+	-	-	-	Lab
		Source tracking	+	+	+	+	-	-	-	-	+	-	-	-	Lab
	Chemical														
		Arsenic	+	+	+	+	-	-	-	-	-	-	-	-	Lab
		Fluor	+	+	+	+	-	-	-	-	-	-	-	-	Lab
		Heavy metals	+	+	+	+	-	-	-	-	-	-	-	-	Lab
		Pesticides	+	+	+	+	-	-	-	-	-	-	-	-	Lab
		Pharmaceuticals	+	+	+	+	-	-	-	-	-	-	-	-	Lab

5 EVALUATED MONITORING TECHNIQUES

The Indian government provides an overview of accepted field test kit producers:
http://www.indiawaterportal.org/sites/indiawaterportal.org/files/FTK_MANUFACTURERS[1].pdf
For many test kits it is hard to find details on sensitivity, ease of use, risk etc. Therefore tests cannot be evaluated by manufacturer. Rather, testing principles were used for evaluating the technology.

5.1 Microbial field kits

An elaborate review of available microbial field test kits was provided by Bains et al. (2012). The summarising tables from this publication are included in Annex 3. Based on the criteria in Table 4-2 appropriate monitoring techniques are selected from these tables. The relevant attributes (columns) of the various field test kits are discussed and applied in order of importance.

5.1.1 Indicator

Indicator Field test kits only test for indicator organisms, not for the actual pathogens. The specificity for faecal contamination varies between tests. Colony counts merely indicate the presence of culturable bacteria regardless where they come from. A very low colony count suggests absence of contamination, but counts can be high even in absence of (faecal) contamination due to growth of (harmless) bacteria in the environment. A high total coliform count is a stronger indicator of faecal contamination, however it may also grow in the environment and is therefore a poor indicator of faecal contamination. *E. coli* is a specific indicator of recent faecal contamination and therefore preferred, and thermotolerant coliforms (TTC) is also acceptable. Only tests including EC or TTC in the column 'Indicator' are therefore considered. This coincides with 'sanitary significance' of ++ or +++.

5.1.2 Sensitivity

The sensitivity of microbial tests is mainly determined by the sample volume. The WHO guideline is absence of *E. coli* in 100 ml, and tests that comply to this are marked + in that column. Some tests apply a smaller volume of 1-10 ml. Although presence of *E. coli* in this volume indicates a high microbial risk, absence of *E. coli* does not provide an indication of a low risk. Even absence in 100 ml is not a guarantee for safety, but it is ten to a hundred times safer than the smaller volumes. Therefore, only tests that comply with the WHO guideline of 100 ml volume are considered.

5.1.3 Precision

The required precision of the microbial test depends on the monitoring objective as indicated in Table 4-2. For awareness raising, the precision of the test is not important, and a presence / absence test can be sufficient. For operation of surface water, it is relevant to regularly test the treated water for faecal indicators to assess whether the treatment is operating correctly. This requires a more precise, quantitative test to differentiate between major or minor failure. So single '+' is required. High precision (+++) is needed to test W4I solutions so that efficacy over time can be assessed accurately.

5.1.4 Required capacities and materials

Many tests need trained technicians and materials to provide controlled incubation, identify sample response with UV light, sterilise equipment, produce deionised water or for cold storage of reagents. These are all requirements that cannot be met in a typical rural Indian setting. Tests that require these resources are not feasible for awareness raising or operational purposes. They might be considered for testing the W4I solutions, although that does introduce the risk of problems, e.g. due to power failure. Remarkably, the more simple presence-absence tests all require controlled incubation, UV light and sterilisation, and are therefore not preferred.

5.1.5 Cost

In India, the financial and technical support for rural and urban water supplies are provided by the central government while the planning, designing, construction, operation and maintenance is undertaken by state government agencies. While larger cities have their own laboratories for testing water, institutional framework for water quality monitoring and data processing is inadequate in rural areas.

Cost is an important factor for selecting field tests that need to be performed regularly. Membrane filtration techniques are relatively cheap per sample but need investment to set up a basic laboratory, or expensive mobile installations. Tests for which the 'Cost of specialist equipment' exceed $500 are therefore not considered feasible for monitoring where costs are important. The cost per test ranges between $0.50 and $7.50. This means that for the price of one test one could also get 15 other tests. Remarkably the more expensive tests don't seem to provide much benefits compared to cheaper ones. The costs per test are typically lower for membrane filtration tests, however these should be considered laboratory tests in the Indian setting. Tests with less sanitary significance are on average cheaper than tests for *E. coli* or TTC. However this is not true for each individual test. Costs will be discussed further when selecting tests.

5.1.6 Selecting tests

For awareness raising, the compartmentalised bag test seems to be the most easy to use by untrained people in tough field conditions. At $10 per test a quantitative (MPN) result for *E. coli* is obtained without the need for a trained technician or specific materials. The test would also be feasible for operational purposes. Unfortunately this method has not (yet) been approved to use for compliance monitoring. Approved alternatives are coliscan easygel ($2.20), multiple tube (LTB/EC-MUG) ($3.50) or Colilert/Quantitray ® ($5.50). However, these techniques need a trained technician, controlled incubation and sterilisation of equipment. The Readycult ® and E*Colite (both $3.00) are approved presence/absence test that don't need trained technicians. Other approved tests are more costly.

5.2 Detection of chemicals and elements

Here in this section the applicability of different analytical techniques for arsenic, fluoride, iron and chloride are evaluated as well as solutions for organic pollutants are discussed. Only a brief and comprehensive overview will be given. An elaborated review, more information and names of test kids can be found elsewhere (UNICEF, TECHNEAU D3.13, WHO drinking water guideline). Table 5-1

summarises a few available advanced analytical techniques and their applicability per metal. This table contains more metals than will be discussed in this section.

Fields test kids are all more or less indicative. They are often related to the standard lab test. For the evaluation one has to rely on chemical reactions that will result in a colour change on a test strip. The results of these test kids are therefore qualitative or semi-quantitative. However, the detection limit is often sufficient and does in most cases meet the requirements set by the ISO 10500 and WHO (see D4.2).

Arsenic concentrations in drinking water should not exceed 10 ppb and available tests allow the detection of arsenic down to <1 ppb and up to values higher than 500 ppb. These tests should only be performed by someone who is properly trained, as false positives or negatives can be equally harmful. Prices for these tests range from ₹10 to ₹77 per test ($0.16-$1.23).
Lab bench tests using SDDC (Silver Diethyldithio Carbamate) can detect 10 ppb of arsenic and are also suitable. For the detection of arsenic, however, there are several chemical reactions available. The most famous one is the Marsh test (detection limit 1 ppb). Only commonly available reagents are needed. Next to this one also Berzellius, Bettendorf, or Gutzeit reactions can detect arsenic at low concentrations.
Advanced analytical techniques such as FI-HG-AAS (flow injection-hydride Generation-Atomic Absorption Spectrometry) can also be applied. The limit of detection (5 ppb), however, is not better than for other techniques. Also ICP-MS qualifies for the detection of arsenic at this concentration. It has to be noted that costs for the ICP-MS are higher than for AAS. Other possible methods are FAAS, EAAS and ICP-OES. Here the detection limit might not be sufficiently low.
Given that costs and speed of the tests are important, field test kits or lab bench experiments are favourable in remote areas. If advanced equipment is available this should be used as generally more experienced personal is operating them and the chance of misjudgement of the results is significantly lower.

Table 5-1 Overview of advanced analytical techniques for different metals. (from Mons 2008)

Parameter	Parametric value DWD [mg/L]	Sensitivity required [µg/L]	Graphite furnace AAS	Hydride Generation AAS	Cold vapour AAS	Cold vapour AFS	Flame AAS	ICP-OES	ICP-MS
Antimony	0,005	1,25		x					x
Arsenic	0,010	1,0		x					x
Boron	1,0	100						x	x
Cadmium	0,005	0,5	x						x
Chromium	0,050	5,0	x						x
Copper	2,0	200	x					x	x
Lead	0,010	1,0	x						x
Mercury	0,001	0,20			x	x			
Nickel	0,020	2,0	x						x
Selenium	0,010	1,0		x					x
Sodium	*200*	*20000*					x	x	x
Calcium	-	-					x	x	x
Magnesium	-	-					x	x	x
Aluminium	*0,50*	*50*	x					x	x
Iron	*0,20*	*20*	x					x	x
Manganese	*0,050*	*5,0*	x					x	x

Field tests for **fluoride** are qualitative and semi-quantitative. The detection range meanders between 0.0 ppm and 3 ppm. This test range is sufficient considering that the guideline value is 1.5 ppm. In comparison to the field tests, the lab bench methods SPADNS (Sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate) and the specific ion electrode method are considerably more sensitive, 0.1 ppm and 0.01m respectively. The specific ion electron method is also the only reasonable laboratory method. In view that the guideline value is relatively close to the test kits range, application of advanced detection methods can be recommended if possible.
The costs for the field kits are in the range of ₹5 to ₹12 per test. The ion electron method is relatively cheap compared to the ICP-MS for arsenic and therefore maybe an alternative for the chemical detection methods

Field test kits for **iron** cover the range from 0.05 ppm to 1 ppm meaning that they are suitable as the guideline value is 1 ppm, but they are also at best semi-quantitative. The limits of detection for the lab bench method (phenthroline colorimetric) and AAS (atomic absorption spectrometry) are 0.05 ppm and 0.01 ppm, respectively. Therefore, all these methods are employable. In view that the guideline value is relatively close to the test kits range, application of advanced detection methods can be recommended if possible.

Cost per test can range from ₹5 to ₹31. There is a factor of 6 between the two extremes. The cost can hence vary significantly depending on the test. Remarkably, the most costly test seems to be the least reliable one. It is advised to consult the UNICEF list for field test kits.

Nitrate concentrations can be tested using field test kits which are semi-quantitative. The detection range is 0.5 ppm to 10 ppm. Given that the guideline value is considerable higher, namely 45 ppm, these tests should definitely be sufficient for water analysis. Alternatives are the lab bench test (Deverda's Alloy reduction, 0.5 ppm) and the specific ion electrode method (0.1 ppm). Detection limits are , however, not significantly better. Considering costs for lab and analytical equipment, the field test is probably the most reasonable choice. Cost per test range from ₹5 to ₹23.

Chloride field test kids are semi-quantitative and the range of detection spans from 0 to 1000 ppm. The guideline value is 600 ppm and the desirable value is 200 ppm (taste is affected at around 250 ppm). Both values can easily be checked with field test kits. As an alternative trimetric methods (argentometry) can be applied. The minimum that can be detected is 5 ppm. Advanced analytical techniques are not recommended for this anion. The cost per field test are about ₹50. This is relatively high compared to the other field tests. However, as chloride does not pose an imminent threat to human health, this should not be a problem.
It is worth mentioning that there are multi-parameter kits that are not mentioned here. These can detect fluoride, iron, nitrate, chloride and chlorine as well determine the pH and hardness of water.

There is a wide range of **pesticides and organic pollutants** that can be encountered in the environment. As field tests are often target specific, either the to-be-expected compound should be known or several test have to be conducted. For this reason advanced analytical techniques such as GC-Fid, GC-MS, LC-UV or LC-MS are the most suitable ways of detection. These techniques are reliable and are highly sensitive. However, a laboratory with skilled and trained personal is unavoidable, which makes detection of these compounds extremely costly. Detailed information on analytical techniques can be found in the WHO drinking water guidelines (WHO2011) and in Tables 7.2, 7.3 and 7.4. Here, for a wide range of organic chemicals, the analytical techniques are mentioned.

Table 5-2 Analytical achievability for organic chemicals from industrial sources and human dwellings for which guideline values have been established (from WHO 2011).

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Benzene			+++						+++					
Carbon tetrachloride				+++					+++					
1,2-Dichlorobenzene			+++	+++				+++	+++					
1,4-Dichlorobenzene			+++	+++				+++	+++					
1,2-Dichloroethane				+++					+++					
1,2-Dichloroethene			+++	+++					+++					
Dichloromethane				+++					+++					
Di(2-ethylhexyl)phthalate								++						
1,4-Dioxane								+++						
Edetic acid								+++						
Ethylbenzene			+++						+++					
Hexachlorobutadiene			++	++					++					
Nitrilotriacetic acid		+++						+++						
Pentachlorophenol				+++				+			+			
Styrene			+++						+++					
Tetrachloroethene			+++	+++				+++	+++					
Toluene			+++						+++					
Trichloroethene			+++	+++				+++	+++					
Xylenes			+++						+++					

Table 5-3 Analytical achievability for organic chemicls from agricultural activities for which guideline values have been established (from WHO 2011).

	Col	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Alachlor				+++				+++						
Aldicarb											+++			
Aldrin and dieldrin				++				++						
Atrazine and its chloro-*s*-triazine metabolites				+++				+++				+++		
Carbofuran		++												
Chlordane				+++				+++						
Chlorotoluron								+++				+++		
Cyanazine				+++				+++				+		
2,4-D				+++				+++				++		
2,4-DB				+++				++				++		
1,2-Dibromo-3-chloro-propane				+++				+++	+++					
1,2-Dibromoethane				++				++	+++					
1,2-Dichloropropane				+++					+++					
1,3-Dichloropropene				+++					+++					
Dichlorprop				+++				+++						
Dimethoate								+++						
Endrin				+++				+++						
Fenoprop				+++								+		
Hydroxyatrazine							+++					+++		
Isoproturon								+++				+++		
Lindane				+++				+++						
MCPA				+++				+++				+		

Table 5-4 Continuation of Analytical achievability for organic chemicals from agricultural activities for which guideline values have been established (from WHO 2011).

	CoI	GC	(PT-) GC-PD	(PT-) GC-ECD	GC-FID	GC-FPD	GC-TID	GC-MS	PT-GC-MS	HPLC	HPLC-FD	HPLC-UVPAD	EAAS	IC-FD
Mecoprop				+++				+++						
Methoxychlor								+++						
Metolachlor				+++				+++						
Molinate		+++						+++						
Pendimethalin								+++						
Simazine				+++				+++						
2,4,5-T				+++								+		
Terbuthylazine								+++				++		
Trifluralin		+++		+++				+++						

Not all test kits that are provided for chemical parameters comply with the requirements set by UNICEF. Table 5-5 shows that generally less than half of the tests comply. This illustrates that care must be taken when selecting tests.

Table 5-5 Results of the field kit evaluation (Unicef, 2005)

No. Type of Kits	No. of Kits Evaluated	Effective Kits (%)
1. Arsenic Test Kits	9	33%
2. Fluoride Test Kits	15	27%
3. Iron Test Kits	13	31%
4. Nitrate Test Kits	11	18%
5. Chlorine Test Kits	9	44%
6. Chloride Test Kits	5	20%
7. Alkalinity Test Kits	2	50%
8. Aluminium Test Kits	1	100%
9. Single Parameter Kits	46	26%
10. Multiple Parameter Kits	4	50%

5.3 On-line monitoring

Several water quality parameters can be measure on-line with an electronic device. Common measurements are turbidity, pH, conductivity, oxygen, chlorine and oxidation reduction potential. This can be especially useful for operation, as changes in water quality or failure of treatment can be detected rapidly and acted upon. Often this response is automated, e.g. to control dosing. On-line monitoring requires reliable power supply, data processing and maintenance. This is generally not feasible in an Indian rural situation. Within the Water4India project on-line monitors will be used to evaluate treatment processes. This is discussed in report D4.3 Testing protocols for safe water solutions.

On-line measurement of microbial water quality is not feasible since bacteria need to be cultured. Recently automated microbial samplers have been developed that can provide results within 3 hours. These can detect *E. coli* or coliform bacteria but no pathogens. The robustness of these systems needs to be improved before application under rural Indian conditions can be considered.

5.4 Experiences in Water4India project

Various water quality analysis methods were applied in Work Package 7 to evaluate the performance of the various solutions in India. Results of these tests are discussed in report D7.3. Although it was not the goal of the project to evaluate analysis techniques themselves, we have collected feedback on the use analysis methods in this section.

5.4.1 Laboratory analysis of water samples in India

Raw water samples were taken to water laboratories for analysis of important water quality parameters (Annex 4) to identify suitable pilot testing sites. Samples were generally taken in empty water bottles that were flushed several times with the tested water. Although this is not according to sampling protocol, where sterilized bottles of specific materials must be used, no significant impact on the parameters of interest was expected. One exception is the microbial water quality, since used bottles may have had contact with the mouth and hands of the user. For surface water this would not have an impact on site selection. Detection of fecal indicators (*E. coli*) in groundwater might be a contaminated sample and this had to be taken into consideration when evaluating the source. However presence or absence of fecal indicators was not a criteria for site selection.

Selection of laboratories depended on location and certification. Therefore various laboratories were involved. On several occasions the results of the analysis seemed inconsistent. Examples include a sample observed as “clear” with a turbidity of 129 NTU, which is very turbid and would be reported as such. Also the ratio between the level of chemical oxygen demand (COD) and total organic carbon (TOC) in a sample was unrealistic. Sometimes values would be unrealistic, indicating highly concentrated industrial wastewater, when this was clearly not the case. When the same sample was tested by different laboratories, the results could also be quite different. These inconsistencies may be resolved by further developing certification and accreditation of water analysis laboratories. These experiences underpin the intentions in the Indian Uniform Drinking Water Quality Monitoring Protocol

(Government of India, 2013), which also addresses this need: "*Laboratories at all levels (i.e. State, District and Sub district) shall strive for accreditation in a phased manner. State level laboratories shall be given top priority for obtaining accreditation by NABL/ ISO-9001 at an early date. As previously mentioned, a system of continuously checking the quality of data produced by labs should be in place, including checking of records (including duplicate and blanks testing) and follow-up on samples testing positive for contamination.*"

5.4.2 Field test kits

According to the Indian Uniform Drinking Water Quality Monitoring Protocol (Government of India, 2013) each village should have a field test kit for water quality testing. However, none of the visited villages was able to show their field test kit, or the results obtained with them. This suggests that these kits are not actively used by the local communities. Thus we could not evaluate the experiences with these kits for periodical water quality monitoring. At the pilot test kits were used by trained staff and students that regularly use these kits which performed adequately under Indian conditions.

5.4.3 On-line monitoring

Both the deployed systems implemented on-line monitoring of water quality and system performance. Water quality monitoring provided direct feedback for automated operation (e.g. chlorine dosing) or alarms. The collected data is also used for evaluation of the system in D7.3. The sensitivity of the sensors was sufficient for operational control of the system and for evaluation of the data. Performing on-line monitoring under Indian conditions proved to be challenging due to the water quality and the reliability of electrical power and data-transmission. High suspended solids levels would interfere with the turbidity monitoring by fouling the sensor in the Amiad pilot. The UV transmission measurement in the Solarspring pilot was disturbed by scaling of the sensor. Electrical power instability and failure interfered with consistent monitoring, data storage and data transmission. Stop-start situations would occur frequently, leading to disturbances such as air bubbles in water increasing the turbidity of the water temporarily. Thus part of the obtained data became unreliable, and some data got lost due to the challenging conditions. Implementing on-line sensors in rural India therefore requires more effort than in similar situations in Europe. Maintenance is more intensive, and local staff is needed to regularly resolve technical issues. Also more robust sensors and data interpretation routines could make on-line monitoring in India more reliable. In addition, good monitoring cannot be achieved without a proper engineering design of the whole components of the water supply scheme, considering likely interference with the proper functioning of the monitoring instruments. In the case of the 2 pilots, the water quality at the locations and the already existing ineffective water intake and pre-treatment of the water caused fouling of the on-line monitors, located at the end of the process. Better consideration of the local conditions and the performance of the water treatment, ahead of the pilot components, could have prevented scaling and fouling of the sensors in the pilot systems.

Table 5-6 Implemented on-line monitoring in the Water4India solution (Report D7.2)

AMIAD pilot	SOLARSPRING pilot
Turbidity settled water	UV transmission
Turbidity filtrate	Pressure at various points
Free chlorine	Flow at various points
Temperature	
Particle count (temporarily)	
Pressure at various points	
Flow at various points	

5.4.4 Continuous large volume sample concentration for *Cryptosporidium* and *Giardia*

The evaluation of the AMIAD filtration system for the removal of pathogenic protozoan microorganisms under field conditions required very sensitive analysis methods. This meant that large volumes of water needed to be tested for their presence or absence. Up to 100 litres of sampled water was continuously concentrated by a cross-flow membrane filtration system which was first tested in the EU project TECHNEAU (Veenendaal and Brouwer-Hanzens 2007). The 0.5 litres of concentrated sampled was transported to a specialized laboratory for further concentration and analysis. This meant that continuous sampling took place over multiple filtration cycles of the system. This strategy thus included the potentially weak moments that could occur, for example during 'ripening' of the filter after backwash. This type of testing requires advanced equipment and significant labour, but it was proven feasible in rural India.

5.4.5 Protozoan analysis in advanced laboratories

There is increasing concern about risks from the protozoan pathogens *Cryptosporidium* and *Giardia*. However there is little data available from India, since there are only a few laboratories capable of analysing these organisms in drinking water sources and treated water. The KWR laboratory collaborated with the Bhavan College microbiological laboratory to perform these analysis and build water quality analysis capacity in India. Logistics needed to implement these methods, such as importing positive controls and required reagents, were challenging. Availability on long term requires adaptation of import procedures, or implementation of production within India. The highly concentrated samples showed inhibition of the methods used for protozoan analysis, reducing recovery to 2%. The specific Indian water composition may require adaptation of analysis procedures to increase the recovery, and thus the reliability of the results.

6 CONCLUSIONS

This study provided an overview of how requirements for monitoring techniques in India can be set and how tests can be evaluated. Currently most gram panchayats have been provided with field kits, however it is not known what types of tests are included and how much they are used. During the field visit none of the gram panchayats representatives could show the test kit or provide information on it. The current study can be used to evaluate the supplied field kits in relation to the objectives. The inventory made clear that both technical and socio-economic aspects of tests are relevant for their applicability. The available capacities and materials seem to be the most restrictive for the choice of method. Although costs per test range over an order of magnitude, more expensive tests seem to provide little added value. Most important improvement in the current situation in India appears to be interpretation of the result, decision support and action taking. Tests that are easy to perform and interpret are expected to contribute most to improving health, even if they are not approved for compliance monitoring. Microbial water safety in rural India largely relies on handling, storage and treatment of water in the household. It is not feasible to test microbial water quality in every household on a routine basis due to costs, complexity and risk. Basic tests could be used to educate people and create awareness of the need to treat and protect water in the household. Adequate testing of the household treatment technologies through the WHO program is performed with advanced techniques in laboratories. This could be supplemented with simple, built-in, monitoring of the condition of the technology, e.g. to indicate depletion of chlorine or leakage of filters. Development and implementation of these concepts to verify performance in the field can improve water safety in the household.

One important issue is the lack of a logical and systematic reporting and communication structure for water quality data from routine monitoring. Results don't reach the person that needs to act on them either in the field (operators) or administration (to develop improvement programs), making monitoring obsolete. This issue cannot be resolved by the monitoring technique itself and needs organisational changes.

For the testing of W4I solutions sufficiently accurate tests were used. This required a critical view of laboratory results in order to find a reliable laboratory. Specific equipment was brought in by the project partners to perform adequate testing of the solutions. Further implementation of these technologies in India requires a supply chain of equipment, reagents and positive controls which is current absent. This showed that it is feasible to do advanced monitoring. Capacity building by training analysts both for the methods and interpretation of the results is needed to create enough capacity on the long term and on a nationwide scale. On-line monitoring equipment, data storage and transfer need to be made more robust for the rural Indian conditions.

7 REFERENCES

BIS, Bureau of Indian Standards, 2012. Indian Standard. DRINKING WATER — SPECIFICATION (Second Revision). ICS 13.060.20. https://law.resource.org/pub/in/bis/S06/is.10500.2012.pdf

Chilundo, M., & Kelderman, P. (2008). Design of a water quality monitoring network for the Limpopo River Basin in Mozambique. Physics and Chemistry of the Earth, Parts A/B/C, 33(8), 655-665.

Government of India, Ministry of Drinking Water and Sanitation. *Uniform Drinking Water Quality Monitoring Protocol*. 2013.

Mons, M. (2008). Monitoring and control of drinking water quality – Inventory and evaluation of monitoring technologies for key-parameters (pp. 310).

Samwel, M., & Möller, D. (2009). Developing water safety plans involving schools, from www.wecf.eu

Unicef, 2005. Evaluation of water quality field test kits. Shiram Institute for Industrial Research.

WHO, ed. *Guidelines for Drinking Water Quality, Fourth Edition* World health organization, Geneva, Switzerland, 2011.

ANNEX 1 SUMMARY OF MONITORING TECHNIQUE EVALUATIONS

Evaluation method field test kits UNICEF

Unicef used an evaluation method for field kits for chemicals in India by effectiveness *vs*. costs. The effectiveness was assessed by the quantitative performance of the kits by calculating the cumulative impact factor. The cumulative impact (CIF) factor is calculated by the sum of the parameter impact factors (PIF, scale 1-10) of 4 parameters (see Table 0-1) times a weighting factor. The parameters technical efficiency and safety have the most important weighing factor. The CIF determines for each compound (As, F) what are the best kits to use in monitoring. The PIF (parameter impact factor) and CIF are used to rank tests kits as a decision support tool. The study results are shown in Table 5-5.

Table 0-1 Evaluation of field kits by Unicef (2005).

Parameter	Weighting factor	Content
Technical efficiency impact	6 x I_{TE}	Overall testing efficiency determined by 1/10 * OTE *(true positives + true negatives) / total number of estimations with respect to each test parameter*
Safety impact	2 x I_{ADQ}	Hazard using kit and leakage
Adequacy impact	1 x I_{SAF}	Ease of handling & adequacy of materials
Information impact	1 x I_{INF}	Instructions & precautions

Evaluation monitoring techniques TECHNEAU

The existing monitoring technologies are identified and evaluated based on information on e.g. ease-of-use, maintenance requirements, cists, and technical specifications. Also the suitability of the techniques for use in small-scalesystems (3S) is evaluated.. The report can be used as reference when deciding on the analytical chemical and biological techniques to be used for monitoring water quality from source to tap.

The monitoring techniques are evaluated using technical specifications (sensitivity, robustness and time to result), operational specifications (ease-of-se, maintenance requirements) and costs (instrumentation and operation) and recommendation for use in small-scale systems (SSS). Each aspect is rated with a number 1-5.

Table 0-2 Evaluation form for test methods in the TECHNEAU programme (2008)

Criteria	1	2	3	4	5	Comments
Technical specifications						
Sensitivity Source water Drinking water						
Robustness Operational robustness						

selectivity						
Time to result						
Operational specifications						
Ease-of-use						
Maintenance requirements						
Costs						
Instrumentation						
Operational costs Consumables Maintenance						
Recommendations for use in SSS						
Overall conclusion						

Evaluation microbiological drinking water tests by Bain et al., (2012)

Bain et al. (2012) list important characteristics which should be considered when selecting a test for faecal indictor bacteria in drinking water. The characteristics include costs, time, technical staff & lab equipment and information provided (see Table 0-3). The information on the characteristics is compiled for 44 tests. According to monitoring requirements (resource and purposes of testing) the reader can select suitable test to evaluate bacterial drinking water quality.

Table 0-3 Test characteristics important to asses for selecting a test method (Bain et al., 2012)

Characteristic	Definition
Resources required	
Cost per test	These costs are based on the purchase of 400 to 500 tests. They do not include delivery or importation costs.
Cost of specialised equipment	Equipment which is needed for this particular test which would not typically be available in a laboratory. The cost is based on a single unit of each piece of durable equipment or in the case of glassware, the quantity typically used for a single analysis.
Analysis time	Time taken to conduct a single test, excluding the time required for transport and incubation. This includes preparation of media, interpretation of results and appropriate disposal.
Trained technician	A trained technician is required if training is at least one day, for example if standard microbiological techniques are needed.
Controlled incubation	Required if specified in the standard procedure for the test.
Ultraviolet light	Required for the detection of fluorogenic substrates.
Sterilization/disinfection	Required unless the test contains an integral disinfectant.
Deionised water	Required for some tests, especially membrane filtration where water samples may require dilution.
Cold storage	Required if the test needs to be stored below room temperature.
Transport	Required if tests cannot be conducted at the water source or if tests require a vehicle
Disposal	Amount of waste generated by each test, including sample collection vessels.
Information provided	
Sample volume meeting WHO	The test is able to satisfy the sample volume aspect of the WHO guidelines

Guidelines	"none detected in 100 mL".
Undiluted range	The lower and upper detection limit for the concentration of bacteria when no dilution is performed and the maximum sample volume is analysed.
Precision	Relative assessment of the precision of quantitative estimates over the range.
Indicator	The indicator bacteria used to identify fecal contamination of drinking-water.
Sanitary significance	Relative assessment of the relationship of the indicator to *E. coli*.
Standard or approved	Whether the test has been approved by the U.S. EPA, is included in the Standard Methods for the Examination of Water and Wasterwater or is an International Organization for Standardisation standard.
Other	
Time to result	The minimum incubation time stated to obtain the final results from a test. A range is given for devices where incubation time varies, for example depending on the concentration of bacteria in the sample or the incubation temperature.
Shelf life	Shelf life from manufacture, based on dehydrated media where available.
Storage temperature	Recommended long-term storage temperature of test or medium.

ANNEX 2 WHO RANKING OF METHOD COMPLEXITY

From WHO 2011.

Table 8.4 Ranking of complexity of analytical methods for inorganic chemicals

Ranking	Example of analytical methods
1	Volumetric method, colorimetric method
2	Electrode method
3	Ion chromatography
4	High-performance liquid chromatography (HPLC)
5	Flame atomic absorption spectrometry (FAAS)
6	Electrothermal atomic absorption spectrometry (EAAS)
7	Inductively coupled plasma (ICP)/atomic emission spectrometry (AES)
8	ICP/mass spectrometry (MS)

Table 8.5 Ranking of complexity of analytical methods for organic chemicals

Ranking	Example of analytical methods
1	HPLC
2	Gas chromatography (GC)
3	GC/MS
4	Headspace GC/MS
5	Purge-and-trap GC
	Purge-and-trap GC/MS

ANNEX 3 CATALOGUE OF MICROBIAL DRINKING WATER TESTS

Type		Product	Resources required										Information provided							Other			Settings		
			Cost per test [1]	Cost of specialist equipment [2]	Analysis time (min)	Trained technician	Controlled incubation	Ultraviolet light	Sterilisation/disinfection	Deionised water	Cold storage	Transport	Disposal	Sample volume meeting WHO Guideline (100mL)	Undiluted range (Per 100 mL)	Precision	Indicator	Sanitary significance	Standard or approved	Time to result (hrs)	Shelf-life (mths)	Temperature (°C)	Low resource	Medium resource	High resource
Presence Absence	Hydrogen sulphide	PathoScreen™	$0.60	$0	<5		x		x			x	S	-	>5	N/A	H_2S	+		24–72	12	RT			
		LTEK H_2S 20 mL	$0.80	$0	<5		x		x				S	-	>5	N/A	H_2S	+		24–72	24	RT			
		HiWater™	$2.40	$100	<5				x				M	+	>1	N/A	H_2S	+		24–72	24	RT			
		LTEK H_2S 100 mL	$1.50	$0	<5		x		x				M	-	>5	N/A	H_2S	+		24–72	12	RT			
		Local manufacture	Δ	$0	<5		x		x				S	Δ	Δ	N/A	H_2S	+		24–72	Δ	RT			
	Total Coliform	Lamotte® Coliform	$1.20	$0	<5				x				S	-	>10	N/A	TC	+		44–48	24	RT			
		Rapid HiColiform™	$0.80	$100	<5		x		x			x	M	+	>1	N/A	TC	+		24	36	2-8			
		Colilert® 10 mL	$1.50	$100	<5		x	x	x			x	S	-	>10	N/A	TC&EC	+++	x	24	12	4–30			
		Colilert® 100 mL	$5.00	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++	x	24	12	4–30			
		Colisure®	$5.00	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++	x	24	12	2–25			
		Colilert® 18	$5.00	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++	x	18	15	2–25			
	E. coli and Total coliform	Modified Colitag™	$4.50	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++	x	16	22	4–30			
		Watercheck™ [BWB] [3]	$5.00	$2,700	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++		24	36	2–30			
		Readycult®	$3.00	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++	x	24	36	15–25			
		E*Colite	$3.00	$100	<5		x	x				x	M	+	>1	N/A	TC&EC	+++	x	28	12	RT			
		EC Blue 100P	$3.70	$100	<5		x	x	x			x	M	+	>1	N/A	TC&EC	+++		24	12	RT			
		AquaCHROM™	$2.60	$0	<5		x		x			x	M	+	>1	N/A	TC&EC	+++		18	24	15–30			
		HiSelective™ *E. coli*	$2.20	$0	<5		x		x			x	M	+	>1	N/A	TC&EC	+++		24–48	12	2–8			

From: Bain et al. 2012

Type		Product	Resources required											Information provided						Other			Settings
			Cost per test [1]	Cost of specialist equipment [2]	Analysis time (min)	Trained technician	Controlled incubation	Ultraviolet light	Sterilisation/disinfection	Deionised water	Cold storage	Transport	Disposal	Sample volume meeting WHO Guideline (100mL)	Undiluted range (Per 100 mL)	Precision	Indicator	Sanitary significance	Standard or approved	Time to result (hrs)	Shelf-life (mths)	Temperature (°C)	Low resource Medium resource High resource
Most Probable Number	Most Probable Number	Compartmentalised bag test	$1.00	$0	<5								S	+	1–43	+	EC	+++		24–72	6–9	RT	
			$1.00	$0	<5								S	+	1–43	+	H_2S	+		24–72	6–9	RT	
		Aquatest™	$4.00	$100	5		x	x					M	+	1–230	+	EC	+++		24	24	RT	
		Coliplate™	$7.50	$200	10	x	x	x	x			x	L	-	5–2400	+++	TC&EC	+++		24	36	2-30	
		EC BlueQuant	$5.80	$100	5	x	x	x	x			x	L	+	1–1610	++	TC&EC	+++		24	12	RT	
		Multiple tube (LTB/EC-MUG)	$3.50	$200	30	x	x	x	x	x		x	S	Δ	Δ	Δ	EC	+++	x	48	36	RT	
		Multiple tube (LTB/BGLB)	$2.10	$200	30	x	x		x	x		x	S	Δ	Δ	Δ	TC	+	x	36	36	RT	
		Colitag/iMPN1600	$5.77	$0	10	x	x	x	x			x	L	+	1–1600	++	TC&EC	+++	?	16	22	4–30	
		Colilert/Quanti-Tray®	$5.50	$4,100	10	x	x	x	x			x	L	+	1–200	+++	TC&EC	+++	x	18/24	12	2–25	
		Colilert/Quanti-Tray® 2000	$6.00	$4,100	10	x	x	x	x			x	L	+	1–2419	+++	TC&EC	+++	x	18/24	12	2–25	
	Plate Methods	Petrifilm™ E.coli/coliform	$1.30	$100	<5		x		x		x	x	S	-	100–5000	+++	TC&EC	+++		24	18	≤8	
		Petrifilm™ Aqua Coliform	$0.70	$100	<5		x		x		x	x	S	-	100–5000	+++	TC	+		24	18	≤8	
		CHROMagar™ ECC	$0.80	$100	15	x	x		x			x	S	-	100–5000	+++	TC&EC	+++		24	36	15–30	
		Compact Dry EC™	$1.50	$0	<5		x		x			x	S	-	100–5000	+++	TC&EC	+++		24	24	1–30	
Colony Count	Gel based	Coliscan Easygel	$2.20	$0	5	x	x		x		x	x	M	-	20–1000	+++	TC&EC	+++	x	24	12	<0	
		ColiGel/PathoGel [6]	$3.50	$100	5		x	x				x	M	+	1–100 (TC) 1–25 (EC)	+++	TC&EC	+++		28	12	RT	

From: Bain et al. 2012

Type		Product	Resources required: Cost per test [1]	Cost of specialist equipment [2]	Analysis time (min)	Trained technician	Controlled incubation	Ultraviolet light	Sterilisation/disinfection	Deionised water	Cold storage	Transport	Disposal	Information provided: Sample volume meeting WHO Guideline (100mL)	Undiluted range (Per 100 mL)	Precision	Indicator	Sanitary significance	Standard or approved	Other: Time to result (hrs)	Shelf-life (mths)	Temperature (°C)	Settings: Low resource	Medium resource	High resource
Colony Count / Most Probable Number	Most Probable Number	Compartmentalised bag test	$1.00	$0	<5								S	+	1–43	+	EC	+++		24–72	6–9	RT			
			$1.00	$0	<5								S	+	1–43	+	H_2S	+		24–72	6–9	RT			
		Aquatest™	$4.00	$100	5		x	x					M	+	1–230	+	EC	+++		24	24	RT			
		Coliplate™	$7.50	$200	10	x	x	x	x			x	L	-	5–2400	+++	TC&EC	+++		24	36	2-30			
		EC BlueQuant	$5.80	$100	5	x	x	x	x			x	L	+	1–1610	++	TC&EC	+++		24	12	RT			
		Multiple tube (LTB/EC-MUG)	$3.50	$200	30	x	x	x	x	x		x	S	Δ	Δ	Δ	EC	+++	x	48	36	RT			
		Multiple tube (LTB/BGLB)	$2.10	$200	30	x	x		x	x		x	S	Δ	Δ	Δ	TC	+	x	36	36	RT			
		Colitag/iMPN1600	$5.77	$0	10	x	x	x	x			x	L	+	1–1600	++	TC&EC	+++	?	16	22	4–30			
		Colilert/Quanti-Tray®	$5.50	$4,100	10	x	x	x	x			x	L	+	1–200	+++	TC&EC	+++	x	18/24	12	2–25			
		Colilert/Quanti-Tray® 2000	$6.00	$4,100	10	x	x	x	x			x	L	+	1–2419	+++	TC&EC	+++	x	18/24	12	2–25			
	Plate Methods	Petrifilm™ E.coli/coliform	$1.30	$100	<5		x		x		x	x	S	-	100–5000	+++	TC&EC	+++		24	18	≤8			
		Petrifilm™ Aqua Coliform	$0.70	$100	<5		x		x		x	x	S	-	100–5000	+++	TC	+		24	18	≤8			
		CHROMagar™ ECC	$0.80	$100	15	x	x		x			x	S	-	100–5000	+++	TC&EC	+++		24	36	15–30			
		Compact Dry EC™	$1.50	$0	<5		x		x			x	S	-	100–5000	+++	TC&EC	+++		24	24	1–30			
	Gel based	Coliscan Easygel	$2.20	$0	5	x	x		x		x	x	M	-	20–1000	+++	TC&EC	+++	x	24	12	<0			
		ColiGel/PathoGel [6]	$3.50	$100	5		x	x				x	M	+	1–100 (TC) 1–25 (EC)	+++	TC&EC	+++		28	12	RT			

From: Bain et al. 2012

Type	Product	Resources required												Information provided					Other			Settings
		Cost per test [1]	Cost of specialist equipment [2]	Analysis time (min)	Trained technician	Controlled incubation	Ultraviolet light	Sterilisation/disinfection	Deionised water	Cold storage	Transport	Disposal	Sample volume meeting WHO Guideline (100mL)	Undiluted range (Per 100 mL)	Precision	Indicator	Sanitary significance	Standard or approved	Time to result (hrs)	Shelf-life (mths)	Temperature (°C)	Low resource Medium resource High resource
Colony Count	Membrane Filtration [4]	$0.50	$2,700	20	x	x		x	x		x	S	Δ	Δ	+++	TC/TTC	++		24	48	RT	
		$2.50	$4,000	15	x	x		x	x	x	x	M	Δ	Δ	+++	TC/TTC	+++	x	24	12	2–8	
		$2.50	$2,500	15	x	x		x	x	x	x	M	Δ	Δ	+++	TC&EC	+++	x	24	12	2–8	
		$2.20	$2,500	15	x	x		x	x	x	x	M	Δ	Δ	+++	TC&EC	+++		24	12	<0	
		$1.50	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC	+	x	24	48	RT	
		$1.50	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TTC	++	x	24	48	RT	
		$1.10	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC&EC	+++		24	36	15-30	
		$1.30	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC&EC	+++		24	36	15-30	
		$1.70	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC&EC	+++	x	24	36	RT	
		$1.20	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC&EC	+++	x	24	60	RT	
		?	$2,500	15	x	x		x	x		x	M	Δ	Δ	+++	TC&EC	+++		24	?	?	

[1] Costs are known to vary greatly from one location to another, depending on supplier, importation taxes and delivery charges. Where not included in the kit, sample collection vessels are required and add an additional $0.50 per test. For plate methods a disposable pipette at $0.10 has been added; [2] Specific equipment costs are based on: UV torch ($100), membrane filtration assembly, including vacuum pump ($2500), glassware and racks for multiple tube fermentation ($200), IDEXX Quanti-Tray Sealer ($4000) and portable membrane filtration kits ($2700); [3] [BWB] refers to the Bluewater Biosciences Watercheck™ and is not to be confused with the B2P version, denoted [B2P]; [4] Costs for membrane filtration are based on one filter. More filters may be used if water is very turbid or may be highly contaminated; [5] Portable kits are available from a number of manufacturers including Wagtech, DelAgua and ELE. The cost varies depending on the kit and ranges from approximately $2500 to $5000; [6] PathoGel includes an indicator for H2S production (P/A)

From: Bain et al. 2012

ANNEX 4 IMPORTANT PARAMETERS IN THE INDIAN MONITORING PROGRAMME

Annexure II

Bureau of Indian Standards
Drinking Water – Specifications for some of the important parameters
IS 10500 – 2012 (Second revision)

S. No.	Characteristic	Unit	Requirement (Acceptable Limit)	Permissible Limit in the absence of alternate source
1	Total Dissolved Solids (TDS)	Milligram/litre	500	2000
2	Colour	Hazen unit	5	15
3	Turbidity	NTU	1	5
4	Total Hardness	Milligram/litre	200	600
5	Ammonia	Milligram/litre	0.5	0.5
6	Free Residual Chlorine	Milligram/litre	0.2	1.0
7	pH	--	6.5-8.5	6.5-8.5
8	Chloride	Milligram/litre	250	1000
9	Fluoride	Milligram/litre	1.0	1.5
10	Arsenic	Milligram/litre	0.01	0.05
11	Iron	Milligram/litre	0.3	0.3
12	Nitrate	Milligram/litre	45	45
13	Sulphate	Milligram/litre	200	400
14	Selenium	Milligram/litre	0.01	0.01
15	Zinc	Milligram/litre	5.0	15.0
16	Mercury	Milligram/litre	0.001	0.001
17	Lead	Milligram/litre	0.01	0.01
18	Cyanide	Milligram/litre	0.05	0.05
19	Copper	Milligram/litre	0.05	1.5
20	Chromium	Milligram/litre	0.05	0.05
21	Nickel	Milligram/litre	0.02	0.02
22	Cadmium	Milligram/litre	0.003	0.003
23	E-Coli or Thermotolerant coliforms	Number/ 100 ml	NIL	NIL

Note : Please refer to BIS Standard IS-10500- 2012 (second revision) for other parameters