# Monitoring plans (D4.2, Updated)

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**Project Acronym:** Water4india
**Grant Agreement Number:** 308496

| | |
|---|---|
| **Issue Date:** | **31 August 2016** |
| **Deliverable Number:** | **D4.2-D4.5** |
| **Work Package Number:** | **WP4** |
| **Status:** | **Final Updated** |

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**Document History**

| Version | Date | Author | Description |
|---|---|---|---|
| 1 | 19.08.2016 | Patrick Smeets | Updated D4.2 for comments |
| 2 | 29.08.2016 | Yehuda Shiva | Including comments |
| 3 | 31.08.2016 | Patrick Smeets | Final updated D4.2 |

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# TERMINOLOGY AND ABBREVIATIONS

| | |
|---|---|
| ADI | Acceptable Daily Intake |
| ADI | Acceptable Daily Unit |
| BIS | Bureau of Indian Standards |
| BOD | Biological oxygen demand |
| CPCB | Central Pollution Control Board |
| DALY | Disability-Adjusted Life-Years |
| DSS | Decision Support System |
| FAO | Food and Agriculture Organisation |
| FC | Faecal Coliforms |
| FIB | Faecal Indicator Bacteria |
| GC | Gas Chromatography |
| GP | Gram Panchayat |
| GV | Guideline Value |
| HPLC | High Pressure Liquid Chromatography |
| ISO | International Organization for Standardization |
| MPN | Most Probable Number |
| 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 |
| 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 |
| ZP | Zilla Panchayat |

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# 1 PUBLISHABLE EXECUTIVE SUMMARY

In this study we identified the most relevant health related water quality issues in rural India and how water quality monitoring can support risk management. The various goals of water quality monitoring were discussed within risk management frameworks like water safety planning (WSP) and quantitative microbial risk assessment (QMRA), focusing on the Indian context. We also evaluated the current water quality monitoring protocols and practices in India from the viewpoint of health risk management. Monitoring is often seen as a means to assess compliance to targets, however thorough analysis of monitoring results can provide added value. Therefore we collected available monitoring data from various sources in India and the scientific literature to see if they could fulfil the identified monitoring goals. The main focus of the study was the protection of health by adequate monitoring. The monitoring data was used to estimate the actual health impact of drinking water quality in India. Thus key water quality issues were identified as:

- Microbial contamination
- Geogenic: Arsenic and fluoride
- Anthropogenic: Lead and potentially pesticides and other industrial contaminants

In some cases the historical data seemed unreliable, as measurement results would always be exactly on the limits of compliance, or large differences in findings between neighbouring regions we observed. In general the quality of the data seems to have improved in recent years, and therefore it provides a better basis for water quality management at various levels. The study provides some examples of how data can be used for this purpose.

There seem to be some discrepancies between the Indian drinking water quality standards IS 10500: 2012 (BIS 2012) and the requirements in the Indian drinking water monitoring protocol. IS 10500: 2012 requires the complete absence of viruses in drinking water and absence protozoan pathogens (*Cryptosporidium* and *Giardia*) in ten litres. However no monitoring of pathogens is performed and there is no framework or alternative methods to determine if these pathogens can be present. This is similar to the situation in Europe where the drinking water directive requires such organisms to be absent but there is no monitoring requirement unless there is evidence or suspected presence (European Commission 1998). Still various countries have implemented quantitative microbial risk assessment (QMRA) to address these pathogens, since monitoring of faecal indicator bacteria provides insufficient insight in their relevance. A framework for QMRA in the Indian context is discussed in Water4India report 4.4. One conclusion from that report is the need for monitoring pathogens in Indian sources of contamination to provide a scientific basis for QMRA in the Indian context. This requires adequate microbial monitoring, for which the infrastructure in India seems to be insufficient and less developed than for chemical analysis. Adequate sampling, cooled transport and timely analysis are essential for microbial water quality analysis. Although this is largely achieved in urban water supply, currently none of these aspects are sufficiently implemented in rural India. There the situation is more challenging due to the high number of small system, distance to laboratories, lack of skilled staff and insufficient sense of urgency and knowledge of the importance of water quality monitoring. In addition research on the occurrence of actual pathogenic organisms in the source water is almost non-existing, while specific knowledge of the Indian situation is essential to manage their risks by protecting sources, adequate treatment and protecting drinking water during storage and distribution.

The Indian protocol for drinking water monitoring in principle provides a good basis for health risk management of drinking water. Improvements appear to be on-going, still the following main recommendations were made:

- Reliable laboratory analysis by implementing inter-laboratory proficiency testing
- Improvement of feedback from water quality experts to the people, operators in the field and decision makers based on monitoring results at various levels, including the results from field test kits at the local level
- Improved monitoring of water treatment processes (and subsequent improved process control)
- Interaction and data exchange between various water quality monitoring institutions (CPCB, NRDPW, CWC, CGWB research institutes and NGO's)
- Implement statistical and trend analysis of accumulated data
- Feedback of this statistical analysis to design to design effective monitoring plans that reduce cost, increase efficiency and meaningful interpretation of data.
- This requires training to obtain skills for water quality monitoring and data interpretation

# 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 supply with water in sufficient quantity and of good quality. This document focuses on how to assess and evaluate 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 develop an optimized monitoring strategy to efficiently assess health risks from drinking water using risk based approaches such as Water Safety Planning (WSP) and Quantitative Microbial Risk Assessment (QMRA). Also the lessons learned in European monitoring programs were incorporated. Since the government of India introduced a new drinking water monitoring protocol in 2013, the study evaluated this protocol and the monitoring results achieved so far. Also methods for interpretation and use of the obtained monitoring data is addressed, since data by itself doesn't provide the best insights. Purpose of the document is to advise Indian stakeholders involved in water quality monitoring and data interpretation on how to improve this. Secondly it provides a basis for water quality monitoring at the Water4India pilots, and finally it also provides input for the other tasks in work package 4 (see section 2.4).

## 2.2 Structure of the deliverable

In Chapter 3 the current knowledge about drinking water quality in rural India is evaluated with respect to health risk to identify the most relevant issues. In Chapter 4 the various purposes of water quality monitoring at different scales is discussed. In Chapter 5 the current water quality monitoring programs that are relevant for drinking water supply in India are discussed. We evaluate how these various programs fit into the identified purposes of water quality monitoring and which monitoring is still missing. The results from various monitoring programs are discussed in Chapter 6 with a focus on how this information can be used to assess drinking water health risk. Finally in Chapter 7 we draw conclusions on how water quality monitoring and data handling could be improved.

## 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). An understanding of the relation between water quality and health impact is crucial to select solutions that result in highest improvement of health (or reduction of health risks). This document provides these insights and also the most relevant issues in rural India. 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 water quality of various (drinking) water sources in India and guidance where detailed data for specific locations can be found.

**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**: The currently applied methods and their results in current monitoring programs were evaluated. Quantitative water quality data was collected to perform QMRA.

## 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 purposes of water quality monitoring. These purposes lead to specific demands for analyzed parameters, costs, sensitivity, specificity and complexity. Since Water4India deliverable 4.1 was the first deliverable due, some of the elements of the current report were already included there. Similarly the testing of the pilot systems, described in Water4India report 4.3, and the testing of on-line monitoring in task 4.5 required insight in the relevant water quality issues and how they occur in rural India. For the pilots the best estimate of local water quality issues based on available monitoring data is needed. This impacts the required water quality parameters, their sensitivity and frequency of monitoring in order to draw conclusions on the impact of the solution in the pilot. The more advanced assessment of health risk through QMRA in task 4.4 builds on the available monitoring data that is presented in this document. The QMRA in task 4.4 approach also provided requirements for the optimization of monitoring in this document.

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. There was already an initial inventory of water quality issues in D2.1 which is refined in this document. Also the current document provides advice to improve monitoring, which in turn will improve the approach developed in work package 2. In work package 3 treatment solutions are studied to address the water quality issues presented in this document. In addition the document provides insight in water quality challenges to operation of treatment processes, such as high turbidity. 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 health indirectly. This document provided a basis to select the water quality parameters to evaluate solution in the DSS developed in work package 6. The intention is to test the monitoring strategy in this document in work package 7 in the pilot areas.

## 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. KWR was also responsible for the health risk assessment for the various contaminants. Adin and Amiad have contributed by providing additional information on water quality monitoring in Chapter 5, providing data from India in Chapter 6 and contributed to the discussion on interpretation of data.

## 2.6 Changes in updated version (D4.5)

In the updated version we included the results from pathogen monitoring in source water at the AMIAD pilot in work package 7 and included more recent findings on protozoan pathogens in Indian drinking water sources. The results of the Indian water monitoring program of 2015-2016 were compared to the results in the previous report from period 2012-2013. In additions some corrections were made, especially concerning the revised Indian drinking water standards IS 10500:2012.

# 3 HEALTH RELATED WATER QUALITY ISSUES IN INDIA

## 3.1 Introduction

In this chapter we provide an overview of water quality issues in India in more depth than Water4India report 2.1. The most important contaminants are discussed with respect to their sources, occurrence and health impact. Relevant contaminant groups are microbial contaminants, naturally occurring chemical contaminants (geogenic), chemical contamination by humans (antropogenic) and contaminants that affect attractiveness of water such as turbidity, colour, taste and odour (organoleptic).

Rather than only evaluating exceedance of guideline values, various methods for actually relating health impact to water quality are presented. The relative health impacts of all contaminants is then estimated and compared for the Indian situation. This leads to a selection of water quality parameters that are most relevant to monitor and the required sensitivity of that monitoring.

## 3.2 Microbial parameters

Micro-organisms are extremely small and invisible to the eye. Most micro-organisms are harmless to humans or are even essential for human life, such as gut bacteria that help digest food. Microbial (or microbiological) risks are caused by pathogenic micro-organisms (pathogens) that can infect humans. An infection means that the organism can survive and multiply in the body, potentially causing illness. Infected persons that don't become ill can still spread the organism and cause infection and illness in others. Zoonotic pathogens are micro-organisms that can infect both humans and animals, and therefore animals can also be a source of disease. Very low numbers of ingested pathogens, or even a single pathogen, can cause an infection.

Since pathogens aren't visible, it cannot be judged visually if a glass of water is safe to drink. Water can be tested in laboratories for the presence of pathogens. However, this is costly and the methods are not sensitive enough to detect the pathogens at the low concentration that is needed to provide safe water. Therefore water is generally tested for faecal indicator bacteria (FIB) that are also present in the gut but in much higher numbers like thermo tolerant coliforms (TTC), faecal coliforms (FC), total coliforms (TC), *E. coli* or enterococci. It is important to know that these FIB do not cause disease themselves and that their absence doesn't guarantee absence of pathogens. Preventing contamination is therefore essential to provide safe water. The following groups of pathogenic micro-organisms are related to water borne diseases:

**Viruses** are the smallest organisms. They cannot replicate themselves, but they are replicated by the human (or animal) they infect. They are generally very host-specific, so generally only human viruses can infect other humans. Well-known waterborne viral diseases are gastroenteritis with symptoms of diarrhoea, vomiting or fever (norovirus), hepatitis A and E (hepatitis virus). Polio appears to have been eradicated since 2012 in India.

**Bacteria** are single-celled organisms. They can replicate very rapidly under favourable conditions. Most pathogenic bacteria replicate only inside infected humans or animals, but some can also replicate outside the host's body. Bacterial pathogens are not very host-specific. Zoonotic bacteria can infect both animals and humans. Well-known bacterial diseases are typhoid (Salmonella typhi), cholera (Vibrio cholerae), gastroenteritis with symptoms of diarrhoea, vomiting or fever (Campylobacter, E. coli O157:H7) and dysentery (Shigella). The bacteria E. coli and enterococcus are generally used to monitor water quality by analysis of water samples in a laboratory. These bacteria are present in large numbers in faeces of warm-blooded animals, so detection in the water indicates recent faecal contamination of the water. The organisms themselves are not infectious to humans.

**Protozoa** are single-celled organisms, slightly larger than most bacteria. They can form (oo)cysts that are very resistant to environmental conditions and to chlorine and other disinfectants. This makes them of special concern. *Giardia* and *Cryptosporidium* are protozoa that are known to cause outbreaks of disease even in chlorinated systems. Shedding of the protozoa *Cryptosporidium* by young calves has been an important cause of water contamination in many cases. Infections with *Entamoeba histolytica* have also been reported in India.

**Worms** (helminths) can cause various infections. Their eggs can be very resistant against environmental impacts and chlorine. Worldwide, worms are one of the principal causative agents of human disease.

**Fungi** type organisms have traditionally received little attention but may be pathogenic. Aspergillis are currently investigated for their health effect.

**Cyanobacteria** (Blue-green algae) grow in surface waters. During algae-blooms they can release toxins. Therefore they are considered as a chemical risk. However, control strategies such as removal through treatment can have a strong relation with other aspects of controlling microbial risks.

**Waterborne pathogens in India**

These pathogens provide different challenges to providing safe drinking water. Data on the actual pathogen concentrations would help decision making on which interventions are most effective and efficient. However analysis techniques for the pathogens themselves require advanced laboratories and are costly. Presence of the indicator organisms *E. coli* or thermo tolerant coliforms (TTC) is a strong indication of recent faecal contamination which could contain one or more of the mentioned pathogens. However, absence of these indicator organisms is not a guarantee that pathogens are absent, since they may survive longer. One example is that *E. coli* dies of very quickly in the presence of chlorine, whereas *Cryptosporidium* is not affected at all.

Actual pathogen data in India is rare, and monitoring results for *E. coli* or TTC can be unreliable for various reasons. Therefore only a rough estimate of the source water quality and drinking water quality in India can be made. Khurana and Sen (2008) state that "*Bacterial contamination of water continues to be a widespread problem across the country and is a major cause of illness and deaths with 37.7 million affected by waterborne diseases annually. The major pathogenic organisms responsible for water borne diseases in India are bacteria (E Coli, Shigella, V cholera), viruses (Hepatitis A, Polio Virus, Rota Virus) and parasites (E histolytica, Giardia, Hook worm).*" The presence of pathogens in Indian water sources will be discussed in Chapter 6, based on monitoring data from India and data from other countries.

## 3.3 Natural occurring contaminants (Geogenic)

**Fluoride**

Since 1997 fluoride is a major problem in Indian groundwater used for drinking water. Highest natural level concentration reported being 38.5 mg/l in Haryana (PHED, 2014). Also in the State of Karnataka, fluoride is a problem (Khurana and Sen 2008, CPCB, 2012). In India and the state of Karnataka fluoride exceeded the limit respectively in 2% and in 8% of the tested samples. Fluoride originates from bed rock, soils and sediments can contaminate groundwater due to erosion, weathering and solution of fluoride-bearing minerals. Water from alluvium sediments contain lower concentrations of fluoride. Fluoride can also originate form industrial waste water from activities such as the production of aluminium, fiberglass and fertiliser. Fluoride concentrations of 0.5-1.5 mg/L prevent tooth decay (dental caries). However, concentrations above 1.5-2 mg/L can lead to dental fluorosis or osteoporosis (bone decalcification). The Bureau of Indian Standards has set a desirable limit of 1 mg/L and a permissible limit of 1.5 mg/L for fluoride in respect to drinking water, similar to the WHO guideline. Fluoride may be kept as low as possible. A fluoride test kit or analytical method should be as sensitive and accurate to obtain information at the 100 µg/L scale.

Prüss-Ustün *et al.* (2011) reviewed the burden of disease by chemicals, including fluoride and arsenic. They refer to the study of Fewtrell et al. (2006), who studied the global burden of disease due to fluoride in drinking water. Overall, excessive fluoride concentrations in drinking water were estimated to have caused about 47 million dental fluorosis cases and 20 million skeletal fluorosis cases in 17 countries (in terms of prevalence, based on point estimates published between 1953 and 2000).

Research conducted in India, estimated that 6.9% of the population is at risk of exposure to elevated fluoride in drinking water (Susheela, 1999). Fewtrell et al. (2006) the estimated population suffering from dental fluorosis for different world regions. The region 'sear D' including India, Myanmar and North Korea has a predicted mean concentration of 3 mg/L. The population estimated to be suffering from fluorosis is: 18.2 million  from dental fluorosis and 7.9 million from skeletal fluorosis (see Table 3-1). They converted the population figures into DALYs (see for details Fewtrell et al., 2006). Fluorosis is not fatal, therefore a DALY calculation is based on YLD (years lived with disability). The estimated DALY for including India is 16 years per 1000 population, which equals to $2.0 \cdot 10^{-4}$ DALY per person-year.

**Table 3-1 Characteristics of burden of disease in India by fluoride (Fewtrell et al., 2006).**

| Dental fluorosis (population suffering) | 18.2 Million |
|---|---|
| Skeletal fluorosis (population suffering) | 7.9 Million |
| DALYs due to skeletal fluorosis (per personyear) | $2.0 \cdot 10^{-4}$ DALY |

**Arsenic**

Arsenic is a serious problem in India and Bangladesh. Arsenic contamination of drinking water increased after drinking water sources switched from the polluted surface water sources to 'clean' groundwater sources. Arsenic has not affected water quality in Karnataka much with only 2 out of 27722 sources tested (0.01%) exceeding the target (NRDWP 2014 and Table 3-2  and Table 6-1). Arsenic is a natural constituent of the earth's crust. Erosion, weathering and solution processes release arsenic to water resources due to leaching and runoff. Areas with volcanic rock and sulphite-bearing minerals contain high arsenic concentrations in water. Besides, arsenic is used in industry and is released in mining operations such as the melting of metals and the combustion of fossil fuels. In the Ganges delta arsenic concentrations are increased in the subsurface more than 20 meters and less than 100 meters deep. Inorganic arsenic is a human carcinogen (WHO, 2013). The Bureau of Indian Standards has set a standard of 0.01 with a relaxation of 0.05 mg/L for arsenic. The WHO guideline is 0.01 mg/L, but has no toxicological or health base. Schriks (in prep.) found in literature that the adverse health effects of inorganic arsenic already occur at 2 µg/L. An arsenic field test kit or analytical method should be as accurate and robust to give information on the 10 ug/L scale.

Two studies have estimated the health impacts of exposure to arsenic in drinking water for Bangladesh (Lokuge et al., 2004) and at the global level (Fewtrell et al., 2005). In Bangladesh, arsenic-contaminated drinking-water alone contributed 9,100 deaths per year and 125,000 DALYs per year in those exposed to arsenic concentrations >50 µg/L (Prüss-Ustün *et al.* 2011, Lokuge et al., 2004). The DALYs are based on total mortality and years of life lost (YLL). In the same period the study was executed (~2011) the total population was estimated 130,523,000 (Wikipedia). The DALYs per person year are estimated at $1{,}7\cdot10^{-5}$ per person year (175,000 /80 average years of lifetime /130,000,000 people).

Fewtrell et al. (2005) made an estimation of the global burden of disease due to skin lesions caused by arsenic in drinking water. For India, the estimated population at risk is 4.5-6 million (exposed to concentrations > 50 µg/L). Skin lesions are not fatal (the progress to skin cancer was not accounted for in the estimate) and therefore the DALY calculation is based on YLD (years lived with disability) only. Fewtrell et al. (2005) estimated 5 DALYs per 1000 population caused by skin lesions due to elevated arsenic concentrations for India. This equals to $6.0\cdot10^{-5}$ DALYs (5 /80 average life years /1000 population) per person year (see also Table 3-2).

**Table 3-2 Characteristics of burden of disease in India by arsenic (Fewtrell et al., 2005).**

| | |
|---|---|
| Estimated population at risk (exposed to >50µg/L arsenic) | 4.5-6 million |
| Maximum reported arsenic conc (µg/L) | 3.700 |
| DALY caused by skin lesions (per person year) | $6.0\cdot10^{-5}$ |

**Salinity**

Seawater intrusion, groundwater exploitation and industrial waste water discharge lead to contamination by salinity in water. Salinity affected water quality occurs in the state of Karnataka (CPCB, 2012). Salinity is defined as the measure of the dissolved minerals in water and is measured as total dissolved solids (TDS in mg/L) or electrical conductivity (uS/cm). The Indian limit for salinity measured as TDS is 500 mg/L, with a maximum permissible limit of 1000 mg/L (BIS, 212). One of the major contributors to salinity is chloride, a naturally abundant component from minerals and present in high concentrations in sea water. Chloride is also discharged by waste water from industry, mining and oil and gas industry. Chloride influences the taste and palatability of drinking water and affects corrosion. The Bureau of Indian Standards has set a standard of 250 mg/L for chloride with a maximum limit of 1000 mg/L. The WHO guideline value is 250 mg/L, based on taste. The concentration of chloride in drinking water is not of health concern. The taste threshold for the chloride anion depends on the associated cation and are in the range of 200–300 mg/l for sodium, potassium and calcium chloride. The field test kit should be able to provide information on the mg/L scale.

Chloride has no known toxicity for humans. A healthy individual can tolerate the intake of large quantities of chloride provided that there is a concomitant intake of fresh water. Excessive intake of drinking-water containing sodium chloride at concentrations above 2.5 g/L has been reported to produce hypertension (Fadeeva, 1971), this effect is believed to be related to the sodium ion concentration.

However, the guideline for chloride in drinking water is not health based. Therefore the DALY for salinity in drinking water is 0.

**Iron**

Iron is a major problem in India and has affected water quality in the district Karnataka (Khurana and Sen 2008). Iron concentrations exceeded the limit in 20% of the sources tested in India and 12% of the sources in Karnataka (Figure 6-1). Iron is a natural abundant in groundwater by the dissolution of iron-bearing minerals. The average lethal dose of iron is 200–250 mg/kg of body weight, but death has occurred following the ingestion of doses as low as 40 mg/kg of body weight (WHO). A dose of 1500 mg/L has a poisoning effect on a child as it an damage blood tissues (Khurana and Sen 2008). Iron in low concentrations mainly influences drinking water taste and induces clogging of wells and pipes. The Indian standard for iron is 0.3 mg/L. There is no WHO guideline value for iron. Because iron has no health based guideline value, the DALY for iron for Indian drinking water is 0.

## 3.4 Human contamination (Antropogenic)

**Nitrate**

Nitrate is a major problem in India. Nitrate has affected water quality in the district Karnataka (Khurana and Sen 2008, CPCB, 2012). Nitrate concentrations exceeded the guideline limit in 2.6% of the sources testes in India and 3.8% of the sources in Karnataka. Nitrate originates mainly from human activities in agriculture, industry and waste water. The main origin of nitrate is fertiliser or manure. In the body, nitrate is transformed to nitrite, which influences oxygen take-up. High concentrations of nitrate can cause methemoglobinemia (Blue Baby disease). It may also increase the risk of cancer by the formation of nitrosamines. The Bureau of Indian Standards has set a standard of 45 mg/L for nitrate, with no relaxation. The WHO guideline for total nitrates is 50 mg/L. The WHO guideline for nitrite is 3 mg/L. Nitrate test kits should provide information on the mg/L scale. The global burden of disease by nitrate in drinking water was not appropriate to estimate by Fewtrell (2004). The importance of nitrate and infant methamoglobinemia is questioned by some authors (Fewtrell, 2004) while nitrate can act as a co-factor. The DALY associated with concentrations of nitrate on the guideline level are unknown.

**Heavy metals**

Heavy metals are metals of environmental concern. Heavy metals are chromium, cobalt, nickel, copper, zinc, arsenic, selenium, silver, cadmium, antimony, mercury, thallium and lead. Heavy metals are frequently mentioned as a problem in India. In 1995 a survey of the CPCB found heavy metals in the states of Gujarat, Andhra Pradesh, Kerala, Delhi and Haryana (Khurana and Sen 2008). More recent data from NRDWP only show significant occurrence of heavy metals in Punjab state. Karnataka and other states only incidentally exceed limits (2012-2013) for arsenic (4 sources), manganese (10 sources) and Copper (3 sources) (NRDWP, 2014). However the extent of monitoring for heavy metals is unclear. Examples from literature show that the main problems are caused by the metals Cu, Cr, (Fazil et al., 2012) and Fe, Ni and Mn (Majagi et al., 2008). Further details are given in the text box. Heavy metals are found naturally in the earth, and become concentrated as a result of human caused activities. Common sources are from mining and industrial wastes; vehicle emissions; lead-acid batteries; fertilisers, paints and treated woods. Heavy metals leaching from industrial and consumer waste leads to water pollution. Acid rain can exacerbate this process by releasing heavy metals trapped in soils. Lead is the most prevalent heavy metal contaminant. The heavy metals included in IS 10500:

2012 standards are: copper (0.05-1.5 mg/L), mercury (0.001 mg/L), cadmium (0.003 mg/L), selenium (0.01 mg/L), arsenic (0.01-0.05 mg/L), lead (0.01 mg/L), zinc (5-15 mg/L), chromium (0.05 mg/L). The maximum values are permissible relaxations of the standard if no other source of drinking water is available. Associated health burden from heavy metals. Field kit tests for metals should be accurate enough to measure up to the ng/L scale, dependent on the component.

For lead, a study was conducted by Fewtrell (2003). In the world region including India 775,000 DALYs and 57,000 death are associated to lead-induced cardiovascular diseases. Mental retardations accord for 1,912,000 DALYs. The total DALYSs divided by the world or region population leads to $3.2 \cdot 10^{-5}$ DALYs per person and year in the Indian world region (2,687,000 DALYs / 1 billion population (in India + Bangladesh + Bhutan + North Korea + Maldives + Myanmar + Nepal) / 80 average life time years if people were not exposed to any hazard).

**Table 3-3 Lead-induced health burden (Fewtrell et al., 2003).**

| | World | South Eastern world region (including India) |
|---|---|---|
| **Death due to lead induced cardiovascular diseases in adults** | 229,000 deaths | 57,000 deaths |
| **DALYs due to lead induced cardiovascular diseases in adults** | 3,112,000 DALYs | 775,000 DALYs |
| **DALYs due to lead-associated IQ deficits (mild mental retardation)** | 9,813,000 DALYs | 1,912,000 DALYs |
| **Total lead induced DALYs** | 12,925,000 DALYs | 2,687,000 DALYs |
| **Total lead induced DALYs per personyear** | $2.6 \cdot 10^{-5}$ DALYs | $3.2 \cdot 10^{-5}$ DALYs |

Data for the toxic mercury was not comparable to estimates of deaths and DALYs (Prüss-Ustün *et al.* 2011). The health burden of other metals in drinking water, such as Cu, Cr, Ni and Mn was not quantified in literature.

**Heavy metal water contamination in India**

Fazil et al.(2012) found IS 10500: 2012 standard exceedences of heavy metals (Cu, Cr) in groundwater in Beed City, Maharashtra, India (not for Zn and Cd). Rajappa et al., 2010) found in groundwater (Hakinaka Taluk, India) Fe, Zn, Cr, Pb and Cu within permissible IS 10500: 2012 limits (Cd, As and Ni were below detectable level). In the Karanja reservoir, Bidar, Karnataka, India, Majagi et al. (2008) found heavy metals have concentrations within the permissible limits, except for Fe and Ni (southwest monsoon) and Mn (northeast monsoon and in summer). Begum (2009) found heavy metal concentrations within IS 10500: 2012 standards in water of the Madivala Lakes of Bangalore, Karnataka.

**Pesticides**

Pesticides are used in agriculture to protect crops from disease, insects or fungi. Other users are governmental agencies, companies, industry, households and shipping. Pesticides can leach to soil and groundwater. There are many different pesticides commonly used in India, see Table 3-4. India is the largest producer of pesticides in Asia and ranks twelfth in the world for the use of pesticides (Abhilash and Singh, 2009). According to that study pesticides are a problem in the states Delhi, Himachal, Pradesh, Jharkahand and West Bengal. Most pesticides have no adverse effects below 0.1 µg/L. Exceptions are the compounds aldrin, dieldrin, hexachloroepoxide and ethylenebromide for which a limit of 0.03 µg/l is used in the Netherlands (Drinkwaterbesluit 2011).

**Table 3-4 Pesticides commonly used in India (Abhilash and Singh, 2009).**

| Pesticide: common name | Chemical family |
|---|---|
| I a Extremely hazardous[a] | |
| 1. Phorate | Organophosphate |
| I b Highly hazardous[a] | |
| 2 Monocrotophos | Organophosphate |
| 3 Profenofos & Cypermethrin | Combination pesticide |
| 4 Carbofuran | Carbamate |
| II Moderately hazardous[a] | |
| 5 Dimethoate | Organophosphate |
| 6 Quinalphos | Organophosphate |
| 7 Endosulphan | Organochlorine |
| 8 Carbaryl | Carbamate |
| 9 Chlorpyrifos | Organophosphate |
| 10 Cyhalothrin | Pyrethroid |
| 11 Fenthion | Organophosphate |
| 12 DDT | Organochlorine |
| 13 Lindane | Organochlorine |
| III Slightly hazardous[a] | |
| 14 Malathion | |
| IV Unlikely to present acute hazard in normal use[a] | |
| 15 Carbendazim | Carbamate |
| 16 Atrazine | Triazine |

*a) WHO classification*

The IS 10500:2012 standard sets limits for 18 pesticides ranging from 0.01 to 190 µg/L (Table 3-5) "*based on consumption pattern, persistence and available manufacturing data. The limits have been specified based on WHO guidelines, wherever available. In cases where WHO guidelines are not available, the standards available from other countries have been examined and incorporated, taking in view the Indian conditions*". The WHO guidelines set standards for 37 pesticides ranging from 0.03 to 100 µg/L. Some of the IS 10500:2012 standards are even more strict than the WHO guidelines (e.g. Atrazine 2 versus 100 µg/L). For some compounds WHO doesn't set standards since concentrations in the environment are well below those of health concert, however they are included in IS 10500:2012 (e.g. endosulphan, malathion). Apparently concentrations in Indian environment may be of concern. Several of the compounds mentioned in Table 3-4 have not been included in the IS 10500:2012 (Table 3-5) based on these considerations. This illustrates that pollution with pesticides is a rapidly changing issue that requires regular updating of detection methods and standards for compounds. This needs to be combined with strict regulation for admitting new pesticides on the market, however other health impacts such as food security also play a role for market acceptance.

**Table 3-5 Pesticide Residues Limits and Test Method in Indian standard (IS 10500:2012)**

| Sl No. | Pesticide | Limit µg/l | Method of Test, Ref to | |
|---|---|---|---|---|
| | | | USEPA | AOAC/ ISO |
| (1) | (2) | (3) | (4) | (5) |
| i) | Alachlor | 20 | 525.2, 507 | — |
| ii) | Atrazine | 2 | 525.2, 8141 A | — |
| iii) | Aldrin/ Dieldrin | 0.03 | 508 | — |
| iv) | Alpha HCH | 0.01 | 508 | — |
| v) | Beta HCH | 0.04 | 508 | — |
| vi) | Butachlor | 125 | 525.2, 8141 A | — |
| vii) | Chlorpyriphos | 30 | 525.2, 8141 A | — |
| viii) | Delta HCH | 0.04 | 508 | — |
| ix) | 2,4- Dichlorophenoxyacetic acid | 30 | 515.1 | — |
| x) | DDT (*o, p* and *p, p* – Isomers of DDT, DDE and DDD) | 1 | 508 | AOAC 990.06 |
| xi) | Endosulfan (alpha, beta, and sulphate) | 0.4 | 508 | AOAC 990.06 |
| xii) | Ethion | 3 | 1657 A | — |
| xiii) | Gamma — HCH (Lindane) | 2 | 508 | AOAC 990.06 |
| xiv) | Isoproturon | 9 | 532 | — |
| xv) | Malathion | 190 | 8141 A | — |
| xvi) | Methyl parathion | 0.3 | 8141 A | ISO 10695 |
| xvii) | Monocrotophos | 1 | 8141 A | — |
| xviii) | Phorate | 2 | 8141 A | — |

NOTE — Test methods are for guidance and reference for testing laboratory. In case of two methods, USEPA method shall be the reference method.

The health impact of pesticides was estimated for the route of self-poisoning (suicides) from preventable pesticide ingestion. The estimated amount is 186,000 deaths and 4,420,000 DALYs in 2002 (Prüss-Üstün and Corvalán, 2006). The human health impact of individual or mixtures of pesticides in drinking water is dependent on the type of pesticide(s). In literature no overview of the health burden of pesticides expressed in DALYs is found. The health impact of pesticides induced by drinking water is smaller than the health impact by food intake (Margini et al., 2011). Pesticides can only be detected with advanced analytical methods such as GC/MS (gas chromatography mass spectronomy).

**Pharmaceuticals**

Pharmaceuticals and their metabolites in water sources have become a point of concern in many affluent countries. Little data is available for India. But over the world, they have been detected in the ng/L to low µg/L range in waste water, surface water, groundwater and to a lesser extent in drinking water (WHO, 2012). The concentrations of pharmaceuticals in drinking water are far below minimum therapeutic dose and ADIs and are unlikely to pose risks to human health (WHO, 2012). Therefore, DALYs associated with low concentrations in drinking water are expected to be negligible. Long-term and cocktail effects are not considered.

## 3.5 Organoleptic contaminants (acceptability)

**Turbidity**
Turbidity is caused by the presence of suspended material, such as colloidal parts, clay, sludge, plankton and micro-organisms. Iron can lead to turbidity by forming flocks. Turbidity can also cause clogging and corrosion of the treatment units and infrastructure. Turbidity causes no adverse health effects, but is related to adsorption of nutrients and microbial growth and can affect treatment efficacy, especially disinfection processes. The Bureau of Indian Standards has set a standard of 1 NTU (max 5 NTU). The WHO has no guideline for turbidity, but states that drinking water below 5 NTU is acceptable for the consumer.

**Odour, colour and taste**
Together with turbidity, odour, colour and taste of drinking water determine the acceptability by the consumer. These can be caused by many different compounds from natural or anthropogenic origin. Natural compounds are produced by bacteria or algae or by the presence of humic acids, metals and manganese. Anthropogenic compounds which affect odour, colour and taste can be released by industry or can be introduced during water treatment. The smell of drinking water can be indicative for water pollution, but does not indicate adverse health effects. The Bureau of Indian Standards has set a standard for odour to agreeable, a standard for colour to 5 hazen units (max 15 hazen units) and a standard for taste to agreeable.

**Indirect health effect of organoleptic contaminants**
Although the organoleptic parameters have no direct health effect, they can have an indirect effect. Water from a safe deep groundwater source may be unattractive due to the presence of iron (taste, colour and turbidity), methane (odour) and manganese (colour). Despite these contaminants the water is safe to drink and unlikely to contain microbial contaminants or pesticides. Still people may prefer to drink from a nearby stream that looks and smells better, but is contaminated by open defecation and agriculture. Therefore organoleptic parameters will be considered when considering health effects.

## 3.6 Variability of contamination
The concentrations of contaminants in sources can vary in time and space. Variations can be due to normal variability of the water system, seasonal variations or events. An example of normal variation is the mixing of wastewater discharge with the river water. When measured at a downstream point, water quality parameters will vary due to the random mixing conditions at that time (Figure 3-1). Depending on the mixing conditions these variations can be small or large, for example the TTC concentration downstream from wastewater discharge can vary over several orders of magnitude between two samples taken shortly after each other.

**Figure 3-1 Example of variation in water quality sampling due to mixing conditions at a discharge**

Seasonal variations in water quality can be due to climatic conditions, like temperature, solar irradiation or snowmelt, or other seasonal effect such as livestock or bird migration, manure, fertilizer or pesticide application and river discharge. Occurrence of algae blooms is also a seasonal event. These variations will show a similar pattern each year. Event driven variations can be very short and have a large impact on water quality. Heavy rainfall can lead to sudden increase of wastewater discharge, runoff of manure and resuspension of sediments in rivers. Dumping of waste or water transportation accidents can lead to sudden high chemical contaminations. For India the monsoon will lead to seasonal variations and rainfall driven events and many rivers will be impacted by snowmelt. Surface waters typically show high variations, while water quality from protected groundwater will be less variable. Shallow wells can be impacted especially by contamination events such as rainfall, fertilizers and pesticides. Variation of geogenic contaminants can occur with varying groundwater levels.

Microbial contaminants can have a large impact on health even during short peaks, since health effect occur instantly. Chemical contaminants generally have an effect after long term exposure, and short term variations or peaks will have less impact on health. Acute chemical health effects only occur as extremely high levels which may be caused by dumping or accidents. Monitoring should be sufficiently frequent to capture these variations to the level that they impact health.

## 3.7 Water quality standards and health targets

Health based guidelines values to ensure drinking water safety are developed by WHO in cooperation with other organisations. Legislators generally adopt the WHO guidelines and adapt them to their own situation. Indian drinking water standards were also developed this way. The Indian standards are described in IS 10500: 2012 (BIS 2012). This section shortly discusses the water quality targets.

### 3.7.1 Microbial standards (BIS 2012).

The general internationally applied guideline of *E. coli* or faecal coliforms absent in 100 ml has also been adopted in India. Some additional requirements are also mentioned, although it appears that they are not applied very strictly. MS2 phages (viruses that infect bacteria) must be absent in 1 litre. When MS2 phages are detected a virological examination with PCR (Polymerase Chain Reaction, a molecular microbial method to detect DNA or RNA of organisms) for Hepatitis A virus and enterovirus must be performed (BIS 2012). The protozoa *Cryptosporidium* and *Giardia* must be absent in 10 litres. In addition drinking water must be “free from” (a sample volume is not defined) the following organisms:

- Viruses

- microscopic organisms (annex C) such as
  - algae,
  - zooplankton,
  - flagellates,
  - parasites and
  - toxin producing organisms

No results from these types of monitoring were found in the study. At the current stage, monitoring for *E. coli* appears to provide enough opportunities to improve water supply safety.

### 3.7.2 Chemical standards

Chemical standards relevant for Indian drinking water quality are the Indian drinking water standards IS 10500: 2012 published by the Bureau of Indian standards (BIS 2012) and the WHO standards (WHO, 2011). Chemical standards are set due to different causes: public health effects, organoleptic issues (acceptability) or operational issues. The WHO sets standards for the protection of public health. The IS 10500: 2012 are set for all the objectives mentioned.

The WHO proposes international guidelines on water quality and human health that can be used as a basis for regulation and standard setting. In the Guidelines for drinking-water quality, WHO presents guideline values for drinking-water for approximately 90 chemical contaminants (WHO, 2011). WHO considers these as 'chemicals that are of health significance in drinking-water'. For another 70 contaminants assessment were performed, but no guidelines are established as either these compounds generally occur in drinking-water at concentrations well below those of health concern or not sufficient data are available to derive a guideline value. For threshold chemicals, WHO guideline values are set at a level at which no human health effects are expected during lifetime consumption of the drinking water.

**Derivation of a health based drinking water standard**
The health based provisional guideline values are based on either a threshold dose (non-linear relationship dose-response) and non-threshold substances (linear relationship dose-response). Threshold dose chemicals are believed to have no adverse effect below a certain threshold. The drinking water guidelines values are set to at a level at which no human health effects are expected during lifetime consumption of the drinking water. Non-threshold chemicals are mainly genotoxic/carcinogenic chemicals and their guideline values are concentrations in drinking-water associated with an estimated excess lifetime cancer risk of $10^{-5}$ in WHO guidelines.

## 3.8 Comparing health impact

One important goal of monitoring is to prioritise the health risks in a habitation, district, state or country and support decisions that lead to efficient improvements. Basically the goal is maximum health gain per rupiah. The concept of Disability Adjusted Life Years (DALY) may be applied for the comparison of health effects resulting from different types of water-related hazards (chemical and microbiological). Table 3-6 provides an overview of the most relevant contaminants, their guideline values and the estimated health impact in India.

Table 3-6 Overview of health relevance of drinking water contaminants as discussed in section 3.2-3.5 (ND=no data).

| Compound | IS 10500: 2012 (mg/L) (max[6]) | >standard India | WHO standard (mg/L) | Goal | Health effect (DALY) | Source | Occurrence |
|---|---|---|---|---|---|---|---|
| **Chemical** | | | | | | | Groundwater |
| Fluoride | 1.0 (1.5) | 1.9% | 1.5 | Health, fluorosis | $2 \cdot 10^{-4}$ | Naturally occurring, industrial pollution | Groundwater |
| Arsenic | 0.01 (0.05) | 0.1% | 0.01 | Health, toxic | $6 \cdot 10^{-5}$ | Naturally occurring, industrial pollution | Groundwater |
| Iron | 0.3 | 20.5% | none | Consumer acceptability (taste and appearance) and technical reasons | 0 | Naturally occurring, plumbing, industrial pollution | Groundwater |
| Salinity DS | 500 (2000) | 0.2% | 250 | Taste | 0 | Naturally occurring, industrial pollution | Coastal areas, inland areas with over abstraction of water |
| Nitrate | 45 | 2.6% | 50 mg/L total nitrogen | Health, particularly for infants aged<6 months | Unknown | Animal and human waste, inorganic fertilisers, decaying vergetation | Agricultural areas |
| Free chlorine<br>*Minimum when chlorinated*<br>[for viruses] | 0.2<br>(1)<br><br>[0.5] | ND | 5 mg/L | Health: protects microbial quality in distribution and storage | Unknown | Disinfection with chlorine | Tap water |
| | | | | | | | |
| Pesticides[2] | Variable 0.00001-0.190 | ND | Variable (0.003 - 200 mg/L) | Toxic | Unknown | Crop protection in agriculture | Agricultural areas |
| | | | | | | | |
| Nickel | 0.02 | Unknown | 0.07 | Health (potential carcinogenic) | Unknown | Natural trace element .Used in industrial and consumer products. Nickel can be released from taps and fittings | Tap water |
| Zinc | 5 (15) | Unknown | none | Acceptability | 0 | Natural trace element. Dissolution of zinc from pipes | Tap water |
| Copper | 0.05 (1.5) | Unknown | 2 | Health, gastrointestinal effects, and acceptability | Unknown | Natural trace element Household plumbing and solder, industrial pollution | Tap water |
| Cadmium | 0.003 | Unknown | 0.003 | Health, toxic | Unknown | Natural trace element | Tap water |
| Mercury | 0.001 | Unknown | 0.001 | Health, toxic | Unknown | Natural trace element | Tap water |
| Chromium | 0.05 | Unknown | 0.05 | Health, carcinogenic | Unknown | Natural trace element | Tap water |
| Lead | 0.01 | Unknown | 0,01 | Health, toxic | $3.2 \cdot 10^{-5}$ | Household plumbing and solder, industrial pollution | Tap water |

**Table 3-6 Continued**

| Compound | IS 10500: 2012 (mg/L) | >standard India in 2013 | WHO standard (mg/L) | Goal | Health effect (DALY) | Source | Occurrence |
|---|---|---|---|---|---|---|---|
| **Microbial** | | | | | | | |
| *E. coli* / FC | <1/100 ml | 4.7% | <1 | Health, microbial | >$1.6 \cdot 10^{-4}$ | Waste water, faeces | Surface water, unprotected groundwater |
| *S. typhi* | ND | 500/100,000[3] | | Health, microbial | $1.1 \cdot 10^{-3}$ | Waste water, faeces | |
| *Vibrio cholerae*[1] | ND | 2680/y | | Health, microbial | $2.5 \cdot 10^{-4}$ | Waste water, faeces | |
| Acute diarrhoea[7] | ND | 11 million cases/y | | Health, microbial | [5]$6.4 \cdot 10^{-5}$ | Waste water, faeces | |
| Enterovirus | 'Free from' | Unknown | | Health, microbial | 0.48 /case | Waste water, faeces | |
| *Cryptosporidium* | <1/10 l | Unknown | [4] <1/10[5] | Health, microbial | $1.5 \cdot 10^{-3}$ /case | Waste water, faeces | |
| *Giardia* | <1/10 l | Unknown | | Health, microbial | Unknown | Waste water, faeces | |

[1] Kanungo et al. 2006
[2] Abhilash and Singh 2009
[3] Ochiai et al. 2008, Aarogya 2014
[4] WHO does not set a standard for *Cryptosporidium*, however a $1,3x10^{-5}$ concentration corresponds to a $10^{-6}$ DALY target in the example Table 7.4 (WHO 2011)
[5] estimated assuming $7*10^{-3}$ DALY per case of diarrhoea based on WHO 2011, Table 7.4
[6] IS 10500:2012 allows relaxation of some standards in the absence of an alternative source
7 Havelaar and Melse 2003

## 3.9 Water quality parameters most relevant for health

In this chapter we discussed the various water contaminants and their relevance for health in India. Looking at the DALY estimates in Table 3-6 Fluoride and Arsenic are relevant geogenic contaminants. Lead contamination by human activity has almost the same health impact. Absence of *E. coli* is insufficient to indicate that a health target of $10^{-6}$ DALY is met. Acute diarrhoea from microbial contamination results in an estimated health burden of the same order of magnitude as the chemical contaminants. The expected health effect could not be established in the form of DALY values for all contaminants. From the discussions in sections 3.2 to 3.5 nitrate appears to be most relevant for health, especially for infants.

# 4 MONITORING OBJECTIVES

## 4.1 Introduction

This chapter discusses the monitoring of (drinking) water quality and its role in providing safe drinking water. We start from the high level views of the World Health Organisation and the Indian government on where water quality monitoring fits into the water supply frameworks. Then we look at the various roles that water quality monitoring can play within the framework of water safety planning and QMRA. Then we apply these insights to define monitoring goals in the Indian situation and discuss the requirements of the monitoring technologies to meet these goals.

## 4.2 Water quality monitoring in the framework for safe drinking water

Water quality monitoring (WQM) has been applied at all stages of drinking water production, in the catchment, source, treatment, storage, distribution, secondary distribution and household storage and treatment. The main goal of water quality monitoring is to provide essential insight in risks associated with drinking water supply. However, in many situations WQM has become a customary ritual where the obtained information is simply stored never to be looked at again. The WHO guidelines for drinking water quality 4 (WHO 2011) highlight the importance of embedding WQM in the framework for safe drinking water (Figure 4-1). Already in the 1997 GDWQ3-Surveillance and control of community supplies (WHO 1997) this relation between monitoring and action at different levels was made clear (Figure 4-3).

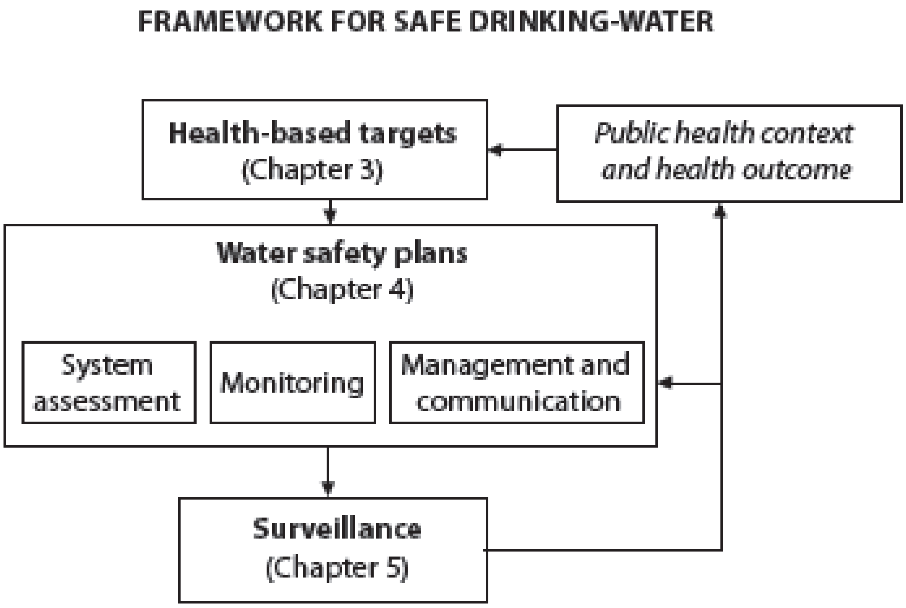



**Figure 4-1 Framework for safe drinking water (WHO 2012)**

The Indian uniform water quality monitoring protocol (Government of India 2013) underpins the important role of water quality monitoring: *Most effective to ensure safe drinking water is through use of a Water Safety Plan (WSP), which ensures the safety and acceptability of a drinking-water supply by eliminating/ minimizing the potential risk of contamination. Conjoined approach of using WSP with Water*

*Quality Monitoring is an important tool which extend its application beyond the creation of water quality database and is useful for preventive and curative management measures. Water quality monitoring leads to identifying sources of contamination and implementation of corrective actions and subsequent verification comprises of components of water safety plan. Below the framework of water safety in rural context is shown.*

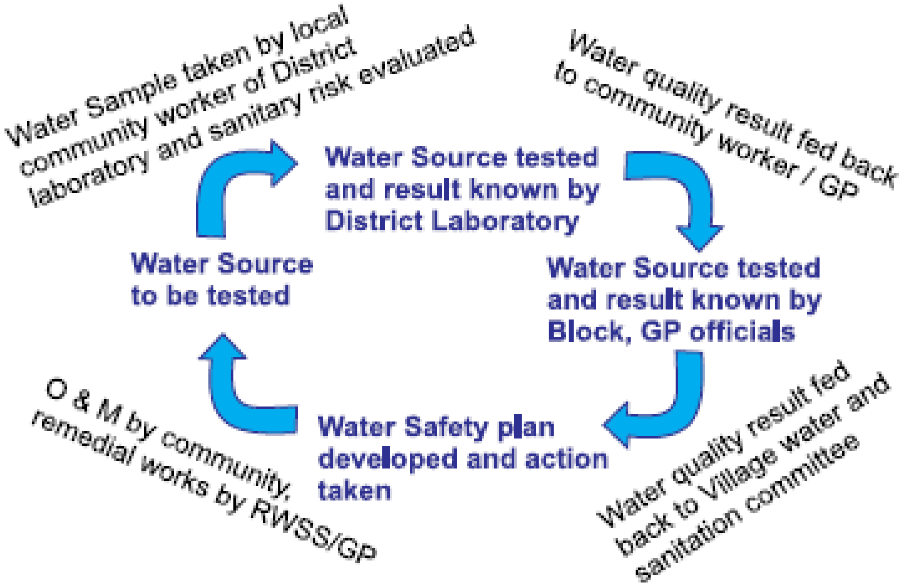



**Figure 4-2 Role of water quality monitoring at the rural level (from Government of India 2013)**

The current study focuses on WQM in the context of providing safe drinking water in India, especially in the rural settings. It discusses the various goals of WQM, the current practice of WQM in India, the insight this provides in the most relevant health risks, the WQM techniques available and the required characteristics of these techniques to achieve the goals. This leads to a framework to evaluate monitoring techniques which is applied in a case study for the pilot sites in Water4India.

## 4.3 Water quality monitoring in rural Indian context

Water quality monitoring is not a goal in itself, but it serves various purposes. WHO illustrated in Figure 4-3 how WQM should be part of a framework for surveillance and improvement of water supply (WHO 1997). After careful planning, WQM should be performed along with sanitary inspection and community survey. The results should be analysed and interpreted together to form a basis for technical interventions, hygiene education and be evaluated for legislative and regulatory aspects.

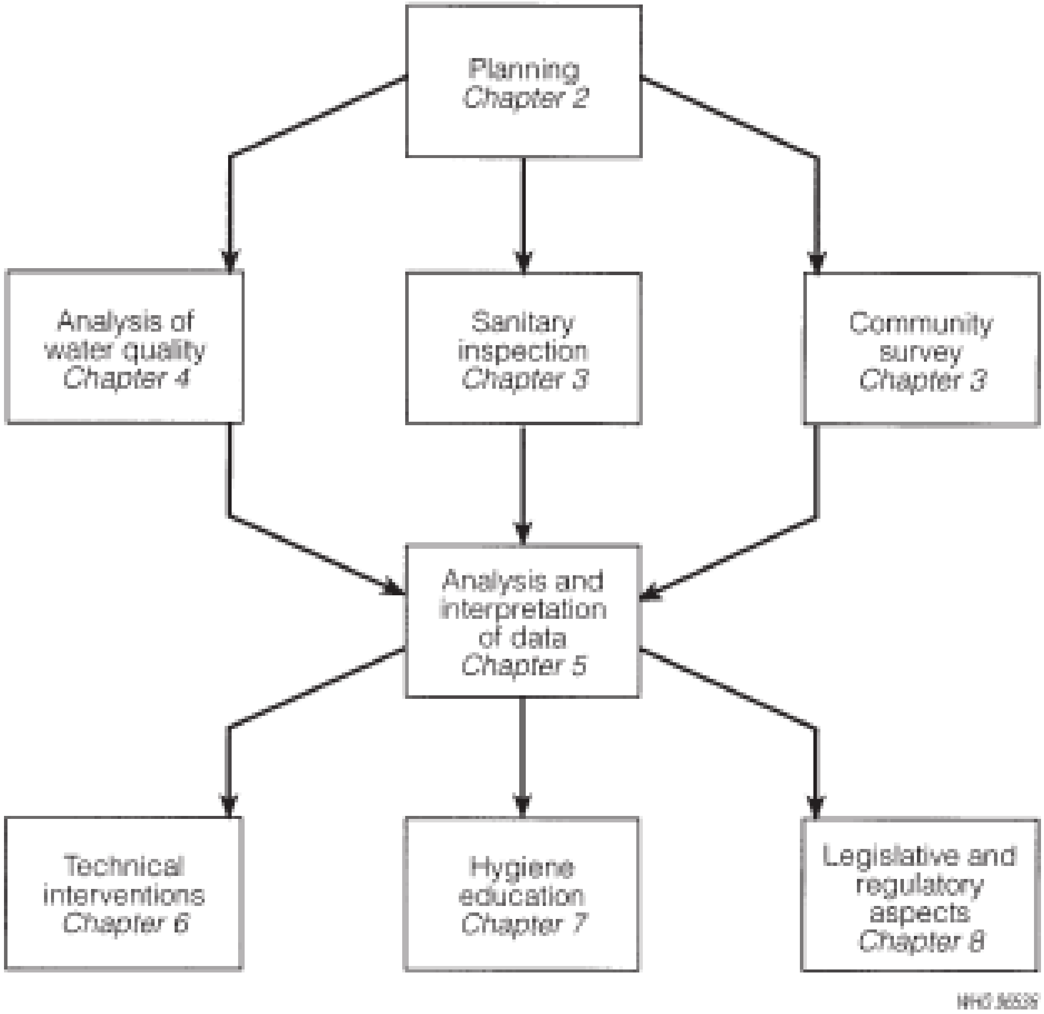



**Figure 4-3 Key stages in the development of water-supply surveillance and strategies for improvement (WHO 1997, Guidelines for drinking-water quality Volume 3—Surveillance and control of community supplies)**

Bain et al (2012) described in Table 4-1 how different goals of water quality monitoring lead to different requirements for microbial water quality analysis. At the operational level, WQM needs to provide information that the operator can interpret and take action on. Generally this requires more frequent sampling and analysis, that not necessarily needs to have a high accuracy. If the operator cannot take any action because lack of controls or materials, then WQM does not provide added value for operational control of water quality. Compliance and surveillance monitoring needs a reliable, uniform and accurate analysis method since results may lead to legal action. Outcomes should not be disputable in that case.

**Table 4-1 Types of monitoring and information needs (Bain et al 2012).**

| Type | Definition | Information needed | | |
|---|---|---|---|---|
| | | Indicator [1] | Quantification | Regulatory Approval |
| Compliance or Surveillance | Compliance monitoring is conducted by water service providers to demonstrate that water meets the regulatory standards | As regulated | As regulated | Required |
| | Surveillance monitoring is conducted by an independent agency to ensure water is safe | Health based, Usually TC and/or EC | Desirable, ideally with range depending on health risk | |
| Operational | The monitoring of operational parameters to ensure treatment is functioning | Operational parameter, often TC | Desirable | Desirable |
| Other | Examples include research into water treatment efficacy testing, educational and awareness-raising or controlling for water quality as part of a study | Varies | Varies, though often desirable | Desirable |

[1] EC—*Escherichia coli*, TC—Total coliforms.

Based on these views and the current monitoring efforts performed in India, we developed a view on monitoring at different organisational levels. In India, the various goals of monitoring are relevant at different organisational levels. This is illustrated in Figure 4-4. At the level of habitations and villages, WMQ can support awareness raising about the relation between water quality and diseases and the importance of safe drinking water. When the village is remote, it needs to operate its own system, or the operation may be organised by the Gram Panchayat. Raising awareness can also help reduce water pollution by the people for themselves or the water users downstream. Raising awareness needs simple techniques that can be interpreted by the general population and does not need to be very accurate. The Gram Panchayat is responsible for the collection of compliance data and therefore requires uniform, reliable techniques in line with legislation. Decisions on (funding for) improvements are also taken at the Gram Panchayat level. This may require additional data beyond the compliance monitoring, e.g. to identify the source of contamination or seasonal variations. At the block (group of several GPs) level no WQM activities seem to be undertaken. At the district level, more advanced laboratories are available to do specific water quality analysis such as pesticides. This is combined with the compliance data from the Gram Panchayats for the state and national data collection. Since water taxes are collected at district level, it is expected that some funding of water supply also takes place at the district level. All compliance data is collected at the state and national level. This forms the basis to assess health risks at a national level and to identify priorities for improvement. This leads to national or state programs for water supply improvement and environmental protection and pollution control.

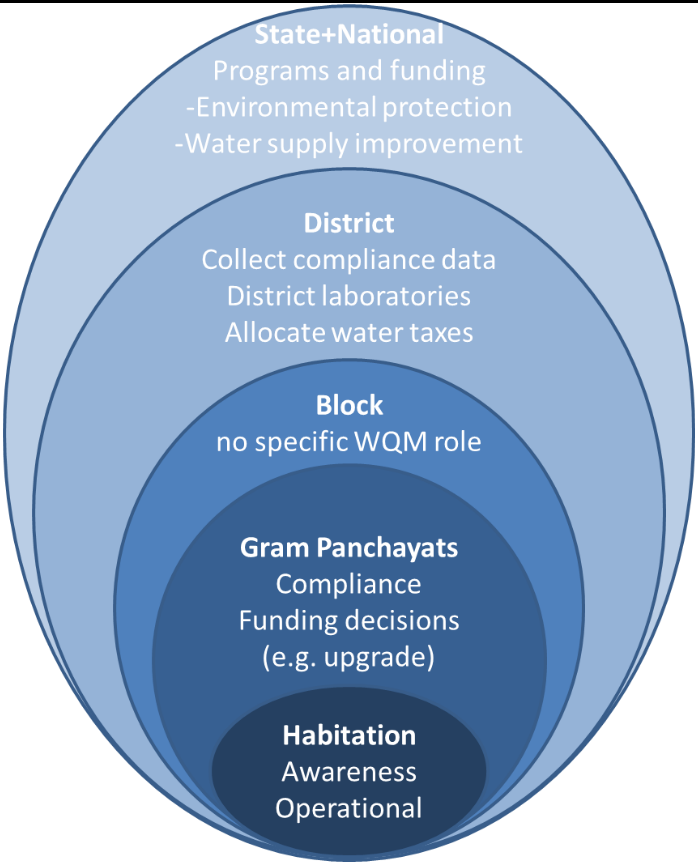



**Figure 4-4 The goals of water quality monitoring at different organisational levels in India.**

### 4.3.1 Awareness

The relation between water quality, sanitation and health is often not clear for drinking water consumers. Especially in developing regions the consumers can have a strong impact on their own risk by selecting the best source, treating the water and preventing contamination. However the first step is to create awareness for this group. WQM at the local level can support awareness programs.

One example is "Developing water safety plans involving schools" (Samwel and Möller, 2009). Nitrate test strips are provided as part of a program to let school children develop WSP's. Monitoring nitrate shows the impact of human behaviour on water quality and how this varies between sources and through the year. Although nitrate at levels below 50 mg/l (or 100 mg/l) are below the guidelines, monitoring variation of nitrate levels does help to raise awareness. Similarly odour, turbidity and colour can be monitored with simple, free methods to make people aware of water quality.

World water monitoring day is a worldwide initiative to create awareness by monitoring at the local level, both in developed and developing countries focusing on water sources (WWMC 2015). It provides information material and test kits, although currently they may not be suitable for India ($15 for 50 samples pH, turbidity, oxygen). The initiative also provides a platform to share data and information, showing a few participations in India, but not in Karnataka state. Monitoring species of insects to indicate the level of pollution was mentioned as an alternative approach to direct WQM for surface waters, however this method is not applied broadly.

These examples illustrate that WQM for awareness raising don't need the same parameters or accuracy as WQM for compliance.

### 4.3.2 Operation

The supply of drinking water can comprise of many activities and is not limited to the operation of a treatment plant. Operation may include protecting the source or catchment, selecting which sources to use under the current condition, which treatment to apply, setting operational parameters for treatment and distribution and give warning to consumers when needed. Even in-house management of water such as secondary distribution, in-house storage and treatment could be considered to be part of the drinking water supply. Key for operational monitoring is that the monitoring results lead to an operational decision. This leads to some requirements for the analysis technique:

- Analysis results must be fast enough to allow change of operation to have an impact
- Frequent samples need to be affordable
- Analysis must be accurate and specific enough to support the decision
- The operator can perform and interpret the analysis in time, or has sufficient access to and communication with a laboratory
- Methods must be safe for operator and environment
- Some results from operational monitoring could also be used to show compliance

**Time to result**

Whether an analysis result is fast enough depends on the water supply system and the ways to respond to the outcome. Chlorine levels can vary rapidly and require adjusted dosing, which can be done almost immediately. Therefore a quick result is needed when monitoring chlorine levels, since otherwise the actual level may have changed again and adjustment may be inappropriate. On the other hand, fluoride levels may rise and fall gradually during the year, making it necessary to switch to an alternative source or to start (or stop) arsenic removal. In that case a week between sample and result does not need to be a problem since changes are gradual.

**Frequent analysis cheaper**

Analysis of samples that need to be taken frequently should be as cheap as possible, whereas analysis that are used infrequent may be a bit more expensive. The total costs of sampling should be integrated in the water price. In the example above the chlorine samples need to be taken frequently (e.g. daily) but a few fluoride samples per year can be sufficient to take timely action.

**Accurate and specific**

Accurately measuring free chlorine is quite complex. More simple tests are available but these may not differentiate between free chlorine and other oxidising products in the water and are therefore not very specific and accurate. The effect of chlorine on pathogens depends on many other factors apart from free chlorine concentration, such as contact time, pH and temperature which are hardly controlled. It makes no sense to put more effort in a more accurate chlorine measurement. Still such simple tests are generally sufficient to dose chlorine with sufficient accuracy.

**Execution and interpretation of results by operator**

When the operator needs to perform the analysis, tests must be simple and safe enough for someone with little training in such procedures. The results need be such that they can be interpreted by the operator. Often this is done with colour charts to estimate concentrations. Then the operator needs to know what action to take (if any). If samples are sent to a laboratory, the results need to be reported back to the operator so that he can take action.

**Safety and environment**

Chemicals and materials used for water quality analyses can be hazardous to the health of the person performing the test. Wastes from the analyses may be hazardous for the environment, for example the chemicals used, wasted glass and plastic. Microbial analysis is often based on multiplication of microorganisms. Pathogenic organisms may be multiplied as well. Disinfection or safe disposal is then very important not to increase the problems already present.

**Coincide with compliance monitoring**

Often only compliance monitoring is performed at the treatment system level. Generally compliance monitoring will not be enough to effectively operate a water supply system. Still samples taken for operation can also be used for compliance monitoring when an appropriate method is used. When the method for compliance monitoring is inappropriate for operational monitoring (costly, hazardous, complicated) two different methods may be used for the same parameter. This will often lead to a slightly different result between the two methods, however than need not be a problem.

### 4.3.3 Compliance monitoring

Compliance monitoring is performed to comply with the legal monitoring obligations. Monitoring frequency, parameters and analysis methods are determined by law. The monitoring results are collected on a regional or national level and evaluated against the applicable (drinking) water standards by a governmental organization. Non-compliance should lead to action by the water supplier or the government to improve water quality. This data is generally also the basis to make funding decisions at different levels. The collected data is often reported publically in some aggregated form. Chapter 4 describes the current compliance monitoring in India.

### 4.3.4 Health risk assessment

Although compliance monitoring is performed with health aspects in mind, it does not provide direct assessment of health. While high level of illness has many negative effects, improving health has a positive effect on the development of people and the economy. For decision making at state or national level, the impact of water supply on health is an important parameter. Better insight in the actual causes of illness can help direct effective interventions either to prevent environmental contamination, to result in appropriate water treatment or to the implementation of other protection measures. The following sections will discuss monitoring in the framework of water safety planning (WSP) and quantitative microbial risk assessment (QMRA) as methods to assess and manage health risks.

## 4.4 Role of water quality monitoring in water safety planning

### 4.4.1 Water safety planning in the Indian context

Water safety planning is a risk assessment and risk management approach promoted by WHO and IWA to provide safe drinking water by managing risks from source to tap. The WSP manual is a step by step guideline for making a WSP for a system and includes various examples (Bartram et al. 2009). In 2011 the WSPortal was launched as an internet platform were the various stakeholders can share experiences in the WSP process (WHO and IWA, 2011). In 2013 the concept was extended to the Water cycle safety plan (WCSP) in the framework of the PREPARED project (Do Ceu Almeida et al. 2010, PREPARED 2013). The WCSP recognizes the interactions that take place between the various effects and uses of water in the urban environment and focused especially on preparing for climate change effect. In this chapter we will only focus on the role of water quality monitoring in the W(C)SP, and the reader is referred to the mentioned references for more information on the total approach. Figure 4-5 shows the basic steps of water safety planning (which differ slightly between WSP guidances). The next sections will discuss the role of water quality monitoring at the relevant steps of the WSP

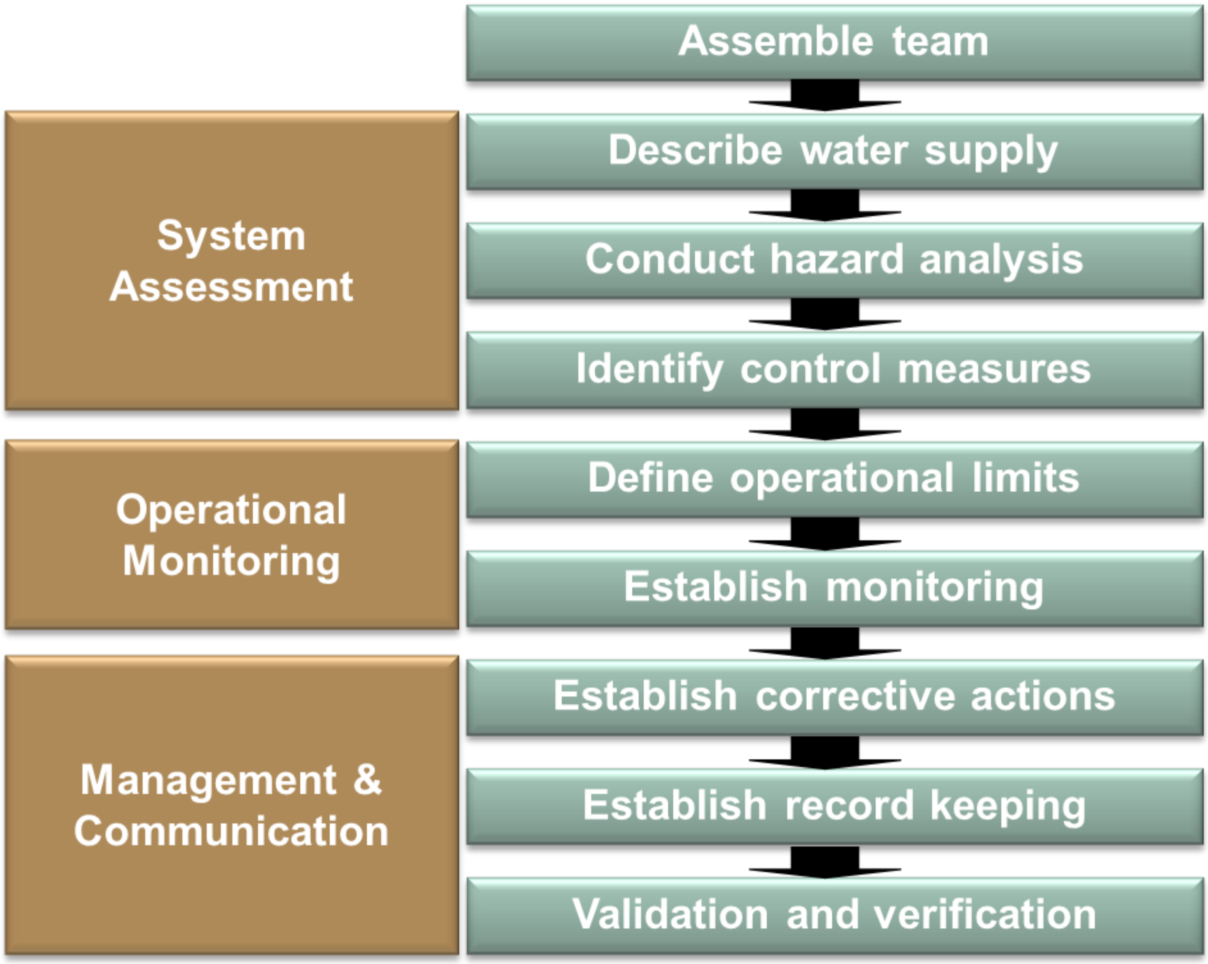



**Figure 4-5 Stages and steps in water safety planning**

The WSP focuses on drinking water supply from source to tap. In the Indian rural context there are no clearly defined boundaries of what should be considered part of the “water supply” since a variety of sources and supplies are used by most people. A centralized supply where treated surface water or groundwater is distributed by a distribution network to taps in the homes is the basic setup in most western countries. In rural India house connections are rare and people have to collect, transport and store water themselves from public taps or public wells. Private wells and harvested rainwater are also common sources of water, and in some areas water vendors, either public or private, sell water that may have undergone treatment. Surface and spring waters are used directly either because of lack of alternative sources or for religious reasons. Finally people may use various types of home treatment, often depending on the observed quality of the water, including boiling, sieving, candle filters or more advanced commercial home treatment. The “source to tap” concept in rural India is actually “sources through routes to mouth”. Managing all risks in such a complex situation is challenging and monitoring this requires more than a yearly sample at a tap.

The boundaries of the system for which a WSP is to be developed will vary with the involved stakeholders. The water boards may undertake a WSP for each of their multiple village schemes to make sure the water at the point of delivery is safe. A gram panchayat may undertake a WSP to manage the risks from all the sources used in the community, including the risks of secondary transport and home storage, to reduce risks in the community. On the zilla panchayat level WSP may be performed for a whole region to prioritize investments in water supply. The various goals and levels of water quality monitoring will be discussed in Paragraph 3.3.

Monitoring water quality plays a role at various stages of the water safety plan. The requirements of monitoring vary with the different goals at the various stages. Each stage will be discussed and guidelines for each stage will be provided in the context of rural India. It is important to consider that not all locations or situations are at different stages of WSP development. In some locations health effects of drinking water may just have started to receive attention or new water schemes are being considered. That requires monitoring to assess the situation for decision making. In other locations the WSP may have already gone through several cycles and monitoring is more directed at consistent management of risks. This already indicates that a single uniform monitoring protocol does not exist. The National Rural Drinking Water Quality Monitoring and Surveillance Programme plays a part in this, but doesn’t cover all monitoring needs.

### 4.4.2 System assessment: identify hazards and assess the risks

General health risks through drinking water have already been discussed in the previous chapters and in the reports D2.2 and D3.2. Key point in this step of the WSP is to sufficiently identify these hazards in a specific water supply system, considering the variety of routes from source to mouth. Especially in rural India the number of water supplies is extremely large and monitoring each possible contaminant for each individual supply and route is not feasible. Instead relevant information is used to make a best estimate potential risks. Observations and knowledge about the situation can provide a first estimation of potential risks. For example the presence of wastewater discharge upstream from a water intake is likely to lead to the presence of faecal pathogens in the abstracted water. Other indications for contaminants may be cattle in the catchment, industry, pesticide use etc. In addition to these observations, water quality can be monitored for indicators of contaminants, so called ‘proxy parameters’. In this section we focus on water quality monitoring for contaminants or proxy parameters.

Contaminants are the substances that actually cause health issues, whereas proxy parameters indicate the potential presence of contaminants. Proxy parameters can be organoleptic (taste, colour, odour and smell), simple water quality analysis such as nitrate or pH paper test strips or more advanced tests like microbial tests (faecal indicator bacteria, FIB).

Organoleptic parameters are especially useful to detect changes in water quality and respond to that. Several people have mentioned that they start boiling water from open wells (or other supplies) when it becomes turbid or the water smells bad. They have learned from experience that these changes indicate contamination, for example during monsoon. However, people get used to organoleptic parameters, and persistent contamination will not be noticed. Also not all contaminations will lead to noticeable changes in water quality. Asking people about variations in water quality can provide insight in the vulnerability of (ground) water sources.

Nitrate tests have been used in water safety planning as a proxy for human contamination of water (Samwel and Möller, 2009). Although high levels of nitrate can be hazardous to infants, lower levels already indicate human impact on water quality in the form of fertilizers, manure or sewage. Samwel and Möller (2009) also provide guidelines and kits for simple tests of pH, turbidity, odour and taste to educate school children about water quality in the framework of water safety planning.

The faecal indicator bacteria (TTC, *E. coli*) are well known proxy parameters for pathogens. FIB generally don't cause illness, but are in indication that the water was recently contaminated with faeces which may contain pathogenic organisms. However their interpretation in terms of actual health risk (or safety) is still subjected to large uncertainties (Saxena et al. 2015).

Knowledge is needed to translate proxy parameters to actual risk. In section 6.6 we provide an example how to estimate pathogen concentrations based on monitored FIB concentrations. Similarly nitrate levels could be linked to the level of risk from pesticides or pathogens from agriculture. However these relationships will vary according to the local situation. In the field nitrate levels can be measured relatively easy using paper strips. In addition the pollution control board keeps track of which pesticides are used in which areas. Thus the combination of nitrate levels in drinking water and their location can provide a better estimate of pesticide levels and therefore health impact of the drinking water sources.

#### 4.4.3 System assessment: Determine and validate control measures, reassess and prioritize risks

Based on the risk from the source water assessed in the previous step, barriers against these risks should be evaluated or implemented. Source protection and water treatment are the most common barriers. Source protection, for example fencing to keep away animals from the source, should result in improved source water quality in the previous step. For water treatment, the potential effect and the actual effect in practice need to be validated and verified. Testing water treatment technologies as described in Water4India deliverable 4.3 is a way to validate treatment processes. Such validation will normally take place under controlled conditions in a laboratory where advanced water quality analysis methods are available. The system can be tested with high contaminant levels to assess the range of their efficiency with various test water qualities that represent real life challenges. The WHO protocol for *Evaluating household water treatment options: health-based targets and microbiological performance Specifications* is an example of this approach (WHO 2011b). In a laboratory setting, treatment systems can be challenged with high concentrations of various micro-organisms in order to establish up to 5 log (99.999%) reduction credits.

When applied in practice, the efficiency of the barriers needs to be verified periodically to assess if they remain effective. The system will be subject to varying conditions and operation of a system may not be optimal. Over time systems will wear, leakage can occur, or clogging, and equipment may start to fail.

Verifying their performance in practice over time is more challenging due to various factors. Lab facilities for water quality analysis may be too distant, so less advanced water quality analysis methods must be used. Concentrations of contaminants (e.g. micro-organisms) in the source water will typically be lower than the spiking concentrations in the lab, thus limiting the span of log removal that can be indicated. Spiking of contaminants in real life systems is not acceptable since it may lead to health risks. Although water quality monitoring in the field is effective to detect failing systems that are not removing contaminants at all, it is often not able to verify the desired level of removal.

With respect to microbial water quality monitoring, the sensitivity of measuring micro-organisms in treated water is often critical. Simple water quality tests only use small volumes of samples from 1 to 100 ml (see Water4India deliverable 4.1). This can be resolved by increasing the sample volume using membrane filtration or the multi compartment bag test (up to 1 liter), a Bag-Mediated Filtration System (10 liter, Fagnant et al. 2014) or cross-flow membrane filtration (1000 liters, Veenendaal and Brouwer-Hanzens 2007). However these methods are also increasingly complex and less suitable for regular sampling. The choice between many simple, cheap tests and a few more complex, expensive tests depends on the system that is tested and the situation that it is placed in.

All the information needs to be combined to provide a best estimate of barrier efficiency in practice. When the effect of barriers is validated and verified, the remaining risk can be estimated again using qualitative, semi quantitative, QMRA or DALY approaches. Comparing the remaining risks to risk targets may lead to other prioritization of risks or the implementation of new risk reduction measures or barriers.

### 4.4.4 Operational monitoring: Define monitoring of control measures

Consistent performance of control measures (barriers) must be monitored to guarantee safety at all times or implement timely corrective actions. Targets for the control measures (barriers) must be set that achieve the desired level of safety (e.g. WHO 2011b). First step is verifying adequate operational conditions: is the system operating within specified operating conditions (temperature, turbidity etc.).Secondly, are there any indications of failing, e.g. cracks in filter pots or leakages? Finally specific tests may be built into the system such as pressure holding tests for membranes or UV intensity measurements.

Water quality monitoring used to validate and verify performance of barriers may also be used for operational monitoring. Examples are turbidity, UV transmission, residual chlorine and pH measurements that are either performed manually or with on-line equipment. Water4India task 4.5 will focus on the on-line measurement of FIB to monitor microbial water quality and evaluate if that approach is practical in the rural Indian situation.

### 4.4.5 Management and communication: Prepare management procedures

Management procedures describe the actions to be taken by operators, or end-users. This includes the instructions for adequate monitoring and responses when monitoring results exceed the critical limits. This is a crucial step that is often not addressed sufficiently in practice. Water quality analysis is performed and recorded in diaries, but no corrective action is taken when critical limits are exceeded. Secondly data analysis of the recorded monitoring results can help to further improve water quality and control of water treatment barriers.

## 4.5 Quantitative microbial risk assessment QMRA

### 4.5.1 Introduction to QMRA

Although the WSP approach provides a practical approach to manage and improve drinking water safety, it is largely based on qualitative assessment of risk. Microbial risks occur even at very low concentrations in water and a qualitative approach is often insufficiently accurate to base important, costly decisions on. Quantitative microbial risk assessment (QMRA) was developed to provide a more scientific, quantitative basis for decision making (Haas et al. 1999). As such QMRA can be used in the WSP as a tool to estimate risks based on the available data (Medema et al 2006, Smeets et al. 2010). In QMRA the pathogen concentrations in water sources and their removal by treatment are assessed based on quantitative data either from the site or from literature. Thus the concentration of pathogens in drinking water can be calculated, and combined with the consumption of unboiled drinking water, the number of ingested pathogens is estimated. Using pathogen specific dose-response relationships the risk of developing an infection can be calculated, and from this the risk of developing illness and the loss of life quality (DALY). By performing stochastic analysis and simulations, the variability and uncertainty about the risk is included in the assessment. These steps of QMRA are illustrated in Figure 4-6.

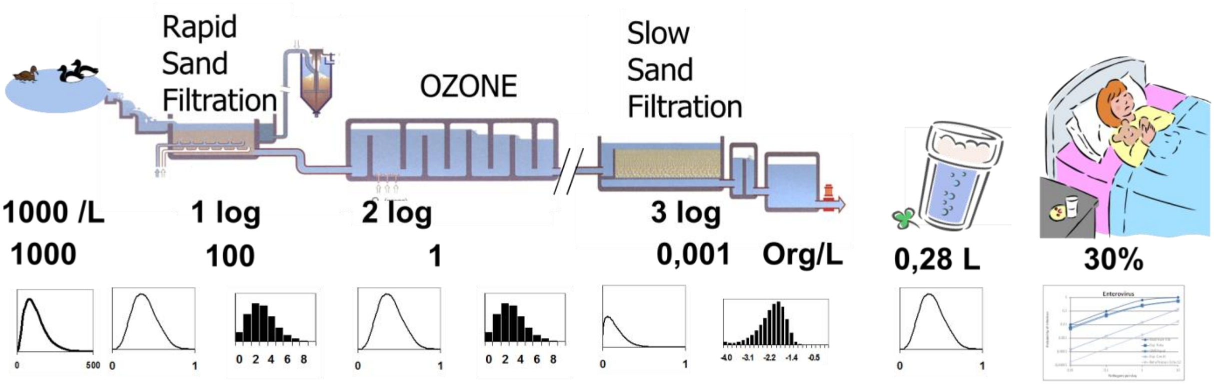



**Figure 4-6 Visualisation of the steps in quantitative microbial risk assessment (QMRA)**

QMRA provides a systematic approach to gain insight in the aspects that determine drinking water microbial risks. Care must be taken when interpreting results, as the risk estimate is only as accurate as the input data. For the rural Indian situation this may be challenging since people use a range of water sources and quantitative information is often lacking. Water4India deliverable 4.4 provides a QMRA approach applicable to the Indian situation. In section 6 of the current report we show how quantitative data from India can be obtained and interpreted for use in QMRA.

### 4.5.2 Current practices of QMRA

In the US, QMRA has been used in the 1990 to set water treatment requirements to reach the health based target of 1 infection per 10.000 people per year ($10^{-4}$ risk target). Initial studies such as Gerba et al. (1988) evolved into elaborate guidelines of the *Long term second enhanced surface water treatment rule* (LT2ESWTR, USEPA 2006). Since 2001 water companies in the Netherlands are required to perform QMRA for their surface water treatment system and show that they comply with the $10^{-4}$ risk

target (Anonymous 2001). Over the past decade they have used QMRA to support decisions on source water selection (river or bank filtration), treatment expansion (UV disinfection) treatment optimization (Ozonation) and operating conditions (UV fluence, ozone dose) (Smeets et al. 2009). More recently the water companies are expanding the QMRA approach to contamination risks during distribution (Blokker et al. 2014). In Australia QMRA has been used to develop regulations for water reuse in the *Water reuse guidelines* (NRMMC 2008). They apply a $10^{-6}$ DALY risk target rather than the risk of infection.
The world health organization incorporated both WSP and QMRA in the 2011 revision of the Guidleines for drinking water quality (WHO, 2011). In 2012 the USEPA implemented the *Recreational Water Quality Criteria* (USEPA 2012) where QMRA is used to set different targets for FIB in bathing water to distinguish between human and animal sources of contamination.

### 4.5.3 Monitoring experiences and needs for QMRA

Goal of QMRA is to achieve the best quantification of health risks, or at least sufficient quantification to support decisions related to health risks. Since monitoring for pathogens requires expensive, sophisticated analysis methods applied to large volumes of water, required monitoring has always been a point of attention for QMRA. The inspectorate guidelines for QMRA in the Netherlands have set monitoring requirements for pathogens of 13 to 19 samples once per three years (VROM-inspectorate 2005). Three of these samples should be targeted on event situations where high peaks of pathogens are expected, and the other samples should be planned periodically. Stochastic methods are then used to estimate the variability of pathogen concentrations and the uncertainty of the assessment. These monitoring programs are costly (approximately €100,000) and for several situations there still remains significant uncertainty about the pathogen concentrations in source waters. Efforts to detect peak contaminations have so far been unsuccessful (Smeets et al. 2010).

In the UK 1,000 litres of drinking water is tested daily for the occurrence of *Cryptosporidium*, an important pathogen. Although the results are only compared to the regulatory standard of absence in 10 litres, this data can also be used to perform QMRA (Smeets et al. 2007). In Australia various alternative water sources such as harvested rainwater and grey water have been tested to develop the reuse guidelines using QMRA (NRMMC 2008). Similarly in the US pathogen monitoring has been conducted to develop the bathing water guidelines using QMRA (USEPA 2012).

These studies provided the following insights:

- Pathogens in sources are highly variable, ranging over several orders of magnitude,
- Risks are dominated by ‘rare’ high concentrations (occurring less than 10% of the time),
- Pathogens of concern can vary from location to location,
- The ratio of FIB to pathogens varies is not equal for all situations due to faecal source type and environmental fate of pathogens versus FIB,
- Pathogen monitoring is costly, but molecular methods continue to decrease in price.

Such extensive monitoring programs are only feasible for very large drinking water production sites or specific scientific studies. For smaller sites or less affluent countries alternative approaches need to be followed to assess drinking water risk for a specific site. A much followed approach is to sample for FIB and then use a ratio between FIB and pathogens to estimate pathogen levels. Unfortunately these ratios are highly variable and seem to shift as water sources become cleaner (e.g. from sewage to groundwater) (Van Lieverloo 2007). His approach has led to monitoring of pathogens in faecal contamination sources such as human and animal faeces, sewage, wastewater and sludge. An overview of the findings from these studies in included in Water4India deliverable 4.4. In Water4India deliverable 4.4 we propose a method to use this scientific knowledge base for QMRA in India. Still this requires site specific monitoring of FIB. Smeets et al. (2012) studied how many samples are needed to adequately characterize the level of faecal contamination in water considering the variability that has been observed in various water sources. Their findings are summarized in Figure 4-7 for a level of variation that is observed in surface water. This shows that a single samples can lead to underestimating the actual mean concentration by three orders of magnitude or even more, but it can also lead to overestimation. Increasing the number of samples initially reduces this uncertainty very rapidly, but at a certain point the impact of taking more samples becomes less. However this is at an assumed variation in surface water, and under the assumption that all samples are positive. When variation is greater, more samples are needed. When many samples are negative, the estimated mean remains uncertain (but low). Based on this study a minimum of six samples (bi-monthly) per year is needed to adequately characterise source water contamination.

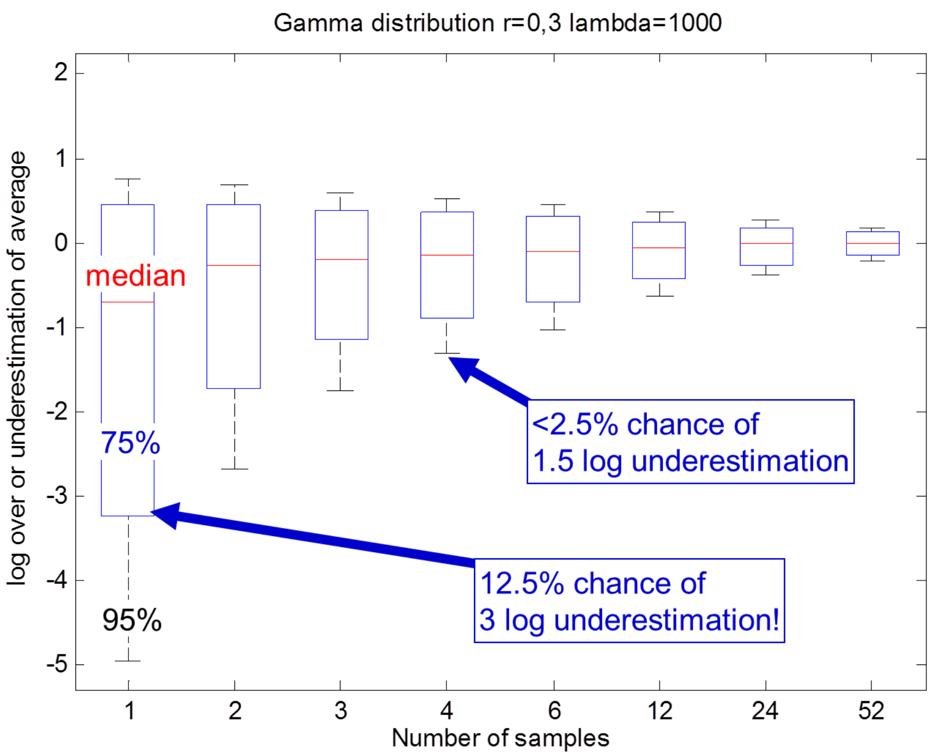



**Figure 4-7 Relation between number of samples and uncertainty about mean concentration (Smeets et al. 2012)**

In India regulatory indicator organisms are measured extensively in drinking water and can inform about the level of contamination present. Combining this extensive data with scientific research data can provide more accurate risk estimates and therefore better support decision making. This will be discussed in section 6.

# 5 CURRENT MONITORING IN INDIA

## 5.1 Development of water quality monitoring in India

In Table 5-1 some important phases are shown for Indian drinking water regulations. Since 2000, water quality monitoring received more attention in India. The government has outlined requisite monitoring systems to observe the quality of drinking water and to disseminate and share information by education and communication (IEC). The Government of India launched the National Rural Drinking Water Quality Monitoring and Surveillance Programme in 2006. The guidelines of this program are found in the report by RGNDWM (2006). The program includes provision for the setting up of new sub-district level laboratories. The program also envisages institutionalization of community participation for monitoring and surveillance of drinking water sources by gram panchayats (local communities) and Village Water and Sanitation Committees. All drinking water sources (both public and private) should be tested using simple field test kits. Positively tested samples are referred to District and Sub-district water testing laboratories for confirmation. Besides, sanitary inspection is also a part of this programme.

**Table 5-1 Important phases for Indian drinking water regulations**

| | |
|---|---|
| 1969 | National Rural Drinking Water Supply programme launched with technical support from UNICEF and Rs.254.90 crore is spent during this phase, with 1.2 million bore wells being dug and 17,000 piped water supply schemes being provided. |
| 1986 | The National Drinking Water Mission (NDWM) is formed (renamed Rajiv Gandhi National Drinking Water Mission (RGNDWM) in 1991 |
| 1987 | Drafting of the first National Water Policy by the Ministry of Water Resources. |
| 2002 | The National Water Policy is revised, according priority to serving villages that did not have adequate sources of safe water and to improve the level of service for villages classified as only partially covered. |
| 2002 | India commits to the Millennium Development Goals to halve by 2015, from 1990 levels, the proportion of people without sustainable access to safe drinking water and basic sanitation. |
| 2005 | The Government of India launches the Bharat Nirman Programme for overall development of rural areas by strengthening housing, roads, electricity, telephone, irrigation and drinking water infrastructure. The target is to provide drinking water to 55,069 uncovered habitations; those affected by poor water quality and slipped back habitations based on 2003 survey, within five years. |

## 5.2 Monitoring surface water

The Central Pollution Control Board (CPCB) serves as a field formation and also provides technical services to the Ministry of Environment and Forests of the provisions of the Environment (Protection) Act. The Board promotes cleanliness of streams and wells in different areas of the Indian States by prevention, control and abatement of water pollution. The CPCB establishes a nationwide network of monitoring station (Table 4-2). Monitoring results are made public through the CPCB website (http://cpcbedb.nic.in/ ). The data provide an indication of the source water quality in India for surface water supplies.

Table 5-2 Distribution of monitoring stations of the Central Pollution Control Board (CPCB, 2012)

| Water Body | No. Of Monitoring Stations |
|---|---|
| Rivers | 1275 |
| Lakes | 190 |
| Drains | 45 |
| Canals | 41 |
| Tank | 12 |
| Creeks/seawater | 41 |
| Pond | 79 |
| Groundwater | 807 |
| Water Treatment Plants (Raw water) | 10 |

## 5.3 Central Water Commission (CWC)

The mission of CWC is to promote integrated and sustainable development and management of India's Water Resources by using state-of-art technology and competency and coordinating all stakeholders (CWC 2015). The CWC monitors surface water quality, including a platform for on-line monitoring of water quality parameters such as temperature, pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, conductivity and TSS (Figure 5-1).

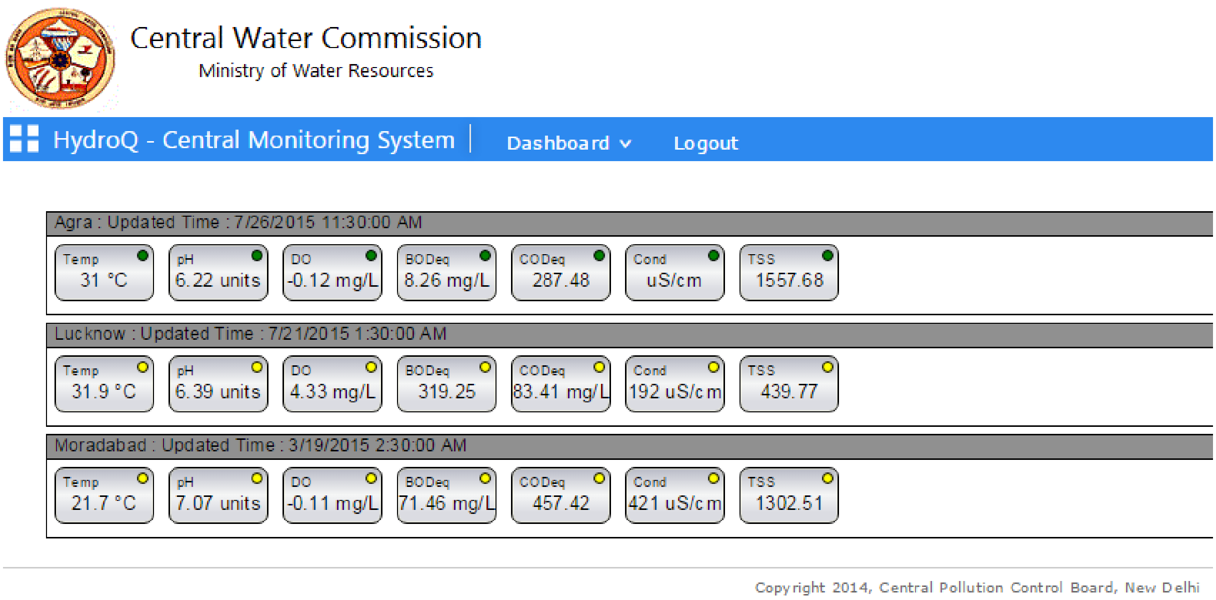



Figure 5-1 Screenshot of CWC on-line water quality monitoring platform.

## 5.4 Central Ground Water Board (CGWB)

Central Ground Water Board (CGWB), a subordinate office of the Ministry of Water Resources, Government of India, is the National Apex Agency entrusted with the responsibilities of providing scientific inputs for management, exploration, monitoring, assessment, augmentation and regulation of groundwater resources of the country. Besides quantitative information, the organisation provides overviews of chemical ground water quality for parameters such as fluoride, arsenic, salinity and nitrate (Figure 5-2).

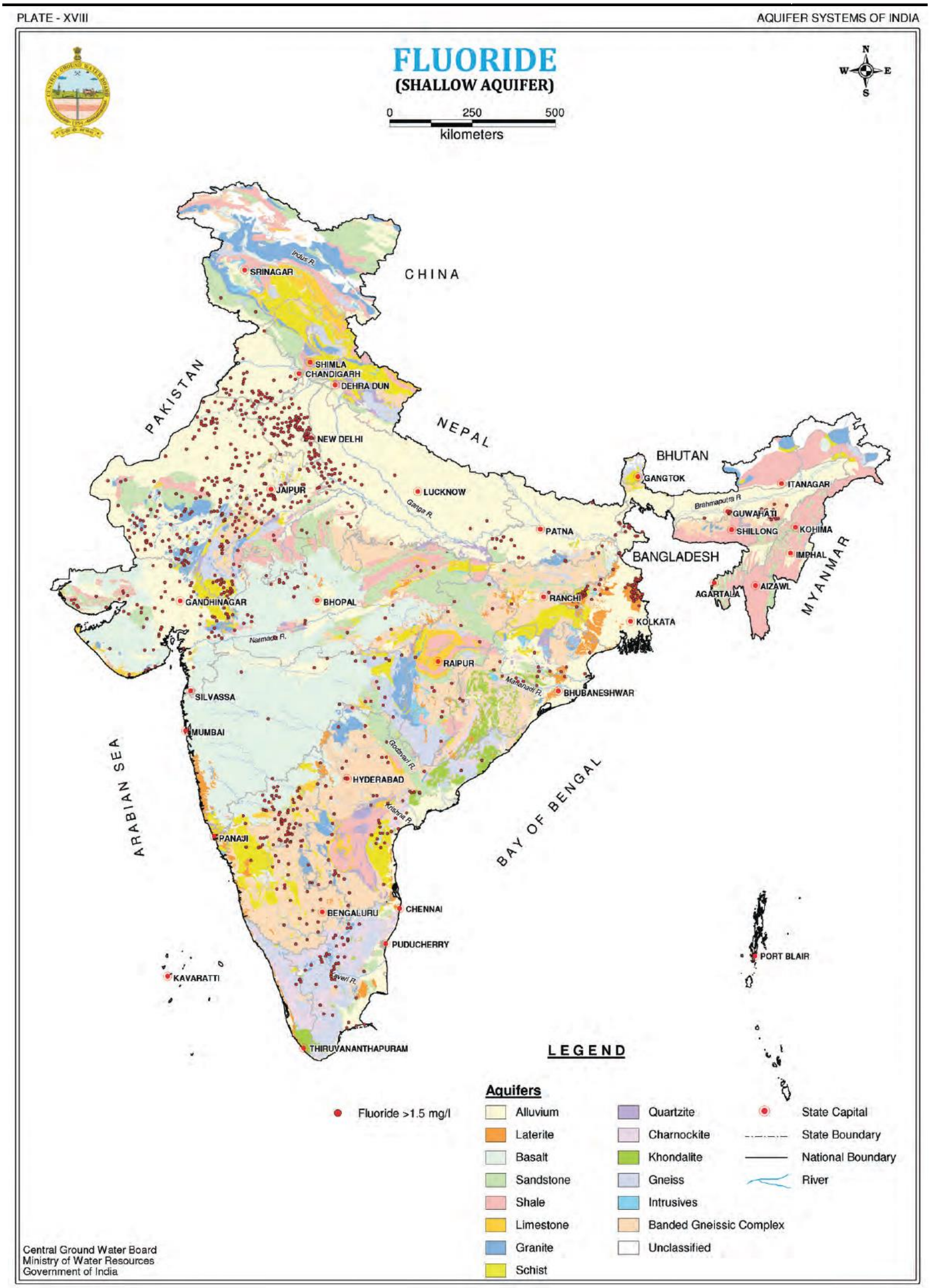



**Figure 5-2 Map of fluoride contamination in shallow wells (CGWC 2015)**

## 5.5 Uniform Drinking Water Quality Monitoring Protocol

The Uniform Drinking Water Quality Monitoring Protocol (UDWQMP) was launched in 2013 and aims to standardise the requirements for setting up and ensure proper functioning of water quality testing laboratories (Government of India, Ministry of Drinking Water and Sanitation, 2013). 3% of the National Rural Drinking Water Programme (NRDP) is allocated for monitoring and surveillance. The UDWQMP is a guideline and will be useful for laboratory personnel, water supply engineers and policy makers working in the drinking water sector operating at State, District and Sub-district levels. The purpose of the document is to describe various elements of laboratory management practices to ensure that the data generated is comparable, scientifically correct and in a form that can be used in implementing interventions to improve water quality. Further, it includes details on water quality testing laboratory, infrastructure and staff requirements. Results are reported by the state rural water supply agencies. The collected water quality data is managed with IMIS (Integrated Monitoring Information System).

The UDWQMP describes the roles of various laboratory levels. The number of current state, district and sub-district laboratories present in India, the state Karnataka and the district are shown in Table 5-3. The functions of the labs are described in the following paragraphs. The district and sub-district laboratories have to share their data on microbiological testing of drinking water sources with the District and State Public Health Departments and also with other laboratories established/ proposed under Food Security Act.

**Table 5-3 number of state, district and block level labs for the India, Karnataka state and the Districts Kodagu and Shimoga (format B12, NRDWP).**

| Laboratory level | India | Karnataka State | Kodagu district | Shimoga district |
|---|---|---|---|---|
| State labs | 27 | 1 | - | - |
| District level labs | 735 | 42 | 2 | 2 |
| Block level labs | 555 | 62 | 1 | 0 |
| Subdivision labs | 922 | 9 | 0 | 0 |

The state laboratory has the capability of analysing a full range of physical, chemical, and microbiological parameters specific to drinking water quality. This laboratory is a referral institute to analyse specific or new/emerging water quality problems and as such is not used for routine water quality analysis. The state laboratories also monitor the performance of district and sub-district laboratories and ensure Quality Assurance & Quality Control (QAQC) in these laboratories. The state laboratories have sophisticated equipment, including analysis of heavy metals and toxic elements by advanced spectrophotometric techniques, pesticides by Gas Chromatography (GC) and High Pressure Liquid Chromatography (HPLC) and more specific bacteriological and virological examination.

District and Sub-district laboratories undertake drinking water quality monitoring of the sources under their jurisdiction. These laboratories analyse 19 physico-chemical and microbiological parameters in drinking water sources as prescribed under IS-10500-2012 (BIS, 2012). The district and sub-district laboratories are responsible for quality assurance of testing and supervision of water quality surveillance and monitoring using field test kits at the grass roots level in the Gram Panchayats (local communities). District and sub-district laboratories also provide a support service pertaining to water quality in remote areas using on-site or laboratory based analytical equipment.

The requirements to set up a water quality testing laboratory described by the UDWQMP, include:

1. WQ field test kit
2. WQ analysis requirements
3. Infrastructure requirements
4. Human resources
5. Funding

The requirements (1) and (2) about the chemical and microbiological water quality monitoring are discussed further in the following paragraphs.

The field test kits can be used for chemical and microbiological tests. The kits are portable, easy to operate and do not require any kind of energy or power. All positively tested samples using field test kits (with certain probability of contamination) are referred to the nearest district/ sub-divisional water quality testing laboratory for confirmation. Field test kits have been supplied to most communities, however they are not always used. In many cases samples are transported to (hospital) laboratories. Sample conservation between sampling and analysis is generally sub-optimal. Analysis results are often not reported back to the population, or not interpreted by the community. Data are collected for national reporting.

Multi-parameter water quality field test kits are provided for physico-chemical analysis with 100 tests for 11 parameters. The parameters include turbidity, pH, total hardness, total alkalinity, chloride, ammonia, phosphate, residual chlorine, iron, nitrate and fluoride. The kit offers quantitative and semi-quantitative results. A separate arsenic field test kit is also available.

The bacteriological test vial indicates the presence/ absence of indicators of pathogens in water samples. This is a simple field test kit to indicate the presence of bacteria in water. The principle of the test is similar to that of Presumptive Coliform Test. It does not attempt to find pathogens but only shows the indicator for the presence of pathogens. The test kit can be used for any water irrespective of its source, including chlorinated water. The test can detect very low bacterial contamination with high specificity and sensitivity.

The requirement for the analysis of water quality can be described by the parameters, the sampling protocol, the analytical quality control, the annual analysis load, the frequency of testing and the recording and reporting of the data.

The number of parameters to be monitored is shown in Table 5-4. The method, instruments and chemicals required are given in the annexes of the protocol (Government of India, Ministry of Drinking Water and Sanitation, 2013). The UDWQMP defines thirteen basic minimum parameters that need to be tested for drinking water quality

- pH,
- turbidity,
- TDS,
- Total Hardness,
- alkalinity,
- fluoride,
- chloride,
- sulphate,
- nitrate,

- arsenic,
- iron,
- total coliforms and
- E-coli.

The frequency of testing is listed in Table 5-4. The services of State level laboratories would be utilised particularly for analysis of specific parameters like metals, pesticides, radioactive substances like uranium, bacteriological investigation and not for general parameters (which could be analysed in district and sub-district level drinking water quality laboratories). Where state labs only test for specific contaminants dependent on the local situation, the district labs have to monitor twice a year for bacteriological parameters and once a year for chemical parameters. The district and sub-district laboratories are estimated to have an analysis load of 3000 samples/year.

For establishing a baseline status, the protocol suggests that all district and sub-district level water quality testing laboratories conduct drinking water quality analysis once in each pre-monsoon and post-monsoon seasons in a year for chemical and bacteriological parameters and then subsequently monitor only those parameters which are found to be present or the concentrations nearing the desirable limits. The UDWQMP requires monitoring to be intensified, if criteria are met, such as a reported waterborne disease; the drinking water rejected by community due to taste, colour or odour; the water is reported to be contaminated (>0.8 times the standard) or to verify the efficiency of improvement interventions.

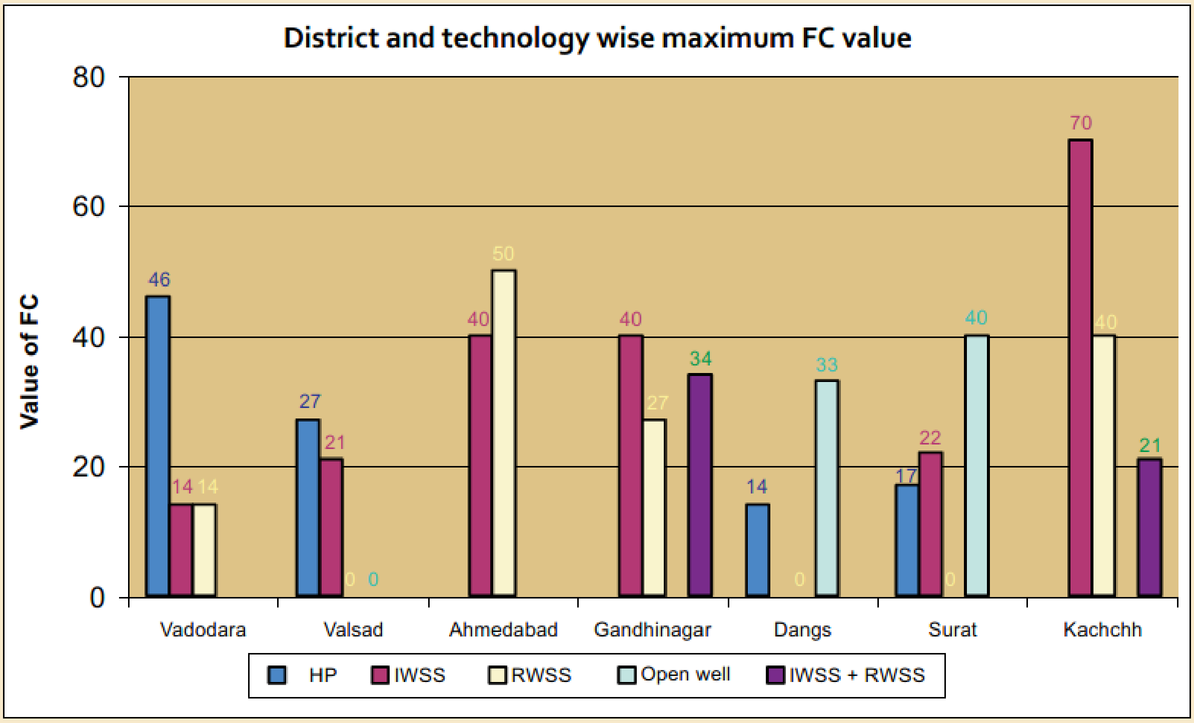
**Table 5-4 Number of parameters to be monitored and the frequency of testing**

<table>
<tr><th>Labo-ratory</th><th>Nr of parameters</th><th>Parameter, motivation and frequency of testing</th></tr>
<tr><td>State</td><td>78</td><td>1. Monitoring for heavy metals, pesticides, radioactive substances, bacteriological for local importance<br>2. Analysis/evaluation/impact assessment specific contaminants<br>3. Virological examination where this contamination is likely (peri-urban, surface water in rural areas or untreated/partially treated sewage into source) and follow-up actions</td></tr>
<tr><td>District</td><td>34</td><td rowspan="2">1. Twice a year for WQ hotspot areas, intensified when sanitary risk, waterborne diseases are reported, source rejected by community (taste etc.), contaminated source or 0.8 times the standard, verify efficiency WQ improvement interventions undertaken<br>2. Twice a year for bacteriological parameters and once a year for chemical parameters. Baseline status: all parameters pre + post monsoon.<br>3. In-vitro UV laminar flow chamber shall be used for testing microbial parameters and for preparation of organic media<br>4. Discrete monitoring during calamities, especially residual chlorine</td></tr>
<tr><td>Sub-district</td><td>19</td></tr>
</table>

## 5.6 Specific studies on water quality in India

### 5.6.1 UNICEF Multi-District Assessment of Water Safety (MDWAS)

UNICEF financed this program in which about 25000 rural water sources were monitored in 2005- 2007. This was based on RADWQ methodology. The study included assessment of both chemical and microbial risks using both water quality analysis and sanitary surveys to determine a risk score. Results were assessed per district and reported per state. Only summarized data could be obtained from this study of which an example is shown in Figure 5-3. These findings illustrate the large variability of contamination between regions and with technologies. Both individual and regional water supply schemes and open wells are frequently faecally contaminated, although differences between districts exist.




% of sample having FC values higher than 2

| District | HP | IWSS | RWSS | Open Well | IWSS + RWSS |
|---|---|---|---|---|---|
| Vadodara* | 12 | 9 | 4 | | |
| Valsad | 1 | 4 | 0 | 0 | |
| Ahmedabad | | 73 | 52 | | |
| Gandhinagar | | 68 | 86 | | 56 |
| Dangs | 3 | | 0 | 25 | |
| Surat | 1 | 21 | 0 | 76 | |
| Kachchh | | 31 | 40 | | 23 |
| *Vadodara values are of Feacal Streptococci | | | | | |

Figure 5-3 Example of conclusions from MDWAS study in eight districts in Gujarat state (WASMO 2008)

FC= Faecal coliforms
HP=Handpump
IWSS= Individual water supply scheme
RWSS= Regional water supply scheme

### 5.6.2 Study on surveillance of drinking water quality in selected cities / towns in India NEERI

NEERI performed a study for about 35 cities in India. This study describes quality of drinking water being supplied, water quality monitoring and surveillance in these cities at various treatment stages, service reservoirs, distribution network, public stand posts, and households. Water quality at various stages was compared with Indian drinking water quality standards. Sanitary survey, health survey (limited to data collection from health centers) , KAP survey, O&M and human resource assessment were also undertaken as part of the study. Although the study was for urban water supply, it can provide information about the potential issues with centralized surface water treatment and supply in the rural multi village schemes.

Together with Georgia Tech and London School of Hygiene and Tropical Medicines, NEERI developed a simple kit to monitor bacterial water quality. This kit seems especially useful to raise awareness in communities.

### 5.6.3 Journal publications

Scientific studies on water quality in India are generally reported in scientific journals. Such studies focus on specific contaminants in specific regions. Because of this focus they often contain more detailed information about contaminants than regulatory monitoring programs. We conducted a literature review to find recent quantitative water quality data with a focus on microbial contamination and specifically pathogens. Since 2010 some 53 journal publications were identified that focused on microbial contamination of water in India. Out of these, 24 studies contained actual quantitative data on contaminants, which was collected for the purpose of this study. The majority of studies monitored *E. coli* or faecal coliforms. *Pseudomonas aerigunosa* and helminths were the only pathogens addressed in just two studies. Quantitative data on the actual pathogens of concern (e.g. enteroviruses, *Cryptosporidium* , *Giardia* , *Campylobacter*, Salmonella) were not found in recent publications. The outcomes of this literature study will be discussed in Chapter 5.

## 5.7 Current issues with monitoring

### 5.7.1 Monitoring not performed (enough)

The water quality monitoring protocol describes how the monitoring is organised, however it is not yet fully operational everywhere in India. According to the Ministry of drinking water and sanitation under the national rural drinking water programme (NRDWP) in 2013-2014 drinking water sources were not tested in 1.1 out of 1.7 million habitations (small villages) in India (details: http://indiawater.gov.in/IMISReports/Reports/Profile/rpt_StateProfile.aspx?rep=1). In Karnataka, in 47,000 out of 60,000 habitations none of the drinking water sources were tested in laboratories. So water quality testing in laboratories, which is needed for some parameters, still needs further implementation. On the other hand 3.3 million water quality tests were performed in India using field test kits. In Karnataka this is 260,000 tests with field test kits. This means on average three samples per habitation, whereas at least thirteen parameters need to be tested yearly and some twice per year.

Although a lot of progress on water quality monitoring has been achieved under the NRDWP, the frequency of monitoring is not yet up to standard. Feedback from the field mentions that most field test kits are never used and samples are often not taken simply due to lack of interest by the local community. On the other hand there are also success stories: "*An integral part of the communication strategy is the water testing kit that has been extremely successful as a trigger to enter the community and initiate dialogue on the need for safe quality drinking water in the village*." (World Bank WSP 2011)

The NRDWP targets one or two samples to be taken in a year. However it is known that water quality can be highly variable and in some cases this low number of samples may lead to underestimation of health risk. Initial microbial tests are conducted by regional hospitals that are supplied with 20 $H_2S$ tests per month. In Karnataka there are 176 blocks with 178,000 public and private water sources, so approximately 1000 water sources per block. Assuming one hospital per block can sample 20 water sources per month, each water source can be tested once every four years.

### 5.7.2 Poor quality of analysis and data

Water quality analysis is either performed in the laboratories or by field test kits. The official laboratories are all accredited for the analyses they perform. However there have been reports of unreliable water quality analysis reports. UNICEF (2014) states: "*Provision for the supply of safe drinking water in rural India, with about 1.42 million habitations and millions of water sources, is an amazing task. Due to the logistical problems and inadequate water quality testing infrastructure, generation of reliable water quality data on regular basis has been an acknowledged problem.*" This suggests that not all samples or parameters are actually analysed, but that reports are 'made up' based on the experience of the analyst. Current practice of accreditation and checks seems to be insufficient to eliminate this practice. For example, according to official WQ data in Figure 6-1 less than 5% of the water supplies are contaminated with *E. coli* whereas Mukhopadhyay et al. (2012) found 27.5% contaminated with *E. coli* , and 92.5% contaminated with coliforms.

Also there seems to be a lack of criticism from the water managers that order the sample analyses. Since analysis outcomes don't lead to decisions or actions, there seems to be little urge to require proper water quality analysis. Eventually these analysis reports end up in the databases of water quality in India. The scale of erroneous analysis reports is hard to estimate, and so is the impact on the database as a whole. However, there are indications in the database itself that the quality of reporting is improving. Figure 5-4 shows the reporting of fluoride concentrations over a three year period for the district of Yadgir. In 2012-13 a remarkable 55% of the samples reported a concentration exactly on the level of 0.5 mg/l used to be the Indian standard before the revision in 2012. This is unlikely to actually be the case. In 2013-14 a range of fluoride concentrations was reported which seems much more likely as if follows a more continuous pattern. In 2014-2015 the highest fluoride concentrations above 2.5 mg/l were no longer detected. This can be expected since sources with very high fluoride content are generally abandoned for drinking water purposes if an alternative source exists. In some cases fluoride treatment is implemented. On the other hand the number of sources that are non-compliant to the relaxed guideline of 1.5 mg/l has increased. This may be the consequence of general deterioration of groundwater quality e.g. due to over-abstraction from wells. This trend in data improvement has not yet been observed for all regions in India. In the study we will focus on the most recent data when discussing current water quality situation since this seems to be the most reliable data.

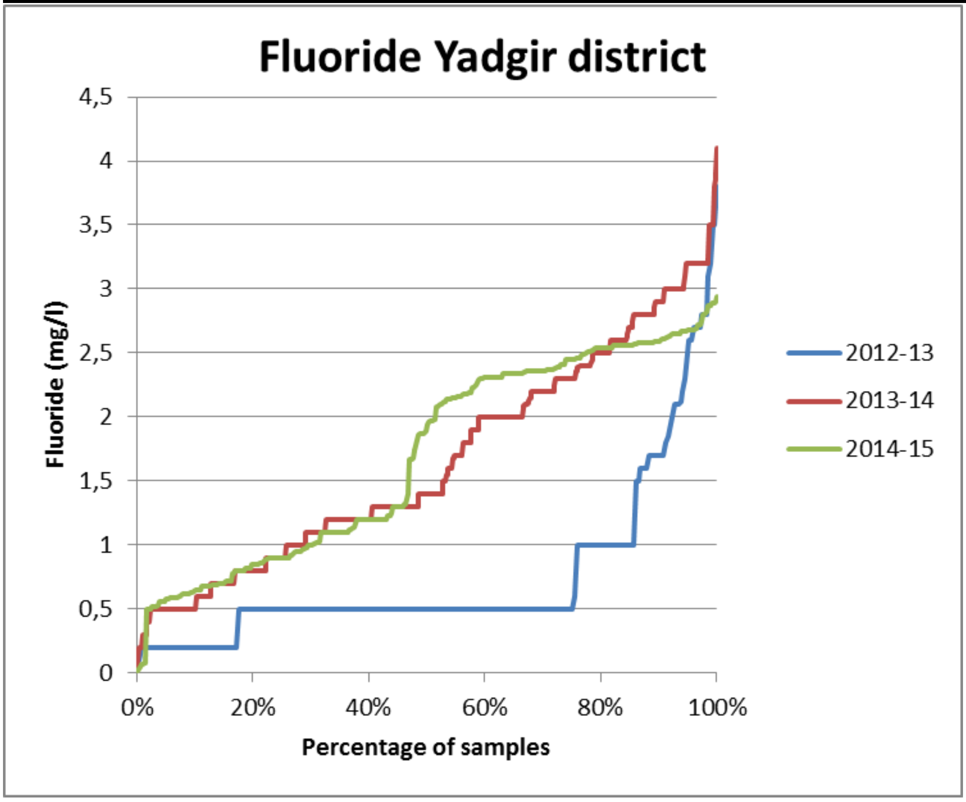



**Figure 5-4 Cumulative frequency distribution of reported fluoride concentrations in Yadgir district over the last three years (NRDWP 2015)**

For microbial monitoring results the same improvement of water quality data seems to occur. Figure 5-5 shows the reported microbial water quality test results in Karnataka over a three year period. Note that the vertical axis reports the number of non-compliant sources on a log scale. The total number of sources tested reflects the number of chemical water quality tests performed by the district and is likely to be higher than the number of microbial testing performed by the hospitals. There has been a dramatic increase of non-compliance for *E. coli* from 3 sources in 1012-1013 to 723 in 2014-15. It is unlikely that the actual level of contamination has increased so dramatically. So this increase in observed non-compliance is likely due to improvements in monitoring and reporting over the past years.

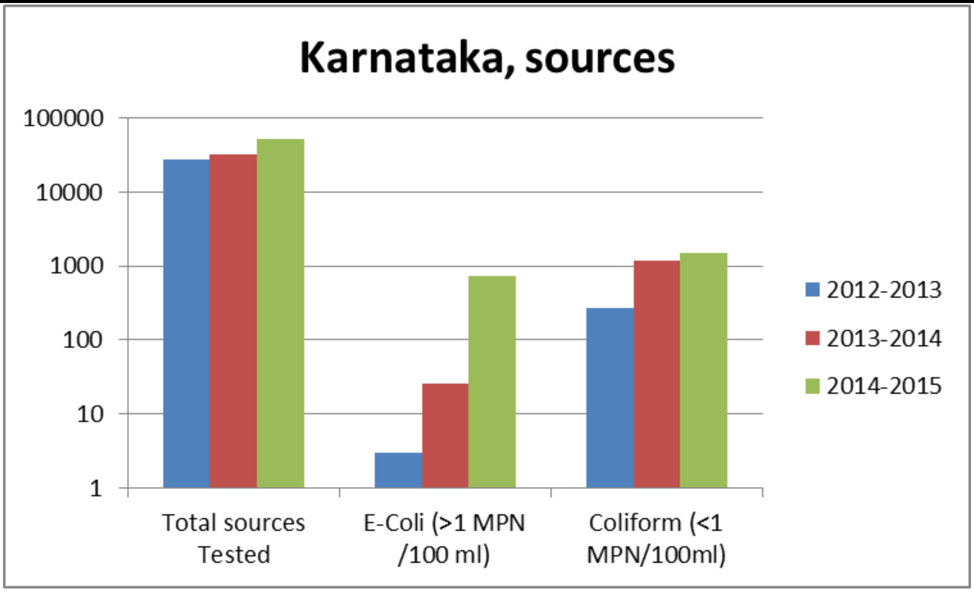



**Figure 5-5 Number of non-compliant sources for microbial water quality over a three year period (NRDWP 2015).**

### 5.7.3 No feedback from results to decisions

Water quality monitoring is not a goal in itself but is performed to support decisions and actions. This was already illustrated in Figure 4-4. However in current practice the monitoring results don't seem to feed back into decision making. The WSP manual for small communities (WHO 2012) discusses the importance of water quality monitoring and data review as a way to learn to know the system and to justify investments. However, when field kits are used at the local level, generally the knowledge is lacking to interpret the results and take necessary action. Lab results are often only reported to the districts for statistics, and not fed back to the water supply operator or the operator does not act on them. It is unclear if water quality data actually impact investment decisions on a district or national level.

# 6 RESULTS OF CURRENT MONITORING IN INDIA

## 6.1 Available water quality monitoring data

The collected monitoring data in India is made available through databases and reports. This section provides a short overview of the data availability.

The ministry of drinking water and sanitation provides elaborate summarised data allowing various selections by state, district etc.
http://indiawater.gov.in/imisreports/Reports/WaterQuality/rpt_wqm_districtProfile_S.aspx?Rep=0&RP=Y

The CPCB provides information about surface and ground water quality up to 2011 organised by basin. Data is provided in the form of an MS Excel® table.
http://www.cpcb.nic.in/Data%20Search/water%20quality%20data/BasinWiseCompiledData-2011.xlsx

The CPCB also provides older information about groundwater sources from research conducted before 2003. Results are reported in a report, with the summarised data in tables in the annexes.
http://www.cpcb.nic.in/Water_Quality_Data.php#

The CPCB provided a report on the status of water treatment plants, including advise for the monitoring and explanation of the various treatment techniques
http://www.cpcb.nic.in/upload/NewItems/NewItem_103_statusofwaterqualitypackage.pdf

The progress of water supply improvement is monitored by the NRDWP not only in terms of water quality but also in terms of coverage and finances.
http://indiawater.gov.in/IMISReports/Reports/Profile/rpt_StateProfile.aspx?rep=1

## 6.2 Summaries of water quality issues in India

India is a riverine country, 14 major rivers, 44 medium rivers and 55 minor rivers besides numerous lakes, ponds and wells. Surface water accounts for 70% of the total amount of water used by the population. The remainder 30% is produced from groundwater. These waters cope with water pollution, a major environmental issue in India Table 6-1.

**Table 6-1 Indian water quality issues for surface water and groundwater. Source: CPCB, 2012.**

| Surface water quality issues | Groundwater quality issues |
|---|---|
| Eutrophication | Arsenic |
| Oxygen depletion | Fluoride |
| Ecological health | Iron |
| Pathogens | Nitrate |
| Salinity | Pesticides |
| | Seawater intrusion |

Flooding during monsoons worsens India's water pollution problems, as it washes and moves solid waste and contaminated soils into its rivers and wetlands. The monsoon rains are limited to only three months of the year. Rivers being fed by monsoon rains run dry throughout the rest of the year often carrying wastewater discharges from industries or cities/towns endangering the quality of our scarce water resources.

**Water contamination contributors**

- 90% of the sewage generated by municipal councils and over 50% of sewage discharged by municipal corporations is dischargeduntreated
- The industrial sector contributes 30729.2 million cubic metres of effluent being discharged into the water bodies.
- An estimated 200,000 tonnes of faecal load is generated every day due to open defecation

The Indian waste water treatment capacity is limited. Several of the sewage treatment plants do not operate properly and are not maintained (CPCB, 2007). Also a large proportion (70%) of the population has no access to sanitation and practices open defecation. The largest source of surface water pollution in India is untreated sewage. Sewage contamination leads to high levels in rivers of biological oxygen demand (BOD), pathogens and nutrients. Other sources of pollution include agricultural runoff and unregulated small scale industry. Pesticides and nutrients (ammonia, phosphate, nitrate) are agricultural contaminants. Heavy metals like lead, cadmium, zinc and mercury could origin from industry. Natural contaminants are fluoride and arsenic, which have a geogenic origin. Salinity increases can be due to seawater intrusion (coastal areas) or overexploitation of groundwater (inland areas).

Water supply agencies provide suitable technologies for the removal of fluoride, arsenic, nitrate, iron and salinity. Community based treatment plants have been installed to provide safe water at centralised locations and are regulated either by the government or private agencies and communities. However drinking water quality often exceed the guideline values ( Figure 6-1 and Table 6-3).

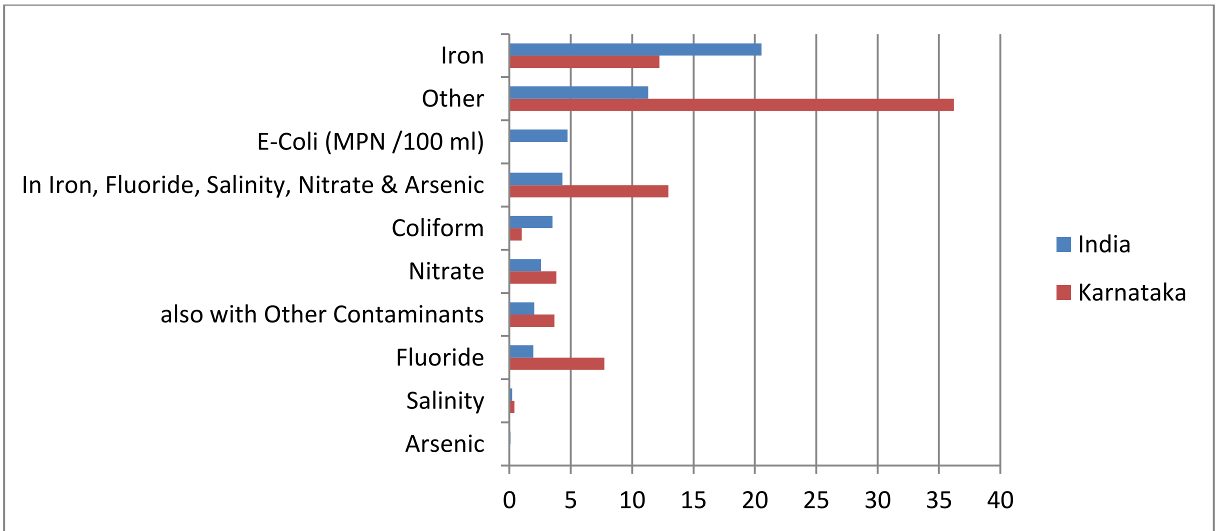



**Figure 6-1 Percentage of rural drinking water sources in India and Karnataka State, where contaminants exceed the guideline values in financial year 2012-2013 (data from NRDWP, format E6).**

Table 6-3 provides an overview of non-compliance to the standards for various water quality parameters. This shows that testing and reporting is yet well organised in every state. Also one needs to consider that the actual quality of the data may be poor. Table 6-3 also shows that water quality issues vary between states. Arsenic is mainly an issue in West-Bengal, whereas nitrate is a major issue in Maharashtra and Rajasthan. Although exceeding the standard provides an indication of problems, this type of data is insufficient to assess the health risks. Generally the health risk increases with increasing concentrations of the contaminant, so the actual concentration of a contaminant is needed to actually assess the health risk. In addition, the relation between standard and health risk may be very different. Arsenic already has negative effects on health below the standard concentration, whereas fluoride actually has a health benefit at low concentrations.

Microbial health risks are generally considered most relevant, causing acute and chronic health impacts (WHO 2011). Natural fluoride and arsenic concentrations cause chronic health impacts in many situations. Human contaminants such as nitrate exceeds the guideline value in a significant number of sources, but health effects have not yet been clearly identified due to lack of epidemiological research. Organoleptic parameters turbidity, colour and odour impact the acceptability of drinking water and may lead to more attractive but less safe water sources. This is an indirect effect on health. These four groups of parameters are now discussed. The ultimate goal is to maximise health improvement focussing on the most relevant contaminants. Therefore health effects of the various contaminants will be discussed in more detail in the following paragraphs.

## 6.3 Update water quality issues 2016

The assessment of water quality monitoring results was updated in 2016. Table 6-4 shows the results of the 2015-2016 Indian water quality monitoring program. The number of tested sources has increased from 1.6 to 2.4 million in three years. This indicates that the monitoring effort is increasing. Still there are seven states that have not reported monitoring results in 2012 and 2015, and may not even have performed monitoring. A uniformly nationally applied drinking water monitoring program is necessary to make transparent the water quality provided to the population, and to direct resources to the areas that need improvement most. In general the reported non-compliance has decreased from 51% to 35% (Table 6-2). However there are large differences per contaminant.  None compliance for Arsenic has increased dramatically from 0.09% to 1.2% of the tested sources. It is unclear this is caused by the change to a more strict standard from 0.05 to 0.01 mg/L, better monitoring and reporting or an actual increase of arsenic contaminated sources. Exceedance for iron on the other hand decreased from 20.5% to 7.8% and *E. coli* from 4.7% to 1.5%.

**Table 6-2 Summarized percentage of tested sources exceding the standard for all states in 2012 and 2016**

| | Iron | Fluoride | Salinity | Nitrate | Arsenic | Other | E-Coli (MPN /100 ml) | Coliform | In Iron, Fluoride, Salinity, Nitrate & Arsenic | also with Other Contaminants | total non-compliance |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 20,54% | 1,94% | 0,23% | 2,58% | 0,09% | 11,29% | 4,73% | 3,52% | 4,32% | 2,03% | 51,27% |
| 2015 | 7,76% | 2,12% | 0,18% | 1,63% | 1,20% | 8,54% | 1,52% | 7,73% | 2,63% | 1,94% | 35,25% |

**Table 6-3 Number of rural drinking water sources in India per state, where contaminants exceed the guideline values in financial year 2012-2013 (data from NRDWP, format E6)**

| S.No. | State | Total Sources Tested | No. of Sources with Single Chemical Contaminants | | | | | | No. of Sources with Bacteriological Contaminants | | No. of Sources with Multiple Contaminants | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Iron | Fluoride | Salinity | Nitrate | Arsenic | Other | E-Coli (MPN /100 ml) | Coliform | In Iron, Fluoride, Salinity, Nitrate & Arsenic | also with Other Contaminants |
| **Total** | | **1598260** | **328251** | **31051** | **3696** | **41213** | **1382** | **180512** | **75579** | **56239** | **69066** | **32427** |
| 1 | ANDHRA PRADESH | 228600 | 36492 | 11193 | 1189 | 3851 | 0 | 33316 | 19055 | 0 | 18734 | 17493 |
| 2 | BIHAR | 101663 | 62984 | 840 | 0 | 4 | 435 | 5632 | 3 | 5 | 2957 | 6 |
| 3 | CHATTISGARH | 20949 | 6066 | 198 | 1 | 12 | 0 | 5569 | 3 | 30 | 114 | 867 |
| 4 | GOA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | GUJARAT | 68219 | 2 | 1578 | 132 | 3415 | 0 | 3926 | 417 | 550 | 1943 | 1940 |
| 6 | HARYANA | 3797 | 126 | 35 | 9 | 1 | 0 | 123 | 7 | 166 | 32 | 42 |
| 7 | HIMACHAL PRADESH | 4226 | 76 | 19 | 0 | 1 | 14 | 543 | 25 | 52 | 24 | 60 |
| 8 | JAMMU AND KASHMIR | 6105 | 129 | 1 | 0 | 12 | 5 | 1966 | 5 | 12 | 4 | 18 |
| 9 | JHARKHAND | 44767 | 13703 | 15 | 0 | 33 | 11 | 6379 | 25334 | 5 | 6373 | 26 |
| 10 | KARNATAKA | 27722 | 3387 | 2145 | 110 | 1063 | 2 | 10036 | 3 | 275 | 3590 | 1019 |
| 11 | KERALA | 29182 | 1085 | 13 | 7 | 94 | 0 | 13377 | 5173 | 19283 | 145 | 881 |
| 12 | MADHYA PRADESH | 212802 | 17046 | 1869 | 218 | 446 | 2 | 42654 | 776 | 905 | 1615 | 2258 |
| 13 | MAHARASHTRA | 165957 | 7390 | 2256 | 589 | 20169 | 0 | 5932 | 8613 | 10389 | 4520 | 111 |
| 14 | ODISHA | 88679 | 56611 | 371 | 37 | 1 | 0 | 6451 | 3 | 7 | 453 | 209 |
| 15 | PUNJAB | 16160 | 1048 | 83 | 5 | 0 | 87 | 1197 | 1 | 4 | 19 | 74 |
| 16 | RAJASTHAN | 95644 | 41 | 9417 | 1003 | 11807 | 1 | 11020 | 26 | 154 | 20170 | 5166 |
| 17 | TAMIL NADU | 245828 | 15911 | 521 | 363 | 131 | 0 | 1890 | 199 | 353 | 1894 | 849 |
| 18 | TELANGANA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | UTTAR PRADESH | 19278 | 4597 | 192 | 7 | 103 | 188 | 3328 | 28 | 302 | 208 | 130 |
| 20 | UTTARAKHAND | 5961 | 122 | 5 | 0 | 3 | 1 | 675 | 17 | 127 | 3 | 42 |
| 21 | WEST BENGAL | 155246 | 77184 | 288 | 24 | 17 | 469 | 12768 | 15536 | 21563 | 6155 | 151 |
| 22 | ARUNACHAL PRADESH | 5113 | 48 | 1 | 2 | 1 | 0 | 2051 | 16 | 0 | 0 | 10 |
| 23 | ASSAM | 34649 | 14562 | 8 | 0 | 0 | 165 | 7179 | 298 | 1862 | 107 | 984 |
| 24 | MANIPUR | 1112 | 127 | 0 | 0 | 49 | 0 | 234 | 0 | 0 | 2 | 13 |
| 25 | MEGHALAYA | 1464 | 93 | 0 | 0 | 0 | 2 | 463 | 14 | 43 | 0 | 26 |
| 26 | MIZORAM | 722 | 25 | 1 | 0 | 0 | 0 | 133 | 0 | 0 | 0 | 1 |
| 27 | NAGALAND | 322 | 17 | 1 | 0 | 0 | 0 | 90 | 6 | 0 | 0 | 2 |
| 28 | SIKKIM | 153 | 0 | 0 | 0 | 0 | 0 | 52 | 18 | 116 | 0 | 3 |
| 29 | TRIPURA | 13940 | 9379 | 1 | 0 | 0 | 0 | 3528 | 3 | 36 | 4 | 46 |
| 30 | ANDAMAN and NICOBAR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | CHANDIGARH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | DADRA and NAGAR HAVELI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | DAMAN and DIU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | DELHI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | LAKSHADWEEP | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | PUDUCHERRY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 6-4 Number of rural drinking water sources in India per state, where contaminants exceed the guideline values in financial year 2015-2016 (data from NRDWP, format E6)

| S.No. | State | Total Sources Tested | No. of Sources with Single Chemical Contaminants | | | | | | No. of Sources with | | No. of Sources with Multiple | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Iron | Fluoride | Salinity | Nitrate | Arsenic | Other | E-Coli (MPN /100 ml) | Coli-form | In Iron, Fluoride, Salinity, Nitrate & | also with Other Contami-nants |
| | Total | 2427533 | 188477 | 51468 | 4322 | 39619 | 29091 | 207362 | 36794 | 187759 | 63794 | 47040 |
| 1 | ANDAMAN and NICOBAR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | ANDHRA PRADESH | 168973 | 10250 | 9215 | 539 | 1277 | 0 | 11548 | 121 | 22772 | 7967 | 11124 |
| 3 | ARUNACHAL PRADESH | 10590 | 62 | 0 | 0 | 0 | 0 | 193 | 58 | 5 | 0 | 0 |
| 4 | ASSAM | 120167 | 45378 | 126 | 0 | 2 | 21 | 22151 | 91 | 2252 | 803 | 3346 |
| 5 | BIHAR | 118264 | 6346 | 2533 | 0 | 11 | 329 | 325 | 1 | 0 | 14 | 13 |
| 6 | CHANDIGARH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | CHATTISGARH | 50286 | 2446 | 166 | 4 | 5 | 0 | 3212 | 1 | 0 | 43 | 883 |
| 8 | DADRA & NAGAR HAVELI | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | DAMAN & DIU | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | GOA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | GUJARAT | 140884 | 0 | 8 | 0 | 23 | 0 | 739 | 35 | 4463 | 8 | 3 |
| 12 | HARYANA | 36667 | 58 | 621 | 56 | 1 | 3 | 403 | 217 | 3497 | 355 | 378 |
| 13 | HIMACHAL PRADESH | 31178 | 9 | 1 | 1 | 1 | 0 | 163 | 2 | 52 | 0 | 5 |
| 14 | JAMMU AND KASHMIR | 19515 | 18 | 3 | 2 | 0 | 1 | 651 | 6 | 1 | 1 | 0 |
| 15 | JHARKHAND | 58591 | 10775 | 364 | 2 | 25 | 17 | 7871 | 4 | 220 | 215 | 618 |
| 16 | KARNATAKA | 204856 | 10817 | 10685 | 212 | 8566 | 31 | 20302 | 568 | 782 | 7322 | 4310 |
| 17 | KERALA | 118023 | 1698 | 4 | 2 | 12 | 0 | 61248 | 12646 | 93653 | 199 | 3451 |
| 18 | LAKSHADWEEP | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | MADHYA PRADESH | 269821 | 1454 | 2592 | 231 | 472 | 0 | 4829 | 561 | 653 | 698 | 1452 |
| 20 | MAHARASHTRA | 149764 | 872 | 293 | 31 | 4247 | 0 | 4871 | 12235 | 20349 | 1376 | 681 |
| 21 | MANIPUR | 2330 | 1 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 |
| 22 | MEGHALAYA | 5165 | 25 | 0 | 0 | 0 | 1 | 49 | 1 | 15 | 0 | 1 |
| 23 | MIZORAM | 4360 | 63 | 1 | 0 | 0 | 0 | 648 | 4 | 47 | 0 | 29 |
| 24 | NAGALAND | 99 | 53 | 0 | 0 | 0 | 0 | 14 | 3 | 0 | 0 | 1 |
| 25 | ODISHA | 203399 | 55729 | 1130 | 112 | 0 | 1 | 2043 | 3 | 1 | 248 | 57 |
| 26 | PUDUCHERRY | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | PUNJAB | 21323 | 1050 | 274 | 6 | 141 | 244 | 2479 | 0 | 0 | 92 | 198 |
| 28 | RAJASTHAN | 188766 | 30 | 13470 | 2714 | 23296 | 2 | 19639 | 5 | 1 | 37275 | 9188 |
| 29 | SIKKIM | 984 | 0 | 0 | 0 | 0 | 0 | 142 | 3 | 0 | 0 | 94 |
| 30 | TAMIL NADU | 81798 | 118 | 62 | 36 | 23 | 0 | 203 | 136 | 1 | 224 | 202 |
| 31 | TELANGANA | 148161 | 2757 | 9325 | 337 | 1272 | 0 | 14051 | 164 | 14364 | 2742 | 6265 |
| 32 | TRIPURA | 13571 | 6364 | 0 | 0 | 0 | 0 | 3443 | 2 | 334 | 0 | 97 |
| 33 | UTTAR PRADESH | 38754 | 4056 | 436 | 9 | 245 | 14 | 2095 | 9 | 2 | 616 | 127 |
| 34 | UTTARAKHAND | 3556 | 71 | 5 | 0 | 0 | 0 | 41 | 1 | 10 | 0 | 0 |
| 35 | WEST BENGAL | 217688 | 27977 | 154 | 28 | 0 | 28427 | 23984 | 9917 | 24285 | 3596 | 4517 |

## 6.4 Surface water sources

### 6.4.1 CPCB Monitoring data

The CPCB provided an overview of the water quality data from all source water monitoring programmes in 2011. This overview provides a first impression of the water quality of Indian drinking water sources for the most common parameters (temperature, oxygen, pH, conductivity, BOD, nitrate, nitrite, faecal- and total coliforms). The information that the CPCB monitoring provides will be discussed for the most relevant contaminants and water quality aspects.

#### 6.4.1.1 Faecal coliforms in river water

Figure 6-2 summarises the monitored concentrations of faecal coliforms at 836 monitoring locations along the Indian rivers. Almost half of the locations (404) can be categorised as high quality source waters with a mean concentration below 200 MPN/100 ml. At 265 locations (32%) the mean water quality is regarded as medium and at 102 locations (12%) faecal coliforms indicate poor water quality. At 65 locations (8%) even the criteria for "poor" source water quality are exceeded for the mean faecal coliform concentration indicating highly faecally contaminated source water. (Note: the limit should actually be applied to 80% of the samples, however this information is not available). The minimum and maximum concentrations at each location indicate the variability of the faecal contamination. At some locations this varies over three orders of magnitude, but generally this variation is less than 2 orders of magnitude. Peak concentrations don't exceed the mean concentration more than one order of magnitude. It must be considered that these observations may be impacted by the limited number of samples taken per location (these were not reported).

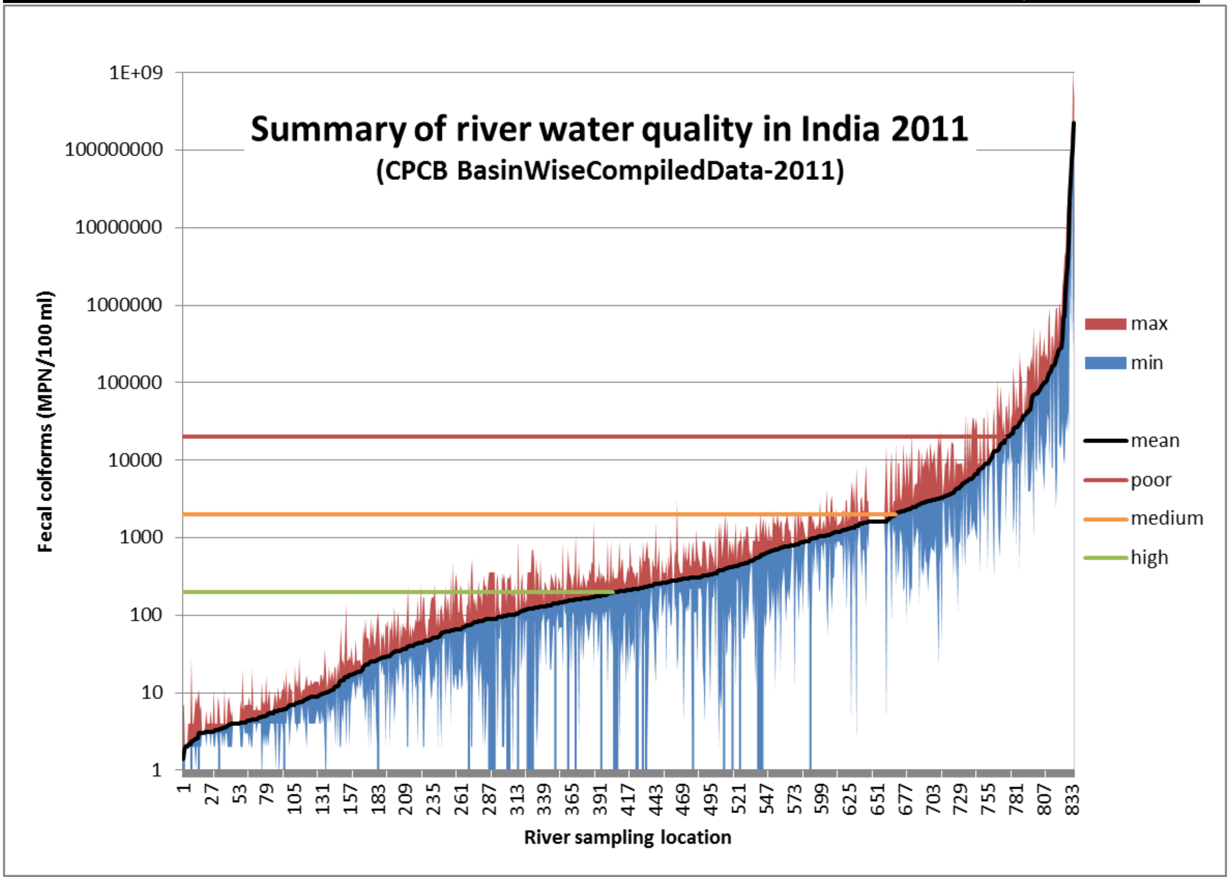



**Figure 6-2 Faecal coliforms in river water at all monitoring stations in India in 2011 (CPCB Basin wise compiled data 2011) and the limiting values for general water quality criteria.**

Figure 6-3 provides the same overview for only the 61 monitoring locations in Karnataka state. This shows that the Karnataka rivers are more or less of average quality with 17 locations (28%) of high quality, 36 locations (59%) of medium quality and 8 locations (13%) of poor quality. None of the source waters exceed the requirements of poor source water. Note that 15 locations along the Cauvery river reported identical results of 1600 MPN/100 ml for min, mean and max. This is likely an administrative error.

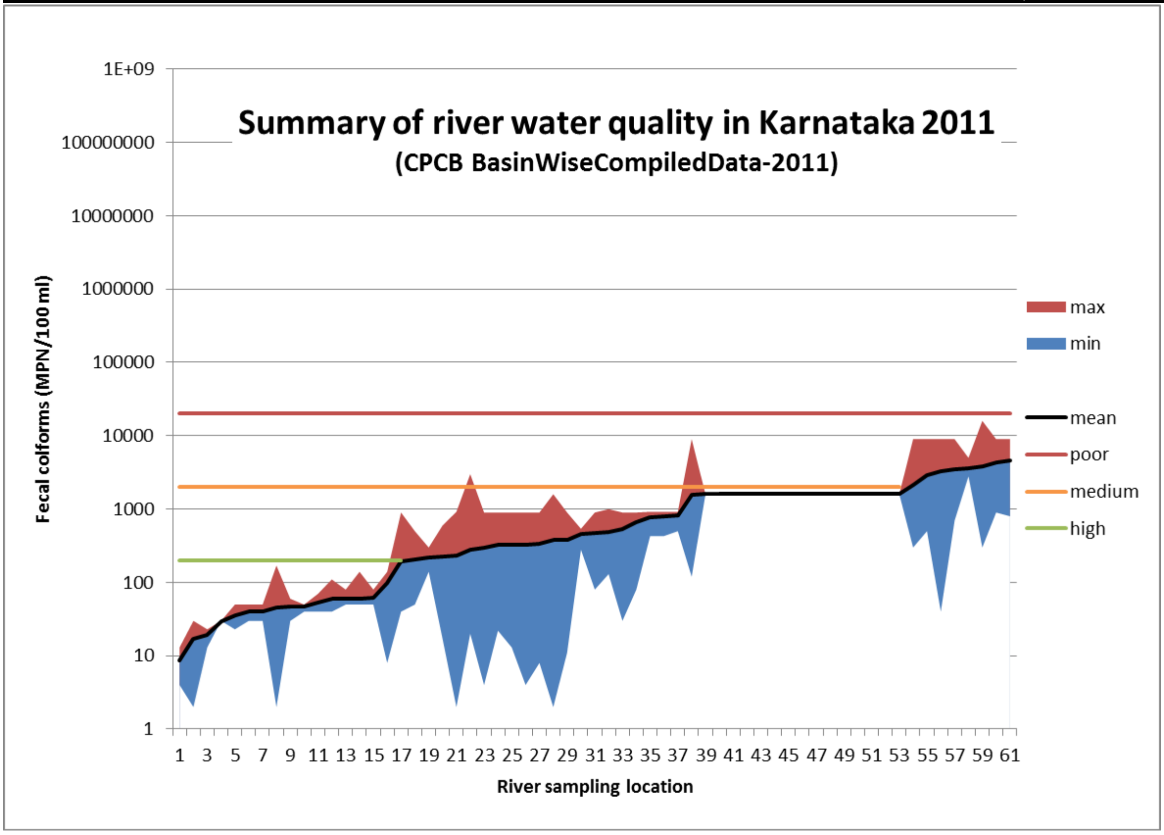



**Figure 6-3 Faecal coliforms in river water at all monitoring stations in Karnataka in 2011 (CPCB Basin wise compiled data 2011) and the limiting values for general source water quality criteria.**

### 6.4.2 River water temperature

A very low (<5 °C) temperature of the source water can affect various treatment processes. Figure 6-4 shows that the temperature in Indian rivers is generally between 20°C and 30°C. Only in very specific regions in the Himalayans temperatures below 5°C occur. These regions need to address this by adapting conditions to the actual temperatures. In surface water treatment systems generally the coagulation-sedimentation and the disinfection process can be affected. Within Karnataka state the river water temperatures vary between 25 and 30° and are not a significant issue.

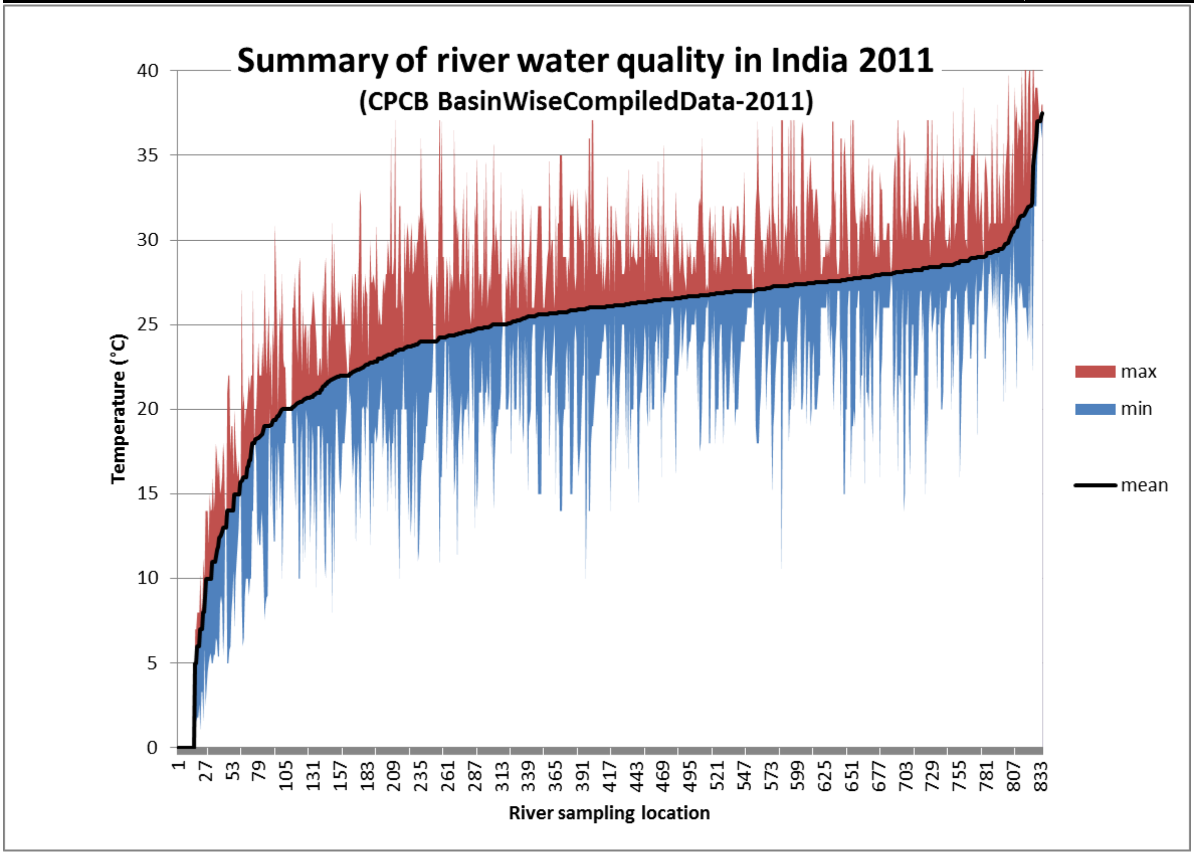



**Figure 6-4 Temperature of river water at all monitoring stations in India in 2011 (CPCB Basin wise compiled data 2011).**

## 6.5 Groundwater sources

Groundwater sources are also included in the CPCB 2011 report, however not every state appears to be represented in the data. Figure 6-5 shows the faecal coliform data that was collected for 301 sites. The total number of groundwater supplies is much greater and it is unclear what the selection criteria were for the CPCB, we assume these are larger, central groundwater supplies. Remarkably all sites reported a minimum of at least 1 MPN/100 ml for faecal coliforms, whereas groundwater is generally considered a microbially safe water source. About 65% of the sites contain less than 10 MPN/100 ml faecal coliforms, 27% ranges from 10 to 100 MPN/100 ml and 8% range from 100 to over 1000 MPN/100 ml. This graph indicates that faecal contamination of groundwater occurs frequently and can reach significant levels.

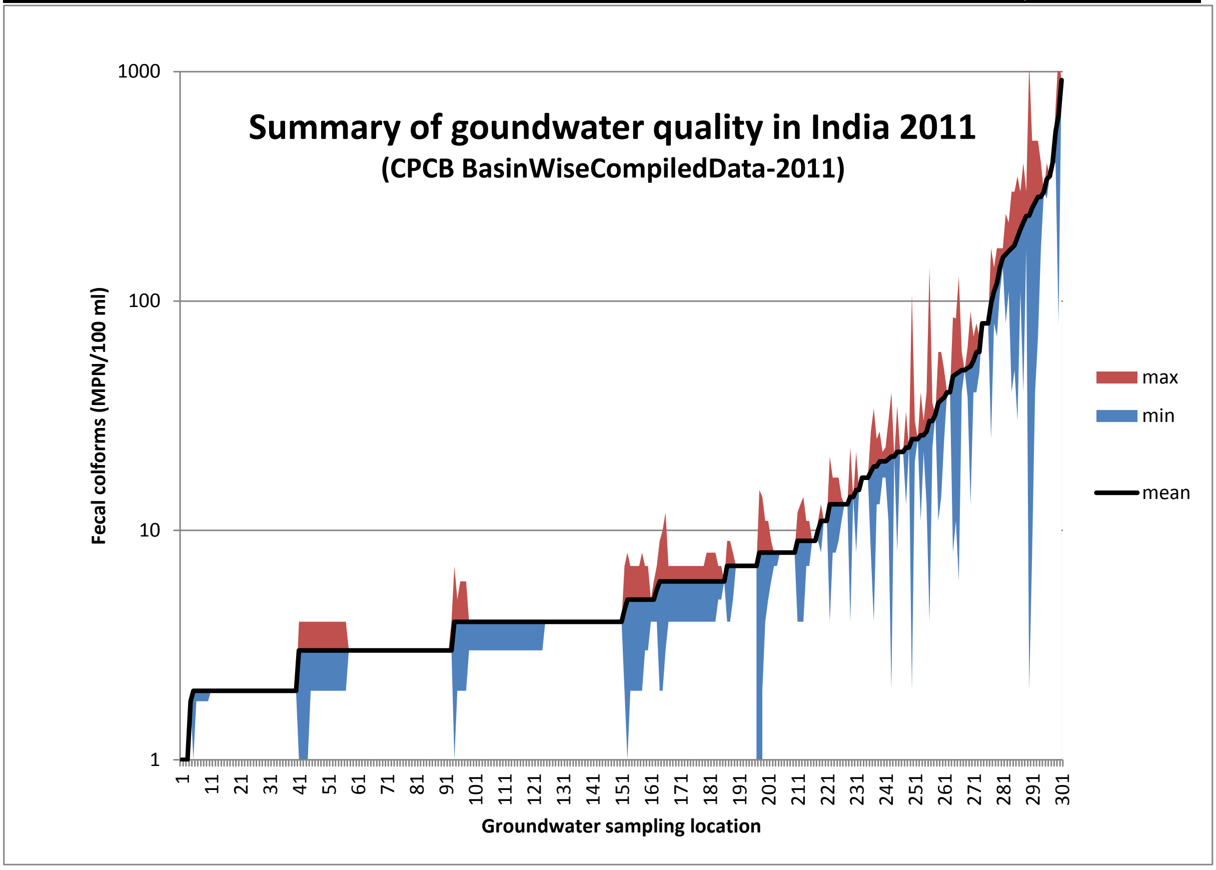



**Figure 6-5 Faecal coliforms in groundwater reported for 301 sites in India in 2011 (CPCB Basin wise compiled data 2011).**

Groundwater sources are also tested in the NRDWP framework since groundwater is generally not treated.

## 6.6 Estimation of microbial pathogens in source waters

We have been unable to find actual water quality data on faecal pathogens in sources for drinking water. Other studies have applied a ratio between *E. coli* and pathogenic organisms based on wastewater composition in western countries (Howard et al. 2006). However they provided little data to support these assumptions. For the current study we collected data from literature about levels of indicator organisms and pathogens in sewage (Figure 6-6, Figure 6-7 and Figure 6-8) (data from Koenraad et al. 1994, Hoogenboezem et al. 2000, Medema et al 2001). The ratios applied by Howard et al. were also plotted in the following figures. This shows that they underestimated the concentrations of protozoa in these sewage samples. For enteroviruses a ratio of $10^6$ seems to be applicable, which predicts less enteroviruses than Howard et al. However Indian sewage may be quite different from Western sewage. The incidence of gastroenteritis is higher in India, therefore a smaller ratio (higher pathogen concentrations) than in Western countries can be expected. This assumes that the Indian diet doesn't affect the presence of indicator bacteria in their faeces.

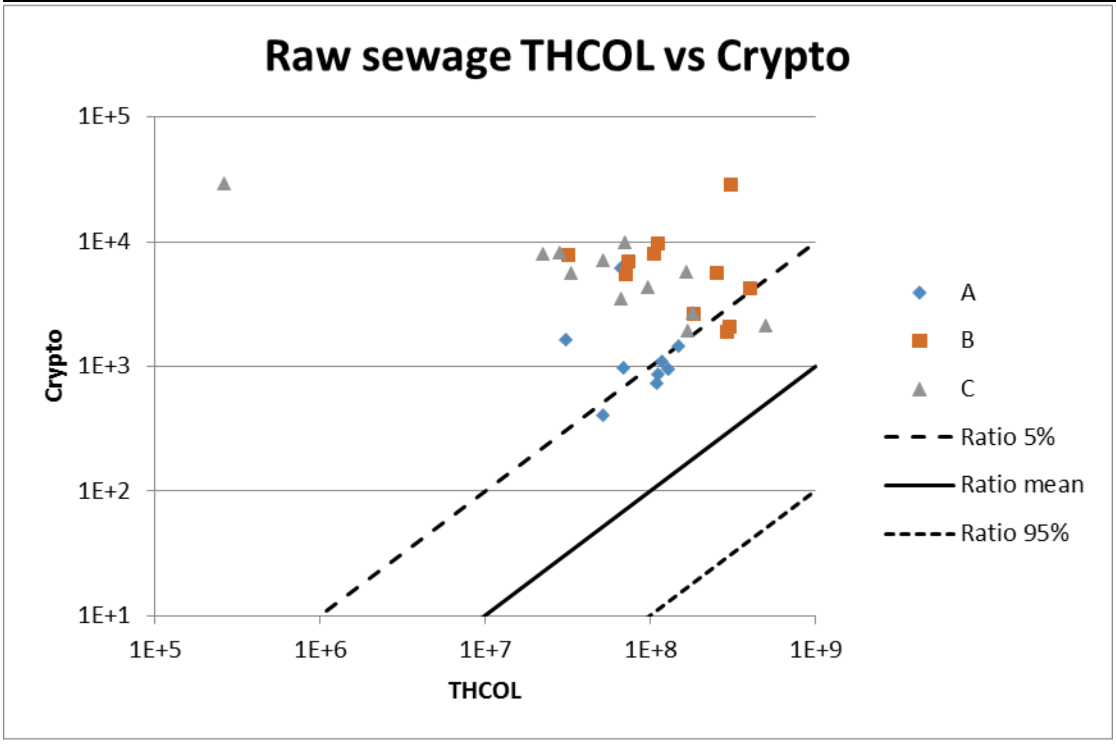



Figure 6-6 Concentrations of *Cryptosporidium* (oocysts/l) versus thermotolerant coliforms (CFU/l) in sewage in the Netherlands (data Hoogenboezem et al. 2001) and FIB to *Cryptosporidium* ratio used by Howard et al. (2006).

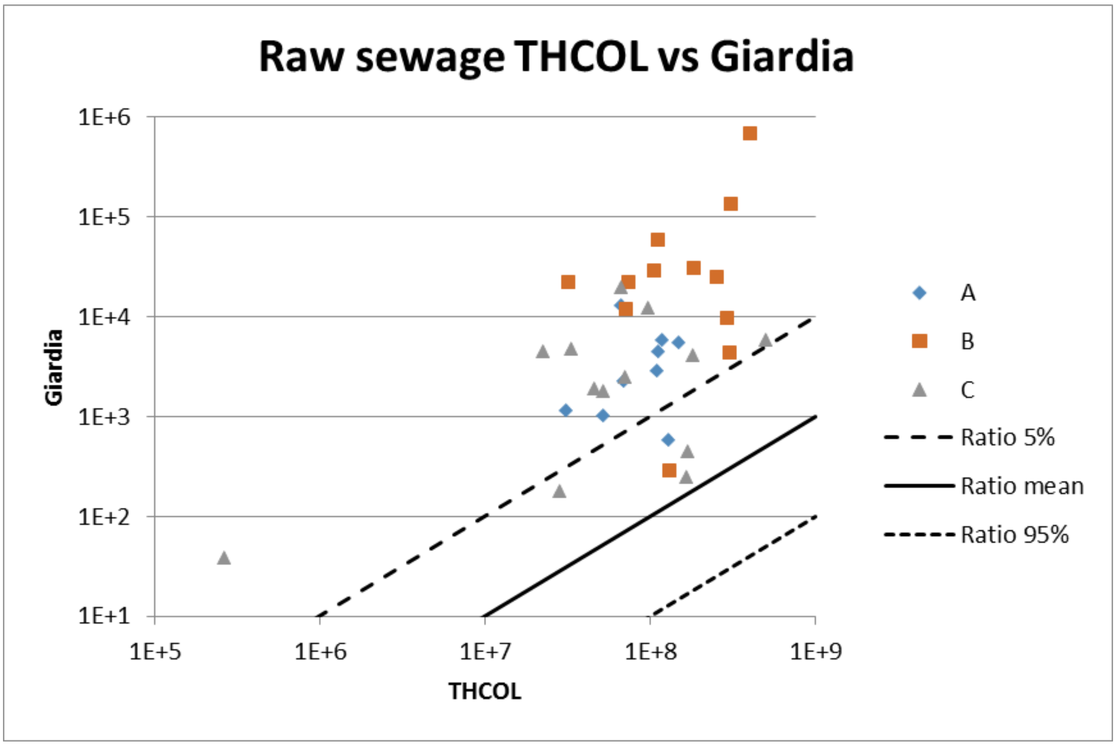



Figure 6-7 Concentrations of *Giardia* (cysts/l) versus thermotolerant coliforms (CFU/l) in sewage in the Netherlands (data Hoogenboezem et al. 2001) and FIB to *Giardia* ratio used by Howard et al. (2006).

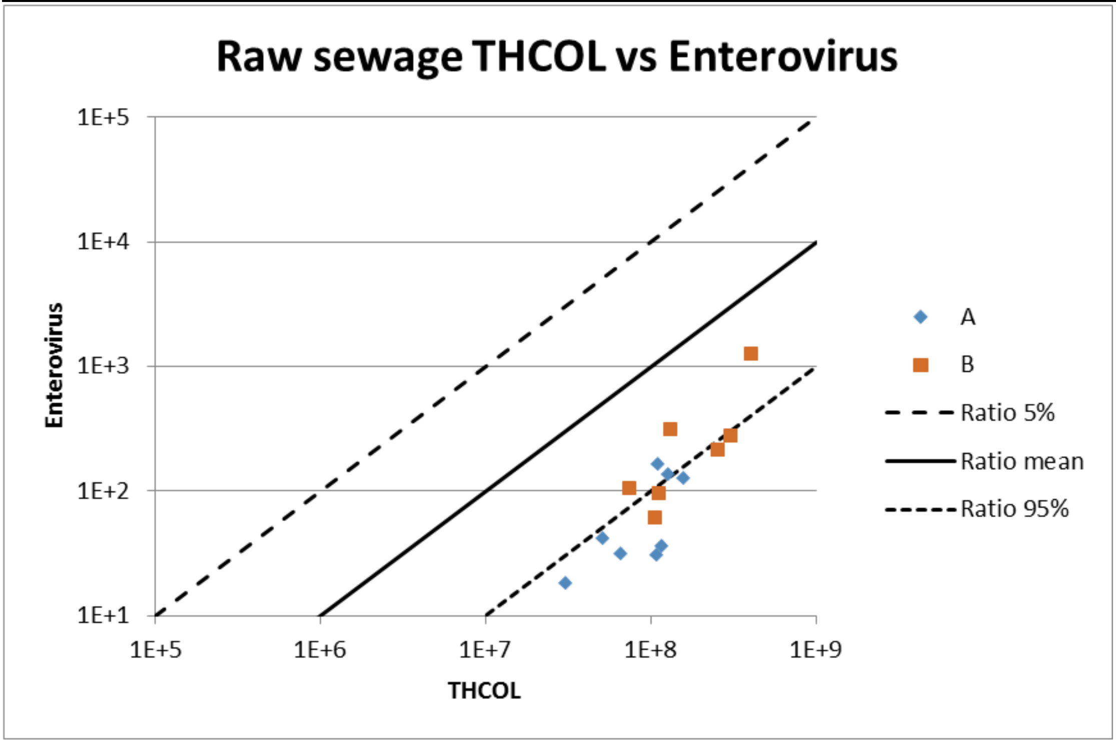



**Figure 6-8 Concentrations of enterovirus (PFU/l) versus thermotolerant coliforms (CFU/l) in sewage in the Netherlands (data Hoogenboezem et al. 2001) and FIB to enterovirus ratio used by Howard et al. (2006).**

Instead of using sewage as a basis to estimate pathogen concentration in surface water we suggest to use pathogen monitoring data from surface water itself. Figure 6-6 Shows the relationship between average concentrations of indicator bacteria (faecal coliforms or *E. coli*) and *Cryptosporidium* in both sewage, treated wastewater and various surface water sampling sites. Although the concentration of *Cryptosporidium* decreases with decreasing indicator bacteria, this relation isn't proportional. Since *Cryptosporidium* are more persistent in the environment, the ratio indicator:pathogen decreases, so there are 'more pathogens per indicator'. Based on the findings an empirical equation was developed to estimate the number of pathogens from the number of indicators for *Cryptosporidium* (Figure 6-6), *Giardia* (Figure 6-7) and Enterovirus (Figure 6-8). Care must be taken when applying these relationships due to variability per location (see Figure 6-7) and the difference in climate and other location specific factors that can influence pathogen survival. Especially the higher temperature of several Indian rivers can impact the relationship.

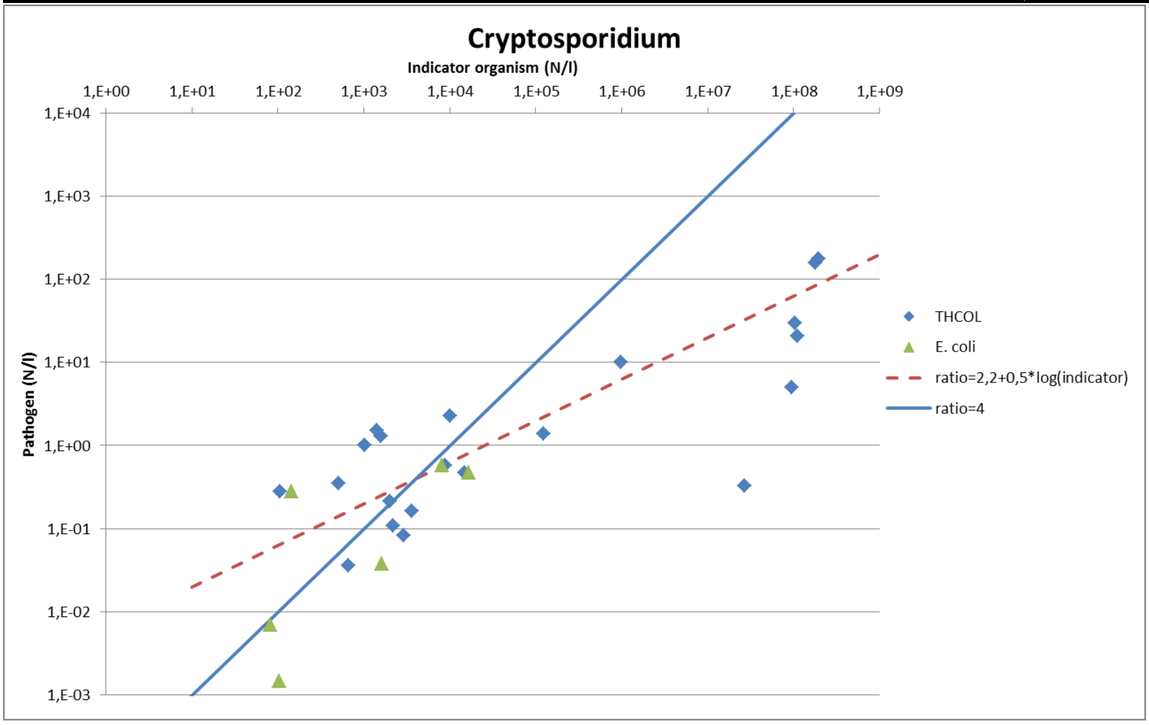



**Figure 6-9 Mean concentrations of Cryptosporidium and indicator bacteria at various sampling points in surface water and wastewater in the Netherlands**

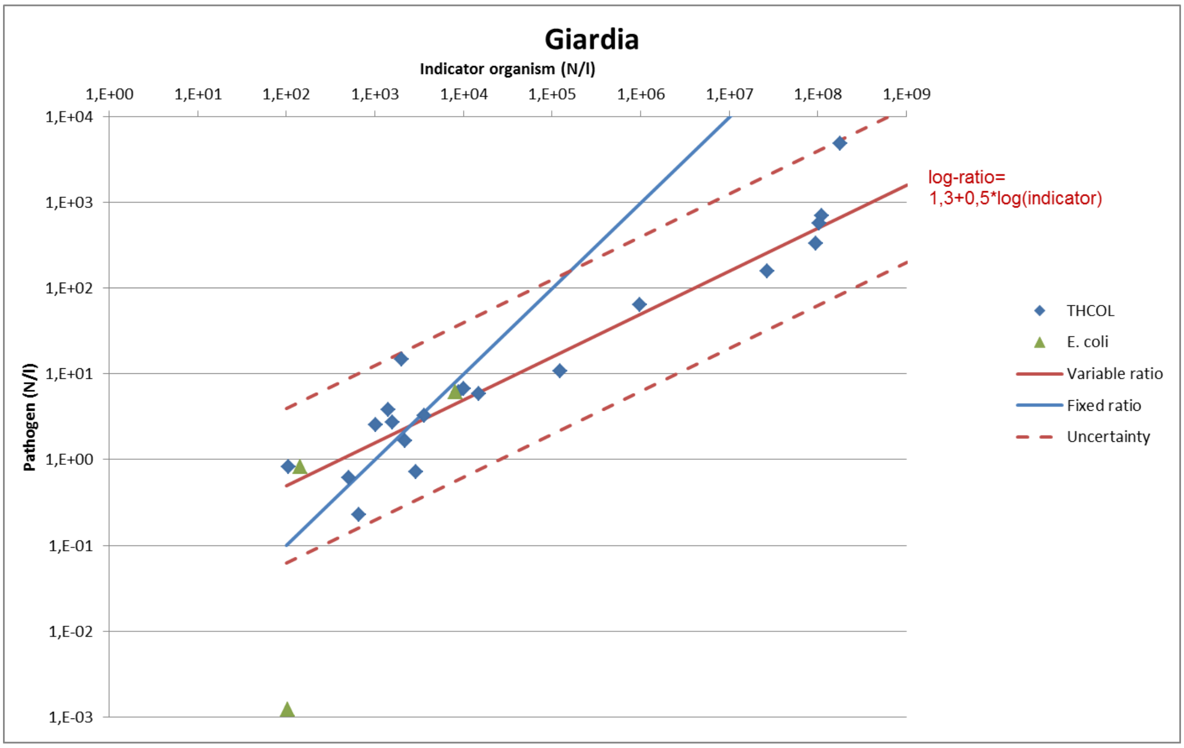



**Figure 6-10 Mean concentrations of *Giardia* and indicator bacteria at various sampling points in surface water and wastewater in the Netherlands**

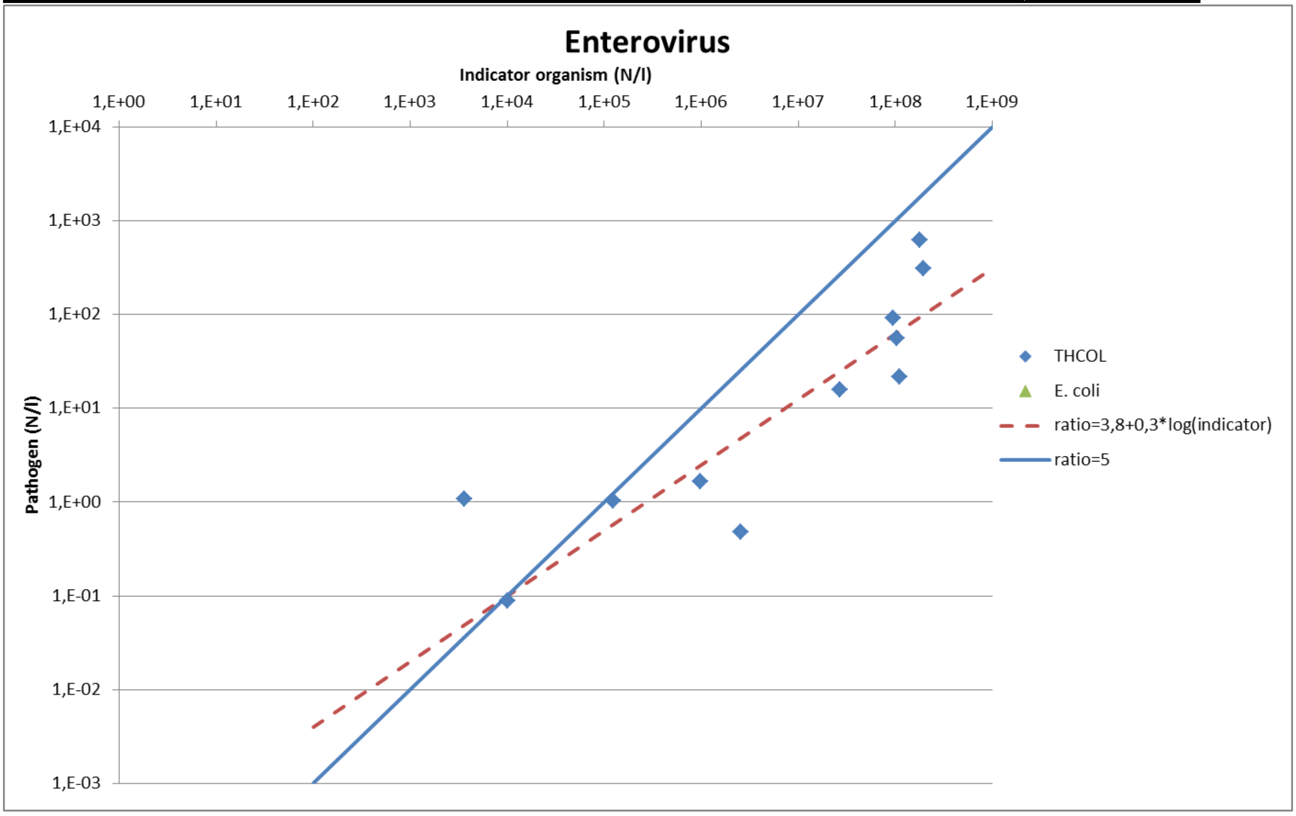



**Figure 6-11 Mean concentrations of enterovirus and indicator bacteria at various sampling points in surface water and wastewater in the Netherlands**

## 6.7 Estimating effect of water treatment

Water treatment is often monitored locally by operators and results are recorded in logbooks. However verification or evaluation of the recorded data by more skilled personnel doesn't appear to take place. This feedback cycle is essential to improve water treatment. Although the produced water is periodically tested for faecal indicator bacteria, this provides insufficient information about the treatment effect or water safety in itself because:

- Monitoring FIB in grab samples misses peak contaminations and treatment failure
- Bacteria are inactivated by chlorine, protozoa and some viruses are not
- WSP requires a pro-active risk management, monitoring each barrier in the system. Some of this information, like chlorine dosing or measured residual, may be recorded in log books but is not available to evaluate treatment efficiency.

QMRA approaches in affluent countries use indicator monitoring at all stages of treatment to assess efficacy against pathogens. This is not feasible for India. Water4India deliverable 4.4 provides alternative approach for QMRA by using collected data on treatment efficacy from literature.

## 6.8 Direct assessment of drinking water

The NRDWP data on *E. coli* indicate that the level of contamination varies strongly between states. Figure 6-12 shows an example of the variation of *E. coli* contamination between states. *E. coli* was found in over 56% of the rural sources in Jharkhand (ranked 1 in faecal contamination), indicating that faecal contamination occurred very frequently. Two states found no *E. coli* in any of the sources in the

2013 sample. On the other hand Mukhopadhyay et al. (2012) found that 27.5% of the Karnataka sources were contaminated with *E. coli* , which is much higher than the 4.5% in the collected compliance data. Some states did not monitor *E. coli* or did not provide monitoring results. *E. coli* is monitored only twice per year. It is known that *E. coli* concentrations can vary significantly. Therefore a single sample per year probably leads to an underestimation of the exposure to faecally contaminated water.

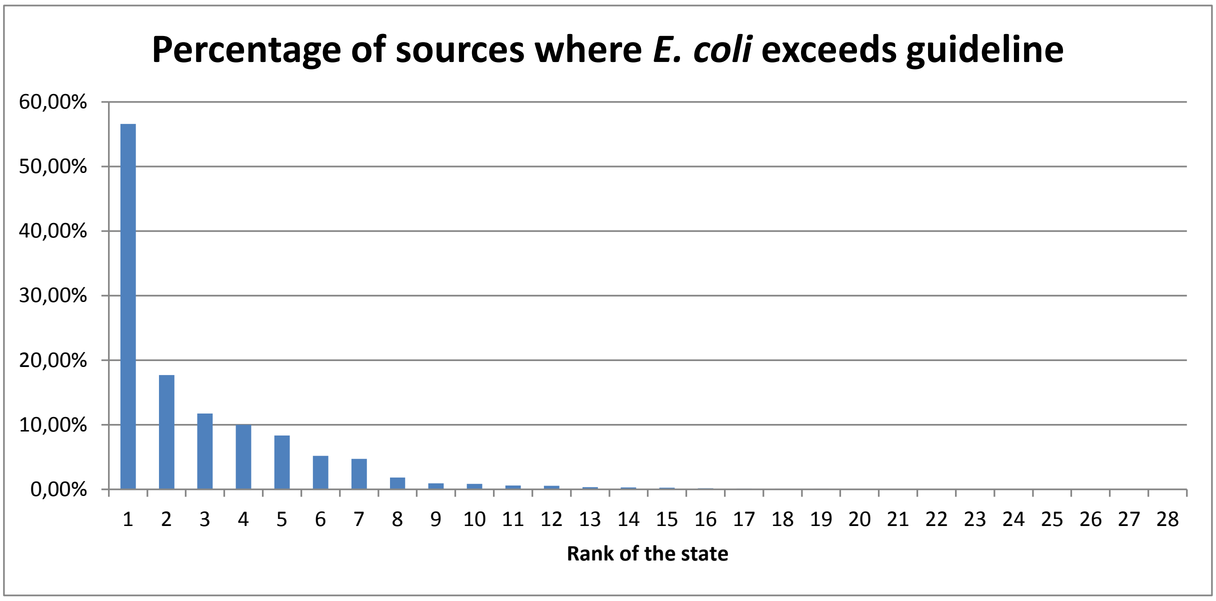



**Figure 6-12 Percentage of sources where *E. coli* was detected in 2013 per state (NRDPW 2014).**

Although the percentage of sources where *E. coli* was detected seems small, Figure 6-13 shows that due to the vast number of sources, the actual number of contaminated sources is substantial.

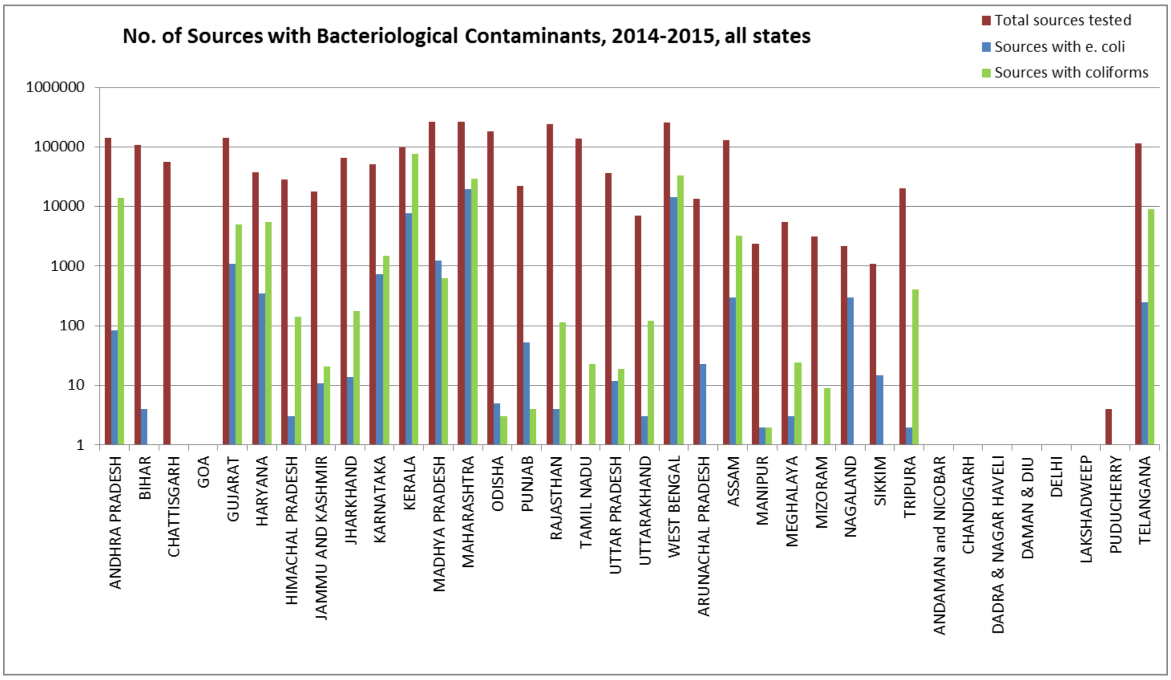



**Figure 6-13 Number of sources tested and number where bacterial indicators were detected**

## 6.9 Variability of contamination

The concentrations of contaminants in sources can vary in time. Current sampling programs only include one chemical sample and two microbial samples per year. Therefore the regular sampling program provides little information about the variability of contaminant concentrations. Figure 6-14 shows that the number of samples exceeding the standards can vary substantially between years (single samples). Non-compliance for iron was halved from 2012 to 2013 while coliform non-compliance doubled. Such differences may be the consequence of short term fluctuations rather than differences between years. Short peaks of contaminants can have a significant effect on the health burden. Especially microbial peaks can be several orders of magnitude higher than nominal concentrations. Since microbes lead to acute health impact, such short peaks are very relevant for the yearly health risk. A very low monitoring frequency of twice per year is very likely to underestimate the health risk from microbes (Smeets et al. 2012 Kampala WSP conference). Weekly to monthly monitoring provides a reliable basis for health risk assessment. Variability of chemical contaminants rarely leads to acute health effects, and variability therefore has less impact on health risk assessment. Also for pathogens the health risk may be underestimated since the single sample may not pick up temporary contaminations, e.g. from pesticide use or industrial dumping activities. The required frequency to pick up such an event cannot be predicted. On-line monitoring of specific parameters could provide an indirect identification of such an event and trigger monitoring to identify contaminants.

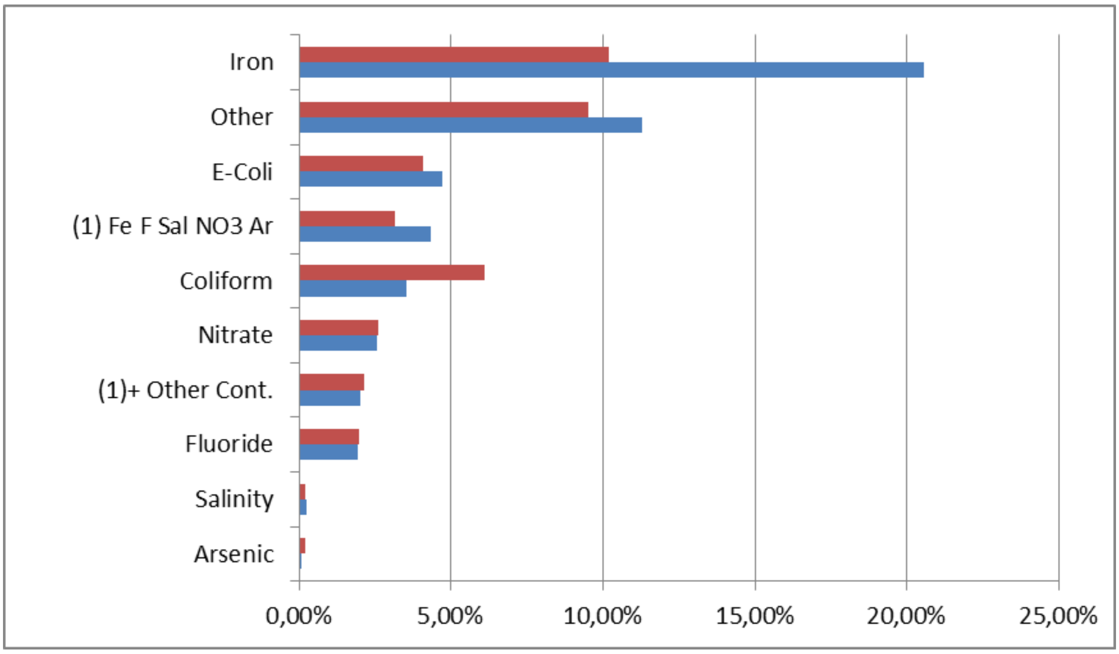



**Figure 6-14 Percentage of sources in India where contaminants exceed the guideline values in 2012 (blue) and 2013 (red) (data from NRDWP, 2014).**

At least one source in habitation found contaminated as per latest lab testing entry are counted under the (1)+Other Cont. column
Habitations with any contamination including Arsenic are counted under 'Arsenic' Column.
Habitations with any contamination including Fluoride and without Arsenic are counted under 'Fluoride' Column.
Habitations with any contamination including Iron and without Arsenic and Fluoride are counted under 'Iron' Column.
Habitations with any contamination including Salinity and without Arsenic,Fluoride and Iron are counted under 'Salinity' Column.
Habitations with only Nitrate contamination are counted under 'Nitrate' Column.

## 6.10 Pathogen monitoring during pilot studies

Monitoring during the pilot studies in work package 7 was focused on evaluating the Water4India solutions. This included some samples from source water that were analyzed for pathogens. At the AMIAD fiber filtration system, the river water after aeration was analysed for the presence of the protozoan pathogens *Cryptosporidium* and *Giardia*. Details of this monitoring are discussed in report D7.2. Although large sample volumes were used to detect low concentrations of these pathogens, the analysis was inhibited by the specific water matrix. This resulted in very low recovery of the method and a detection limit around one organism per liter. *Giardia* was detected in one out of three samples at a concentration of 0.56 cysts/L after correction for recovery. The estimated *Giardia* concentration in the Tunga river is 0.7 cysts/L based on the level of fecal indicator bacteria (see report D4.4). The monitoring supports the first estimation. *Cryptosporidium* were not detected at a detection limit of 0.5 to 1.1 oocysts/L. The estimated concentration based on a fecal indicator bacteria concentration of 600 cfu/l is 0.15 oocysts/L. Due to the low recovery the presence of *Cryptosporidium* could not be confirmed.

A recent study by Daniels et al. (2016) highlighted the presence of these pathogens in (unprotected) groundwater sources. They conclude that: "*piped supplies of centrally treated water might need to replace local groundwater drinking sources in settings which are vulnerable to faecal contamination from latrines*". The results from the Water4India project indicate the presence of these pathogens in source waters for these piped supplies. In report D4.4 the safety of these systems is assessed using quantitative microbial risk assessment. This shows that the current centralized, piped supplies provide insufficient protection against these pathogens. A holistic approach is needed to improve the total water hygiene situation in India, including sanitation, groundwater source protection and centralized surface water treatment and distribution. Monitoring water sources and treated water form an essential part of this holistic approach.

# 7 CONCLUSIONS

## 7.1 Evaluation of Uniform Drinking Water Quality Monitoring Protocol

The Uniform Drinking Water Quality Monitoring Protocol (UDWQMP) provides a good basis for water quality monitoring in India once it is fully implemented. Currently the execution of the protocol needs to be improved. The protocol could be focussed more towards health based monitoring by:

- More frequent microbial monitoring of water sources (minimum of 6 times per year)
- Include pathogen monitoring to build a knowledge base on occurrence of pathogens and their ratio to faecal indicator bacteria specifically in India.
- Clarify the current guidelines for pathogen (viruses, protozoa) monitoring in specific situations in the UDWQMP and stimulate actual implementation of these analysis
- Focus chemical water quality assessment on health related parameters to make most efficient use of resources:
  - Pathogens
  - As
  - F
  - Pb (currently not a standard parameter)
  - $NO_3$
- Parameters that are relevant for acceptability of water (organoleptic) might be reduced, since customer complaints registration would show if targets (customer acceptance) is met for the following parameters:
  - Turbidity
  - TDS
  - Total hardness
  - Chloride
  - Iron

The UDWQMP could also provide more guidance on the interpretation of monitoring results. Currently focus is on compliance to guideline values (fail or pass). For microbial risks a more advanced assessment could be made based on insights from QMRA. Finding FIB in a chlorinated system indicates serious failure of disinfection, or incidence of recontamination. A step further would be to link river water monitoring results to treated water results to evaluate treatment performance. Anthropogenic contaminants like pesticides, industrial chemicals, persistent organic pollutants, heavy metals and pharmaceuticals are rarely monitored but may pose a significant risk. Regular screening for these contaminants is needed to assess the relevance for health in India.

## 7.2 Improvement in labs: State, district, region, mobile

Several aspects of the laboratories could be improved:

- Reliability by implementing Round Robin Testing to verify lab quality
- Accessibility by developing cheap methods for sample storage and transport
- Costs by limiting the number of parameters (7.1)
- Technologies to analyse for actual pathogens need to be implemented
- Support and follow-up by providing feedback on what analysis outcomes mean

## 7.3 Field test kits

The current programme as described in the UDWQMP is good in principle, but needs support including:

- Interpretation and feedback from trained person on what results mean and which actions must be taken
- Provision of sufficient testing materials
- Control of environmental impact of materials and chemicals used or produced in the test kits

## 7.4 On-line monitoring

On-line monitoring of critical control points at water treatment facilities would allow risk management in line with water safety plan concept. The UDWQMP currently doesn't address the opportunities for on-line monitoring. The following applications can be considered:

- Turbidity monitoring of filtration processes
- Monitoring of chlorine residual after contact time (treated water reservoir)
- Monitoring UV dose for UV disinfection
- Monitoring *E. coli* automatically
- Particle counting after fiber filtration or membrane filtration (novel approach tested in Water4India)

## 7.5 Data exchange between monitoring institutions in the WCSP framework

Various institutions are responsible for the different parts of the water supply system such as river water, ground water and drinking water. Better interaction between these institutions and exchange of monitoring data would allow a more integrated risk assessment for drinking water production. In addition the pollution control board and health authorities could provide additional information. The water (cycle) safety plan approach provides a framework for these institutions to work together towards improving drinking water quality and health.

## 7.6 Expand monitoring to the household

The current monitoring protocol focuses on the point where water is produced, either at a treatment plant or at a well. However contamination can take place during distribution, especially since the system isn't pressurized continuously. Also contamination can take place between the point of delivery (standpipe or well) and the home and during in house storage. Fecal contaminations seem to be just as relevant for health risk as the produced water quality (Water4India deliverable 4.4). Routine monitoring of each household for faecal contamination isn't feasible. Cost and logistics to perform these analysis laboratories would be very high and field test kits would also be costly and too complex for families to use. 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.

## 7.7 Case studies of health based approaches

The best way to assess the added value of health based approaches like water safety planning and quantitative microbial risk assessment is to initiate case studies to test these approaches. In the Water4India deliverable 4.4 an example of QMRA application is provided. A next step would be to involve the stakeholders in this example and assess how they would benefit from this. This would also highlight knowledge gaps to focus research on, like the lack of knowledge about pathogens in faecal contamination sources in India.

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