



# **WATER4INDIA**

**Smart, Cost-effective Solutions for Water Treatment and Monitoring in Small Communities in India.  
Decision Support System Integration.**

Project no. 308496

Collaborative project

Spec ENV.2012.6.6-1: EU-India cooperation in water technology:  
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## **Final Publishable Summary Report**

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## 1 Executive summary

EU FP7 project Water4India is a research project that studied different centralized and decentralized options for water treatment at community level in India, giving special consideration to resource availability, management, treatment solutions, water quality, socio-economic, and environmental factors. Water4India is a collaborative project with experts from 9 different countries distributed across the European Union, Switzerland, Israel, and Australia. It is funded through the European Union's Seventh Framework Programme (FP7-ENV-2012). Water4India was officially launched in September 2012 and ran for 48 months. The project website can be found at: <http://water4india.eu/>

Fresh water of sufficient quality for human consumption is becoming a scarce resource and its availability is a concerning issue in India whose growing wealth and population create increasing needs leading to higher water consumption while quality standards for drinking water are being enhanced. In this context, there exists a significant need of initiatives and projects like Water4India that can impact and affect the improvement of the existing situation.

The overall objective of the Water4India project was to optimise and implement a set of technological alternatives for water supply in India. The first step performed was to analyse the existing socio-economic and environmental Indian framework and the availability and quality of water. Water quality monitoring was of capital importance at each step of the process, and several technology options were considered, such as the Quantitative Microbial Risk Assessment (QMRA), in the frame of the Water Safety Plan of the project.

In parallel to the assessment of the availability and quality of water resources in India, different technologies for clean drinking water production were analysed. The project specially focussed on decentralized drinking water solutions using advance Microfiltration (MF) and Ultrafiltration (UF) membranes, and an innovative self-cleaning approach for MF. Innovative adsorbents were also studied for the efficient removal of water contaminants. In order to obtain the needed energy for the decentralized systems, a deep study on matching renewable energy sources with this type of systems was performed.

A Decision Support System (DSS) was developed based on the previously gathered information and technology research, allowing to find the optimal solution considering not only its cost but also the overall sustainability of the process, paying particular attention to energy consumption and obtaining for this purpose, the friendliness of the proposed technologies and their adaptation to the social environment.

The proposed technologies of the DSS were applied in two places with different climatic and social situations that constituted the pilot sites validating the developed work.

Water4India created several possibilities proved to be of interest for the Indian context. A strong importance was given to ensure that the knowledge and outcomes of the project had an impact and were accessible by the groups of interest: local authorities, small communities, and families. Several awareness and dissemination events were carried out in India, an e-learning took is accessible through the project website, and a compendium of solutions for practitioners and engineers has been written.

## 2 Summary description of project context and objectives

The overall objective of the Water4India project is to optimise and implement a set of technological alternatives for water supply in India. The project will focus on the Western part of India, where problems with water quality are most important and where, even though current riverine supplies are adequate, future demand will be unsustainable due to increasing needs faced to an approximately fixed annual water supply (1). To achieve this, the aim of the project is to produce a comprehensive set of applicable solutions, taking into account technical, environmental, social and economical factors, which will be eligible for each specific situation. The selection will consider the previous factors together with management issues such as resource availability, available water quality, or current and expected demand; the designed set of solutions will produce drinking water of a quality that matches the respective Indian standards. Each set of solutions will include everything needed to obtain potable water of an appropriate quality including monitoring techniques, treatment equipment, and harvesting or reuse solutions when applicable.

While Water4India focuses mainly on decentralised solutions such as Small Scale Systems (SSS) and Point of Use (POU) technologies, the already existing infrastructure for the production of drinking water by using centralised technologies will also be taken into account, considering the quality and quantity of drinking water produced by these systems and their possible optimisation. The integration of renewable energies will be considered in each case, specifically for small scale treatment, for it will allow drinking water production on a completely decentralised basis, being independent both from the main water and energy infrastructures. The use of renewable energies will also enhance the sustainability of the system.

The project will comprise in-depth literature research as well as assessment of the current and future situation and resources in order to develop optima solutions for each specific situation. To allow for easy access to expert knowledge regarding availability, management, selection of centralised and decentralised technical solutions and consideration of key factors, e.g. socio-economic conditions, a Decision Support System (DSS) will be developed.

Based on the previous ideas, the main objectives of the Water4India project are as follow:

**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.

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

**Objective 3:** Adapt and develop a set of solutions based on technological components for water treatment at small scale to the end-users needs at the identified areas. These

technologies will include: Ultrafiltration with optimised energy demand, Filtration based on microfibers, Desalination technologies such as reverse osmosis, UV disinfection, Membrane distillation, Adsorption using conventional and novel low-cost, locally available materials

**Objective 4:** Assess and quantify existing technologies for water quality monitoring to evaluate the quality of raw and treated water, and also the composition of waste water. Special attention will be given to pathogens, studying the quality of water by state-of-the-art methods such as Quantitative Microbial Risk Assessment within the framework of Water Cycle Safety Plans based on good- housekeeping.

**Objective 5:** Develop a Decision Support System which integrates Multi-criteria Evaluation of technological alternatives for obtaining drinking water of the appropriate quality in each socio-economic situation, together with its management and sustainability assessment. This DSS will allow stakeholders and authorities to compare and select the best components to meet environment, economic and social aspects.

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

**Objective 7:** Propose best practice guidelines for the end-users, especially for the cases when small scale technologies are chosen. Best practice guidelines will also allow policy makers to develop new regulations which make water access easier for all the Indian people.

## WP2: Water availability and management in India

Work Package 2 aims to assess the water challenges in the selected Indian regions (Karnataka) based on an Integrated Water Resources Management Approach.

To that purpose a framework to characterise the water challenges facing communities based on indicators for the local situation, the existing water infrastructure, the needs of the stakeholders and expected developments will be developed. Such a typology allows identifying communities with different types of water challenges and ranking them according to the severity of their challenges. This assessment will be used to tailor solutions to overcome the different identified challenges in the following Work Packages.

Therefore the objectives of this WP are threefold:

- Overview of Indian water supply situation and major challenges in communities
- Development of a community water assessment framework
- Framework application in a region and selected communities and pre-selection of piloting options

## WP3: Innovative solutions for clean drinking water production

The overall objective of this WP is to introduce decentralized drinking water treatment technologies

state-of-the-art at EU-level with the existing Indian solutions, to develop and adapt them to local conditions in order to ensure the most appropriate, robust, safe and cost-effective technological solutions in India. Specific objectives are to:

- Review both existing European and Indian technologies addressing the decentralized solutions for drinking water during droughts and flood periods.
- Assess and to identify most suitable technologies for the local conditions where a centralized drinking water supply is not technically viable or not affordable.
- Research and develop selected decentralized technologies to increase the robustness, cost-effectiveness, energy efficiency, affordability and accessibility for drinking water.
- Develop recommendations of most appropriate decentralized drinking water treatment technologies that should be introduced and scaled up within India.

## WP4: Water quality verification, monitoring techniques

The aim of Work Package 4 is to develop methods to assess current health risks from drinking water, to identify the important causes of risk in the water cycle and to assess the impact of the solutions developed in this project on health risks from drinking water. Chemical/toxic risks will be addressed by smart water quality monitoring and comparing outcomes to water quality standards. Microbial contaminants in drinking water and drinking water sources are highly variable and water quality analysis cannot provide full verification of drinking water safety.

Microbial monitoring will therefore be combined with water cycle safety planning and quantitative microbial risk assessment.

The current practice of monitoring microbial drinking water safety generally consists of water sample analysis for absence of indicator organisms that would indicate fecal contamination (E.coli). This has several shortcomings. Pathogens may be present also when E. coli is absent in 100 ml, and the result of the analysis takes 48 hours, so the water has already been consumed when the result is known. In small systems these analyses are rarely carried out (once a year) whereas microbial contaminant levels can vary hourly.

The main objective of WP 4 is to develop monitoring plans for the situations in Indian communities based on the Water Safety Plan approach. This includes both chemical and microbial water quality monitoring and monitoring of other health related aspects. Quantitative Microbial Risk Assessment (QMRA) will be used to identify key control points in the water supply system and to determine monitoring frequencies of these control points. Strategies will take into account the aspects of available (reused) water identified in WP 2.

WP4 will develop protocols to test the efficacy of new and existing solutions for water supply identified in WP3 both in the field. AMIAD will execute these tests in WP7. An inventory of

available water quality tests for the Indian community context will be made. The applicability and sustainability of these tests and the monitoring strategies will be assed as an input for WP5. This includes a field test for on-line monitoring for pathogens like E.coli and Cryptosporidium.

### **WP5: Social, environmental and economical implication of Water4India**

The overall aim of this activity is to ensure that the technologies that will be developed by Water4India are capable of being socially and economically adopted by intended user groups. This WP will be developed in the regional area selected in WP2, with the collaboration of local stakeholders. Specific objectives are to:

- Assess whether the technologies developed by Water4India will be accepted by the communities using them.
- Identify stakeholders in the technology and related services value chain and characterize affordability.
- Identify the social and economic constraints to widespread and long term technology adoption and develop recommendations on how these might be overcome.
- Develop recommendations on how the technologies should be introduced and scaled up within India.

### **WP6: Decision Support System Development**

This Work Package is aimed at providing support for decision making related to water management projects with particular focus on drought management, provision of safe and affordable potable supplies and uncertain data driven risk mitigation in decision making. The tools development is envisaged to be based on information and data provided by the previous work packages in a format consistent with DSS framework requirements. The tools in DSS are aimed to facilitate:

- Technology selection - to enhance overall sustainability and investigation of potential trade-offs resulting from the implementation of selected technological innovations.
- Project implementation – to manage uncertainties in decision influencing parameters and enable robust evidence based decision making.

### **WP7: Technological deployment and validation of the selected solutions in India**

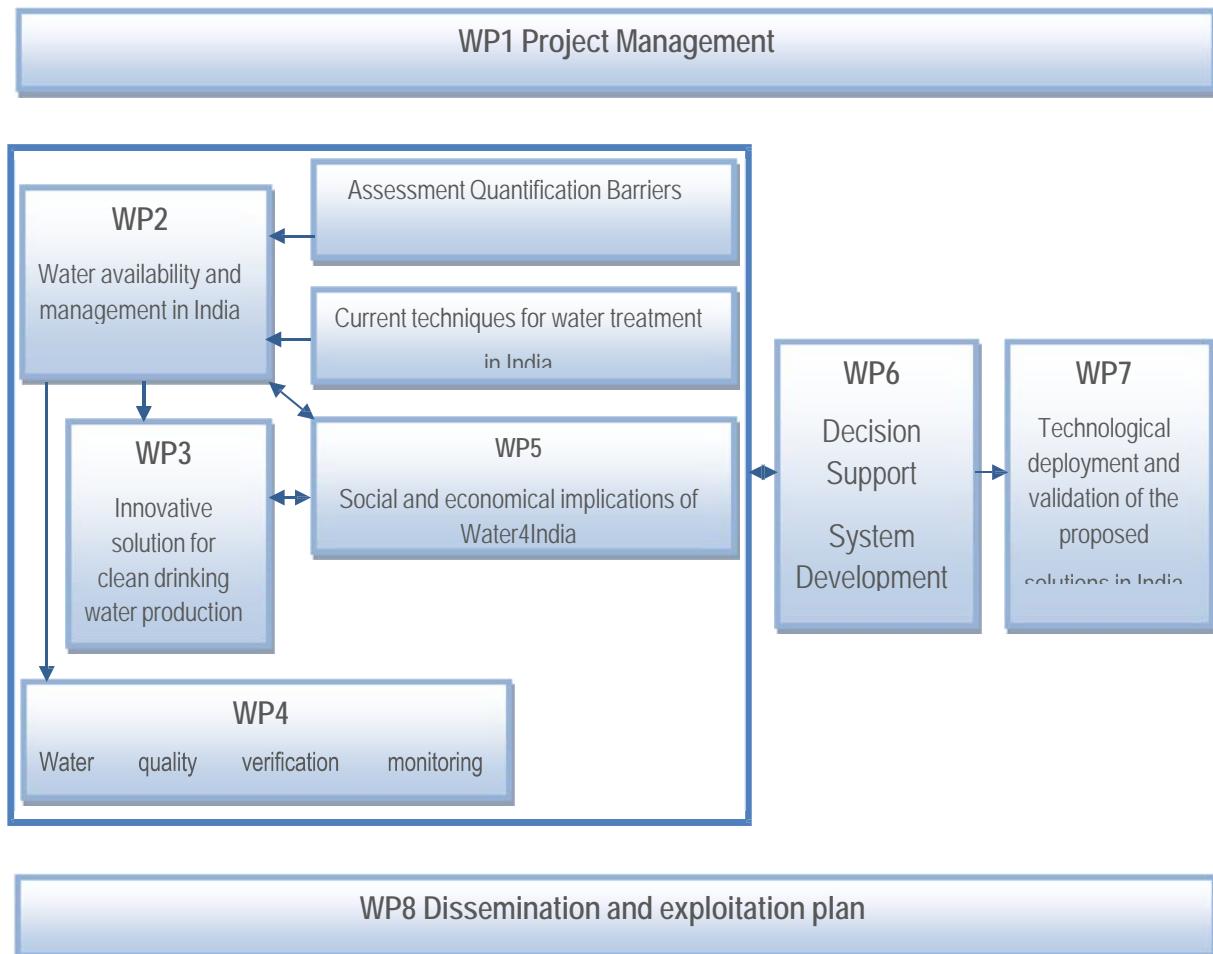
Up to this point, all activities of this project have focused on providing optimal solutions for real water challenges in Indian communities therefore this WP is a cornerstone in the proof of concept. This WP will effectively validate the proposed solution implementation approach not only for a specific community, but for India in general.

Proof of concept will be achieved through the application of the frameworks and DSS-system and the implementation of proposed solutions in selected pilot communities in India facing different water challenge situations.

The frameworks and the DSS will be applied in real situations and the effects and efficiency of the solutions proposed by the DSS will be evaluated to allow final adjustments and learning points for further dissemination and uptake.

### 3 Description of the main S&T results/foregrounds

The work carried out in the project comprised research, innovation-related and development as well as management activities. The activities were structured in well-connected work packages (WPs) as illustrated in Figure 1. **¡Error! No se encuentra el origen de la referencia.** The methodology as well as the results and innovation of the activities are described subsequently.

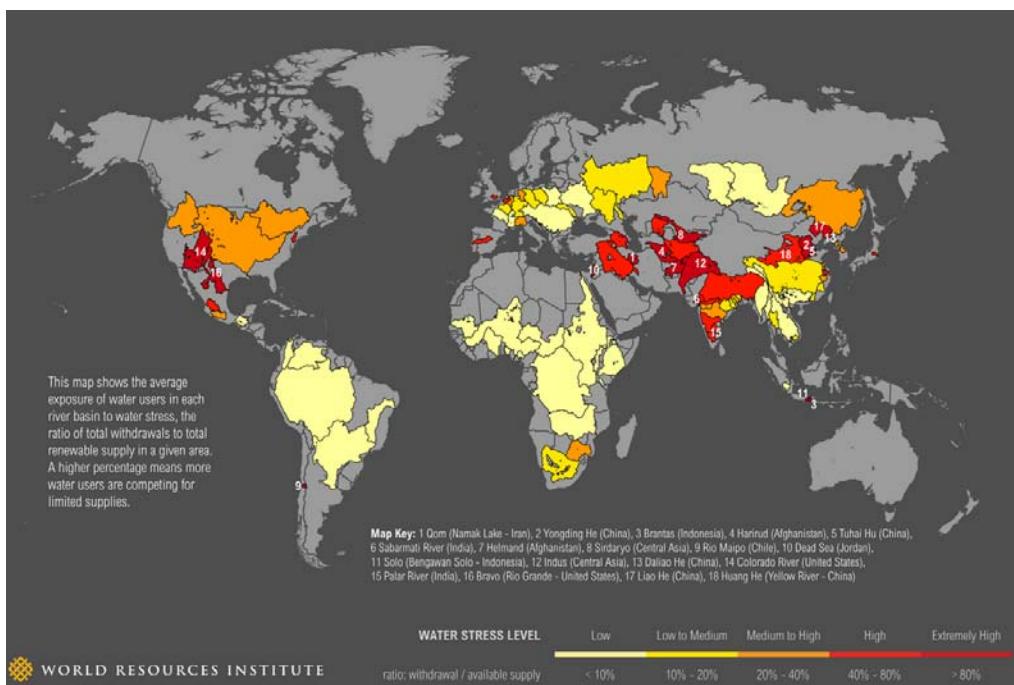


**Figure 1. The WATER4INDIA work packages and their interconnection**

## WP2: Water availability and management in India

### BACKGROUND

Water resources in India are under pressure from an increasing population and living standards, associated with a rapid urbanization and industrialization. With the rising water demand, water abstraction from groundwater and surface water has reached and exceeded sustainable limits in several riverbasins (Figure 2). The deficits in wastewater treatment and changing climatic conditions have led to water scarcity and pollution in many Indian regions, threatening a safe and sufficient drinking water supply.



**Figure 2. Water stress by most populous river basins (WRI, 2014)**

The safe and sufficient supply of drinking water accessible to all members of society is required by the new Sustainable Development Goal 6 (SDG6: *'achievement of universal and equitable access to safe and affordable drinking water for all members of society'*) as well as the Indian National Water Policy by the Ministry of Water Resources. The National Rural Drinking Water Programme (NRDWP) aims to improve the drinking water situation in rural communities, where safe drinking water is still often lacking. Contextualized solutions for drinking water sourcing and treatment are needed to achieve these goals in a sustainable manner. The selection among different treatment technologies depends on site-specific aspects and should be embedded in an overall Integrated Water Resources Management (IWRM). Particularly under water stressed conditions, knowledge of spatial distribution and seasonal fluctuation of water resources are of crucial importance and different water users (i.e. industry, agriculture, domestic uses) should be considered on a river basin scale. However, in India poor or lacking data on available quantities and water qualities as well as poor to no coordination between stakeholder groups has been observed, leading to unsustainable water management practices within many watersheds.

The well-known Drivers-Pressures-State-Impacts-Responses (DPSIR) model (EEA 1999) extended towards the influences from infrastructure and climate change as drivers (Kossida et al. 2009) provides a useful framework for an integrated assessment of water resources and gives valuable insights for decision makers. In Work Package 2 (WP2) a DPSIR framework implemented along with an open source Geographic Information System (GIS) and the open source riverbasin water quantity and quality model Soil and Water Assessment Tool (SWAT) has been developed and applied to two Indian case study communities and their riverbasins to tackle the following guiding questions:

- Which water challenges exist in the case study communities and what are their causes?
- Which objectives at community, riverbasin and larger scale can be derived from these observed challenges in order to locally achieve SDG6 under current conditions and projected future scenarios?
- How do the W4I solutions contribute towards achieving these objectives in the case study communities?

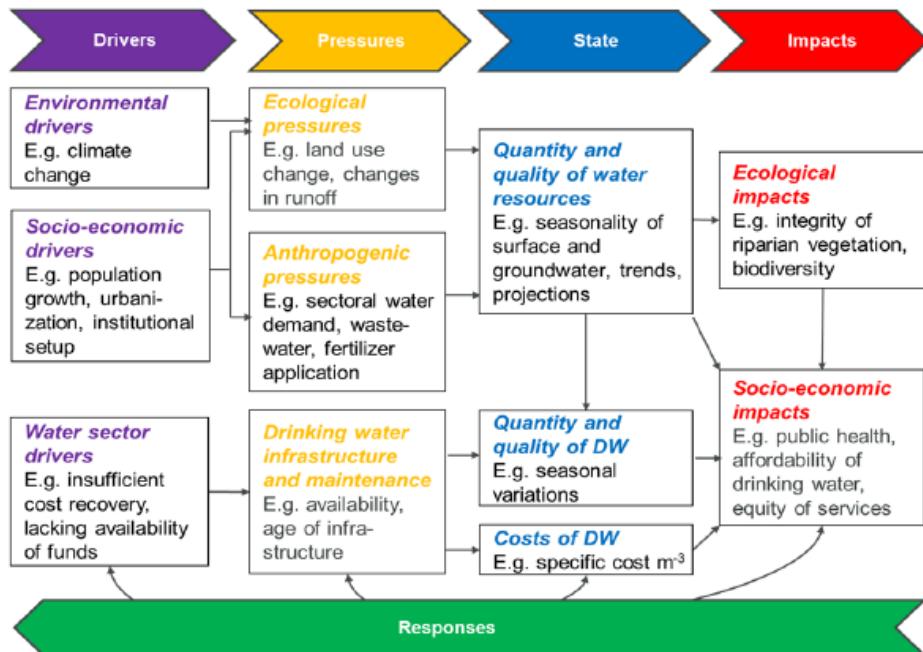
## METHODOLOGY AND RESULTS

In WP2, an adapted DPSIR conceptual framework (Figure 3) combined with the open source GIS platform QGIS ([www.qgis.org](http://www.qgis.org)) and the riverbasin water model SWAT ([swat.tamu.edu](http://swat.tamu.edu)) was developed and applied to identify relevant drinking water challenges in Indian communities and their drivers at riverbasin and larger scale. Where data on water quality and quantity ('state') was lacking, modelling of water resources with SWAT on the basis of input parameters from the DPSIR assessment provided qualified estimates of water quantity and quality throughout the year in each riverbasin. Water4India Deliverables D2.1 ('Assessment and objectives setting framework for Indian communities') and D2.2 ('Application of framework for selected region') provide a preliminary description of the framework as well as application in the Water4India project region. Deliverable D2.3 ('Pre-selection of solutions for case study region') demonstrates a site-specific selection process of favourable drinking water measures ('responses') based on findings from the application of the framework, taking into account socio-economic, environmental and technological aspects.

Learnings from these preliminary assessments provided the basis to describe the final version of the assessment framework as well as its application in the two Water4India case study communities and their riverbasins in Deliverable D2.4 ('First evaluation of implementations of solutions in case study region - An evaluation of drinking water technologies in Indian communities using DPSIR and SWAT') according to the following steps:

- Step 1 - Assessment of *status quo* IWRM situation using DPSIR, QGIS and SWAT
- Step 2 - Definition of reasonable future scenarios of water resources states based on the *status quo* DPSIR assessment
- Step 3 - Identification of site-specific challenges and derived objectives for drinking water management based on the previous two steps

- Step 4 - Assessment of potential Water4India technological drinking water responses to achieve objectives and suggestion of further responses.



**Figure 3: Example DPSIR structure including drinking water (source: Gross et al. 2016)**

A brief summary of findings in the two Water4India case study communities and the effects of the implemented Water4India technologies are given below. A complete overview of the overall methodology developed in WP2 and results and conclusions from its application to the two selected case study sites is presented in D2.4 ‘First evaluation of implementations of solutions in case study region’.

**Case study 1 – Thirthahalli in Tunga Riverbasin:** Thirthahalli in the Tunga Riverbasin abstracts water for drinking water production in an existing DWTP from Tunga River. Source water shows significant quantity and quality fluctuations throughout the year due to monsoon climate with high soil erosion and resulting turbidity during torrential monsoon rains. Agricultural practices and insufficient wastewater collection and treatment are the main pressures on water resources in the riverbasin which lead to soil erosion (agriculture), nutrient and pathogen inputs from point-sources (communities with wastewater drainage but no wastewater treatment) and nonpoint-sources (open defecation, livestock as well as fertilizer and pesticide application on fields). Derived site-specific objectives include among others basin-wide coordination especially between agriculture and water users, monitoring of land use change and assurance of turbidity control and pathogen removal (e.g. *Cryptosporidium*) from drinking water throughout the year. A number of more site-specific challenges are not presented here due to confidentiality reasons. The Water4India technological ‘response’ consisted of upgrading the existing DWTP with shallow media filtration, micro-fibre filtration and chlorine disinfection as well as on-site monitoring for immediate quality control and feedback on operational parameters aiming for better control of turbidity removal compared to more conventional rapid sand filters. The Water4India response performed well for

turbidity removal and furthermore provides a safer barrier against the protozoan pathogen *Cryptosporidium*. The drinking water treatment remains within locally affordable ranges. To achieve continuous drinking water supply total water storage should be further increased, proper distribution network maintenance guaranteed and power outages minimized by central power generation and reinforcement of the power grid.

**Case study 2 – Kanbargi/Belgaum City Corporation in Markendeya Riverbasin:** With regard to safe and sufficient drinking water supply, the community members in Kanbargi settlement at the outskirts of Belgaum city do not have piped water supply within their premises but rely on a public stand posts or wells. Drinking water quality is considered as unsafe as it is neither disinfected nor safely transported and stored. In the orphanage, the piped water supply is frequently interrupted, leading to storage of the water and subsequent treatment in a household water treatment system. Based on the challenges identified with DPSIR, a set of locally relevant objectives have been defined for Kanbargi settlement. The Water4India technological 'response' consisted of a new solar-driven ultrafiltration drinking water treatment unit which was installed in the orphanage. The implemented technology alongside the water kiosk project for Kanbargi settlement provides reliable redundancy to the vulnerable tap water supply. The availability of safe drinking water from a water kiosk in a water-deprived informal settlement is considered as an important achievement and efforts should be taken to realize access to this safe water supply for a bigger group of consumers in the settlement.

## CONCLUSIONS

The DPSIR approach allowed identifying relevant conditions and trends in the water sector and pinpointing causes of challenges at community, riverbasin and larger scale. As such it was possible to maintain an IWRM perspective at riverbasin scale while following a main target, i.e. to contribute to the achievement of Sustainable Development Goal 6 in Indian communities: '*Achieve universal and equitable access to safe and affordable drinking water for all.*' DPSIR can thus be used as an overarching frame-work aiming to bring together different sectors and disciplines at spatially relevant scales.

A next step toward practical application of the framework results in drinking water management would be a close stakeholder interaction with critical reflection of results and interdisciplinary discussion involving relevant sectors. The DPSIR assessment highlights linkages between the different sectors and together with water modelling can be used to compare possible future scenarios for decision making. Even though national policies exist promoting the coordination of the different sectors affecting water resources, there has been until now very little to now such coordination. The application of conceptual models such as DPSIR together with numeric water models such as SWAT could contribute to systematic planning approaches between different sectors. As such, the approach elaborated by Water4India WP2 is not intended to replace drinking water specific planning guidelines, but should rather provide an overall umbrella helping to align and coordinate various activities influencing water resources.

## WP3: Innovative solutions for clean drinking water production

### BACKGROUND

In rural and peri-urban areas of India, often centralized supply schemes for drinking water are absent. On the one hand, these full scale drinking water treatment plants and adjacent drinking water distribution networks are absent due to lacking investment on infrastructure, lacking power supply, lacking maintenance activities to keep systems operational. On the other hand, a large portion of Indian people lives in rural areas. Hence, access to drinking water of good quality in rural India must be improved. This addresses both, the coverage with sufficient quantity of drinking water within acceptable distance to households (target: within the premises) and the quality of drinking water that must meet Indian drinking water standards (BIS 10500).

Furthermore, employed drinking water treatment technologies are designed for full scale plants and the designs predominantly include conventional drinking water treatment plants comprising of aeration, coagulation/flocculation, sedimentation, sand filtration and chlorination with bleach powder. In particular, these systems are vulnerable to fluctuating water flow rate and quality caused by i.e. flooding monsoon, droughts, power outages. Hence, the investigation of suitable, resilient technological solutions and their adaptation to local conditions and scale are of priority.

### METHODOLOGY AND RESULTS

#### Survey of appropriate technologies for decentralised water treatment in India

The literature was reviewed to give an extensive overview of the state-of-the-art of decentralised drinking water treatment technologies, both in Europe and India. Thereby, the following questions have been answered:

- What are the local constraints of quality and quantity of European/Indian water resources leading to water scarcity?
- What are the existing decentralised drinking water treatment technologies in Europe/India?
- What are their technical, economic and social characteristics?
- What is their market relevance and which references are there in Europe/India?
- Which measures are implemented to face floods and droughts?

Most existing Indian water treatment plants, even in rural areas, follow conventional treatment system design comprising of aeration, coagulation/flocculation, sedimentation, sand filtration and chlorination with bleach powder. On this basis, an adapted framework for technology selection and evaluation has been derived based on performance criteria. Performance criteria included economic, environmental, socio-economic and technologic aspects. Technology assessment was conducted in order to, on the one hand, highlight promising water treatment and supporting technologies that consequently were investigated in more detail during the project, and on the other hand, further develop and conduct the

technology assessment that will result in the water purification technology selection tool (WETSUiT) of the Decision Support System (DSS) in WP6.

### **Advanced micro-/ultrafiltration (MF/UF) membrane based solutions for point-of-use (POU) purposes and other small scale systems (SSS)**

The research and development activities focused on three fields:

- Testing and characterisation of commercial Indian membrane and other point-of-use systems,
- Modification of locally available membranes in order to establish anti-fouling and anti-microbial properties, and
- Process development of point-of-use purification concept combining membrane filtration and adsorption.

Commercial Indian POU systems were characterised with regard to their disinfection performance in particular, since from literature review, this is considered their main purpose (in rural India). Hence, *Escherichia coli* bacteria and MS2 bacteriophages were used as pathogen surrogates. The tested systems (Eureka Forbes Aquasure Xpert, Kent Gold Plus and Hindustan Unilever Ltd. Pureit Classic) consisted of different purification principles including coarse matter sieving, activated carbon adsorption, ultrafiltration, reverse osmosis (RO), UV irradiation and passive chlorine dosage. The test evidenced that all three systems achieved WHO performance target “highly protective” against bacteria, and the RO- and chlorine-based systems achieved WHO performance target “protective” against viruses. Physical barriers (i.e. membranes) effectively increased removal of turbidity and organics. However, fouling potential increased in turn.

On the membrane material level, membrane coatings using poly-electrolytes (cationic and anionic polymers) and carbon nanotubes (CNT) were conducted in order to improve anti-fouling and anti-microbial behaviour. Ceramic membranes were selected since they last longer, are more robust in principle and can be produced from locally available raw material, i.e. recycling material bagasse fly ash. Pristine and coated membranes were characterised regarding pore size distribution / bubble point determination, pure water permeability, SEM imaging, cut-off size / yeast retention. During real application, gravity driven river water filtration (Yamuna river in Delhi) retention of total suspended solids and turbidity was significantly improved and anti-fouling behaviour could be shown by less flux decline of the coated membrane.

On a process level, the proof of concept of a pump-free membrane cleaning concept designed for gravity driven ultrafiltration (POU or SSS) was performed. It was demonstrated that this concept is competitive to today’s cleaning methods employed in POU/SSS applications. In addition, the cleaning concept is particularly suited to combine ultrafiltration and activated carbon adsorption.

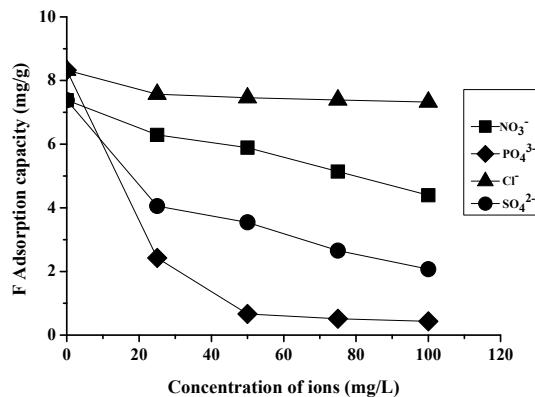
### **Self-cleaning advanced filtration for decentralised safe potable water production**

The pilot plant including AMIADs self-cleaning microfiltration system AMF was constructed, shipped and commissioned at the identified case study site in Thirthahalli town (Karnataka State). The pilot plant was incorporated into an existing treatment plant originally comprising of intake from Tunga River, cascade aeration, coagulation with alum, sedimentation, sand filtration, bleach powder chlorination. The scheme with the included pilot plant contained intake from Tunga River, cascade aeration, coagulation with alum, sedimentation, shallow media filtration (AGF), self-cleaning 7 µm straining (AMF), proportional disinfection with sodium hypochlorite. First trials and optimisation revealed that the new filters AGF (shallow media filter) and AMF fine filter removed the turbidity safely also during heavy rain events. This enables effective disinfection and thus is the basis for a good water quality. Thus, proper functionality of the proposed solution was proven, particularly in the context of peaking turbidity during monsoon period.

### **Innovative adsorbents for removal of hazardous compounds for drinking water sources**

The investigation of adsorption in Indian problem context focused on removal of fluoride, nitrate and heavy metals. Of the seven adsorbents (four anion exchange resins, three multivalent metal oxides) tested on lab-scale, hydrous ferric oxide (HFO) had the highest adsorption capacity for fluoride. Competition with other prevailing ions was also tested (Figure 4). HFO was characterized using scanning electron microscopy, X-ray diffraction, zeta potential and FTIR. Modelling is done with Langmuir and Freundlich for adsorption capacities, and Thomas model and artificial neural network approach for breakthrough data.

Nitrate removal from water by adsorption onto agricultural wastes and surface modified agricultural wastes and ion exchange resins was conducted. Surface modification is performed by amine grafting method and will be expanded to metal incorporation and protonation techniques. Heavy metals (Cr, Cu, Cd, Pb, Ni and Zn) removal from water using granular activated carbon, modified zeolite and industrial wastes was performed. As organic matter and suspended particles can interact with heavy metals adsorption the effect of turbidity and humic acid on heavy metals adsorption was also studied. The exhausted adsorbents with these heavy metals will be incorporated in building materials for safe disposal. In addition, a possible pathway for adsorbent regeneration was investigated with a model herbicide.



**Figure 4. Effect of complementary anions on F adsorption by hydrous ferric oxide (HFO) (initial F concentration 10 mg F/l and adsorbent dose 1 g/l). Phosphate competes most for adsorption sites. Figure taken from Nur et al. / Chemical Engineering Journal 247 (2014) 93–102.**

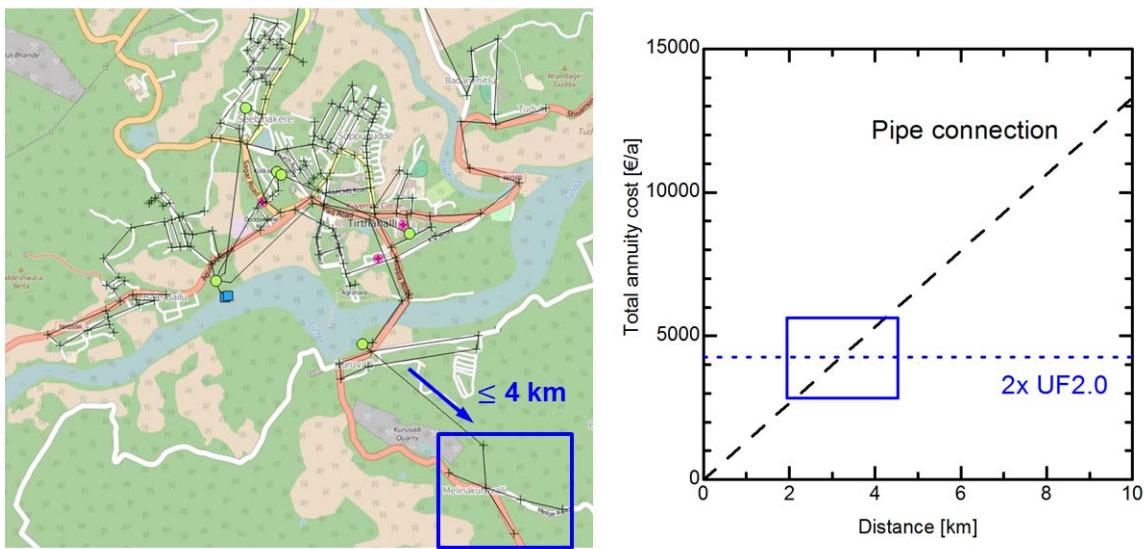
### Matching renewable energies with decentralised solutions for safe drinking water

Possibly employed renewable energy technologies include photovoltaic, solar thermal energy, small wind turbines and small hydro power plants. While photovoltaic and solar thermal energy are always available, local conditions for the operation of small wind turbines or small hydro power plants may vary a lot. According to the available local renewable energy characteristics at the case study site in an orphanage in Belagavi town (Karnataka State) the proposed solution comprises of a photovoltaic driven ultrafiltration system with integrated pre- and post-treatment modules. According to the site-specific treatment requirements the employed treatment system consisted of mechanical pre-filtration, ultrafiltration, activated carbon filtration, and UV disinfection. Water source was a private borewell. The ultrafiltration and UV device represented effective barriers for microbial contamination. The technological solution was proven to be very robust. Local commitment of the operator is a key feature for sustained operation. Continuous water supply can be assured by the combination of energy storage in form of an integrated battery as well as storage of produced water. Excess water production can serve the nearby informal settlement.

### CONCLUSIONS

Due to legislation and availability the most important raw water source is river (or surface) water bearing the risk of (variable) turbidity / total suspended solids, pathogenic and organic pollution as well as trace metals to a minor extent. Limiting boundary conditions for long term use of decentralised drinking water treatment solutions (POU, POE and SSS) were identified (i.e. intermittent power supply, limited operational skills, unfavourable supply chains for consumables and spare parts etc.) and located (Figure 5). Recommendations for technology development (i.e. proper disinfection and prevention of microbial re-contamination on

household scale, offer of comprehensive drinking water solutions including investment, (automated) operation, energy management, water supply to consumers and tariffs on community scale etc.) and adaptation to Indian conditions were delivered - for treatment on household and community scale as well as for centralised plants. These recommendations also include the lessons learnt during pilot plant operation.



**Figure 5. Boundary condition for extended piped supply versus small scale system in Thirthahalli.**

The hydraulics of the distribution network of Thirthahalli Town (30 km pipes and 2,300 m<sup>3</sup>/d supply) were simulated with Epanet 2.0. The supposed pipe extension was 30 m<sup>3</sup>/d serving approx. 400 residents. The economic break-even point compared to a decentralised small scale, solar-powered UF system was found to be approx. 4 km from the next overhead tank.

## WP4: Water quality verification, monitoring techniques

### BACKGROUND

Good drinking water quality is key to public health. Water suppliers take several measures to provide safe water, including source selection, appropriate treatment and protection during storage and distribution. Monitoring the quality of the water and the performance of the supply system is essential to adequately perform these tasks. The applicability of monitoring depends on the context, including the existing threats, the available financial resources and skills for monitoring and the goals of the monitoring. Drinking water legislations prescribes the water quality parameters to be monitored and the monitoring frequency. Although this provides some verification that a water supply system is working adequately, it is by itself insufficient to protect the population from drinking water related risks. Generally water has already been consumed when the monitoring results become available. In addition, it's impossible to monitor the millions of possible chemical contaminants and microbial risks are highly variable and are still relevant below the limit of detection. The world health organisation (WHO) therefore promotes implementation of a water safety plan (WSP). The WSP methodology consists of several steps providing a pro-active risk management framework. Monitoring plays an important role in this framework both for risk identification and risk management. The WSP links monitoring results to risk management actions such as corrective actions when critical limits are exceeded. These limits can be set for water quality, but also for observations or water treatment process conditions. Because the role of monitoring in the WSP goes beyond legal verification of water quality, there is a need for new guidance on how to select monitoring techniques and design monitoring strategies within the WSP framework. Furthermore technological developments provide new methods for monitoring, such as continuous, on-line monitoring or molecular microbiological methods. These provide opportunities for more sensitive, informative, frequent or affordable monitoring.

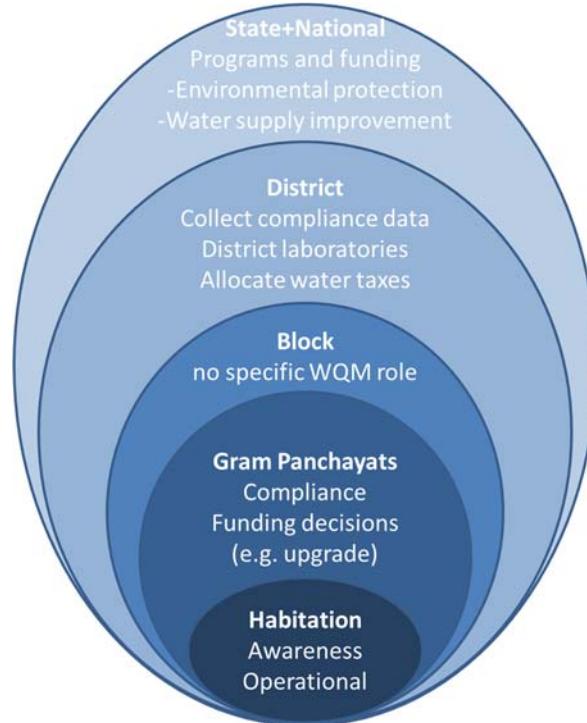
Monitoring in rural India is challenging due to the decentralised character of water supply and less dense population. Laboratories for water quality analysis are often far away, making sample transport difficult and introducing risks of sample deterioration. There are numerous small water sources and supplies, so many locations to monitor. The local actors in water supply management are generally less trained than their urban colleagues. This makes that the requirements for monitoring techniques and approaches in rural India are very different from those in large scale urban systems. In this work package we addressed the various roles of monitoring water quality and other aspects in rural India and how that relates to techniques and data interpretation.

Drinking water supply in rural India is challenged by many factors both qualitative and quantitative. The central drinking water supply may still pose microbial risks since drinking water sources are polluted and treatment systems may not be sufficient to remove pathogens to an acceptable level. Central water supply is generally distributed intermittently for a few hours per day. The lack of constant pressure means distribution system hydraulic integrity isn't maintained and microbial contamination can occur. Most households need to collect and store water in their homes, also leading to potential contamination. When central water

supply is insufficient or not preferred, people turn to other sources such as private open wells, bore wells, springs, rainwater harvesting or local surface waters. When consumers think there is a risk they may treat the water in various ways such as boiling, filtering with sieve, cloth, biosand filter or commercial home filters. People generally use different sources during different periods of the year based on tradition, observations and perceptions. Monitoring all these various routes isn't feasible. Therefore quantitative microbial risk assessment was used to identify which drinking water sources and behaviours introduce the highest risk of infection.

## METHODOLOGY AND RESULTS

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. The role of monitoring varies with the context. At the level of the consumer, monitoring can help create awareness about risks. At the operator level monitoring is key to control processes and verify operation between critical limits. At the governmental level, monitoring provides insight in the occurrence of risks to the population. These risks can be prioritised to first address the highest risks. It can also be used to allocate resources efficiently to improve the situation, for example investing in source protection, treatment, accessibility or education.



**Figure 6. The goals of water quality monitoring at different organisational levels in India.**

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. 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 was developed. One conclusion is the need for monitoring pathogens in Indian sources of contamination to provide a scientific basis for QMRA in the Indian context. Adequate sampling, cooled transport and timely analysis are essential for microbial water quality analysis. Currently none of these aspects are sufficiently implemented in rural India. There appears to be insufficient sense of urgency and knowledge of the importance of water quality monitoring and research on the occurrence of actual pathogenic organisms in Indian source waters is almost non-existing.

The various objectives of water quality monitoring were linked to requirements of monitoring techniques. Technical and socio-economic criteria such as sensitivity, accuracy, specificity, cost, safety and ease of use vary with the objectives. Although microbial health risk emerging at the household level is highly relevant in rural India, routine monitoring at the household level isn't feasible due to costs, safety and complexity of methods. However, tests can be used as part of education and awareness raising at the household level. For awareness raising, accuracy is less important than safety, ease of use and costs, whereas accuracy is very important for evaluating treatment and costs are less of an issue. These considerations were brought together in a framework to evaluate monitoring techniques. The framework was applied to a range of microbial and chemical field test kits and laboratory techniques. Existing data on raw water quality or treatment efficacy was used to predict expected water quality

results during the Water4India pilots and to set treatment targets that are needed to reach BIS requirements. Feedback from Water4India demonstrations highlights the need for capacity building and an adequate supply chain for equipment and materials.

**Table 1. Overview of health relevance of drinking water contaminants as discussed in section 3.2-3.5 (ND=no data).**

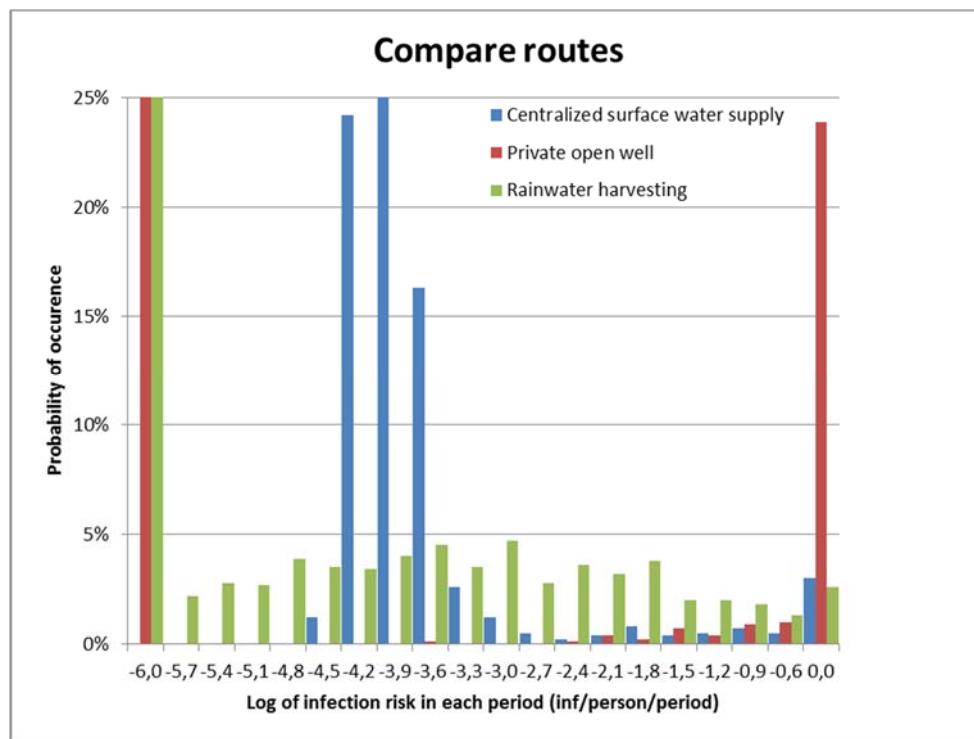
Compound	IS 10500: 2012 (mg/L) (max <sup>6</sup> )	>standard India	WHO standard (mg/L)	Goal	Health effect (DALY)	Source	Occurrence
<b>Chemical</b>							Groundwater
Fluoride	1.0 (1.5)	1.9%	1.5	Health, fluorosis	2·10 <sup>-4</sup>	Naturally occurring, industrial pollution	Groundwater
Arsenic	0.01 (0.05)	0.1%	0.01	Health, toxic	6·10 <sup>-5</sup>	Naturally occurring, industrial pollution	Groundwater
Iron	0.3	20.5%	none	Acceptability, technical	0	Natural, 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, esp. infants aged<6 months	Unknown	Animal and human waste, inorganic fertilisers	Agricultural areas
Free chlorine <i>Minimum when chlorinated [for viruses]</i>	0.2 (1) [0.5]	ND	5 mg/L	Health: protects microbial quality in distribution	Unknown	Disinfection with chlorine	Tap water
Pesticides <sup>2</sup>	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, industry, consumer products. Release from taps	Tap water
Zinc	5 (15)	Unknown	none	Acceptability	0	Natural 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	$3.2 \cdot 10^{-5}$	Plumbing and solder, industrial pollution	Tap water
<b>Microbial</b>							
<i>E. coli</i> / FC	<1/100 ml	4.7%	<1	Health, microbial	$>1.6 \cdot 10^{-4}$	Waste water, faeces	Surface water, unprotected groundwater
<i>S. typhi</i>	ND	500/100,000 <sup>3</sup>		Health, microbial	$1.1 \cdot 10^{-3}$	Waste water, faeces	
<i>Vibrio cholerae</i> <sup>1</sup>	ND	2680/y		Health, microbial	$2.5 \cdot 10^{-4}$	Waste water, faeces	
Acute diarrhoea <sup>7</sup>	ND	11 million cases/y		Health, microbial	$56.4 \cdot 10^{-5}$	Waste water, faeces	
Enterovirus	'Free from'	Unknown		Health, microbial	0.48 /case	Waste water, faeces	
<i>Cryptosporidium</i>	<1/10 l	Unknown	<sup>4</sup> <1/10 <sup>5</sup>	Health, microbial	$1.5 \cdot 10^{-3}$ /case	Waste water, faeces	
<i>Giardia</i>	<1/10 l	Unknown		Health, microbial	Unknown	Waste water, faeces	

<sup>1</sup> Kanungo et al. 2006<sup>2</sup> Abhilash and Singh 2009<sup>3</sup> Ochiai et al. 2008, Aarogya 2014<sup>4</sup> WHO does not set a standard for *Cryptosporidium*, however a  $1.3 \cdot 10^{-5}$  concentration corresponds to a  $10^{-6}$  DALY target in the example Table 7.4 (WHO 2011)<sup>5</sup> estimated assuming  $7 \cdot 10^{-3}$  DALY per case of diarrhoea based on WHO 2011, Table 7.4<sup>6</sup> IS 10500:2012 allows relaxation of some standards in the absence of an alternative source<sup>7</sup> Havelaar and Melse 2003

In the Thirthahalli pilot focus is on the effect of fiber filtration for removal of particles and pathogenic protozoa like *Cryptosporidium* and *Giardia*. These pathogens are expected to be present in river water and are highly resistant to chlorine disinfection. The performance of particle removal is also assessed by continuous on-line monitoring of turbidity and challenge testing of particle removal. The Belgaum pilot focussed on removal of high iron content and turbidity by sample analysis on site and on detection of faecal contamination of well water. Assessment of barrier efficacy consisted of monthly membrane integrity tests and on-line UV intensity monitoring.

As microbial risks result in the most significant health effect, and microbial monitoring is the most challenging, extra focus was put on interpretation of microbial monitoring data. The obtained knowledge about microbial treats was combined with the efficacy of treatment and the behaviour of people in rural India with respect to drinking water sources and use, and translated into a multi-route quantitative microbial risk assessment (QMRA). We estimated pathogen densities in source water and effect of treatment based on literature and databases. Contamination of drinking water during distribution and storage was estimated for scenarios. The QMRA model estimates the exposure to various pathogens and combines that with dose-response models to estimate the risk of infection. The contribution of each route to the total risk is then evaluated.



**Figure 7. Probability of infection from the three exposure routes assessed with multi-route QMRA for the Shimoga case study**

The behaviour of the rural Indian communities affects their water safety and varies per region and also within a community there are great differences between individuals caused by economic and social status, religious motivation, level of education and perception of vulnerability. The introduction of centralised, intermittent supply through multiple village schemes using a surface water source provides little safety. The condition and operation of these treatments as observed seems inadequate to provide safe water to consumers and the lack of hydraulic integrity of distribution systems and the need for secondary transport and home storage are likely to result in contamination. The lack of reliable microbial water quality data in India, especially on pathogens, is a main cause of uncertainty in the risk assessment.

## CONCLUSIONS

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, NRD PW, 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.

Current monitoring in India is focussed on compliance monitoring. Implementation of a logical and systematic reporting and communication structure for water quality data is needed so that results reach the person that needs to act on them or make decisions. This issue cannot be resolved by the monitoring technique itself and needs organisational changes.

Technical, logistic and administrative issues and lack of knowledge and capacities make adequate monitoring challenging in rural India. We achieved knowledge exchange and capacity building through working with the Bhavan laboratory for *Cryptosporidium* and *Giardia* analysis and introduced continuous large volume sampling and innovative challenge testing using fluorescent beads in the field.

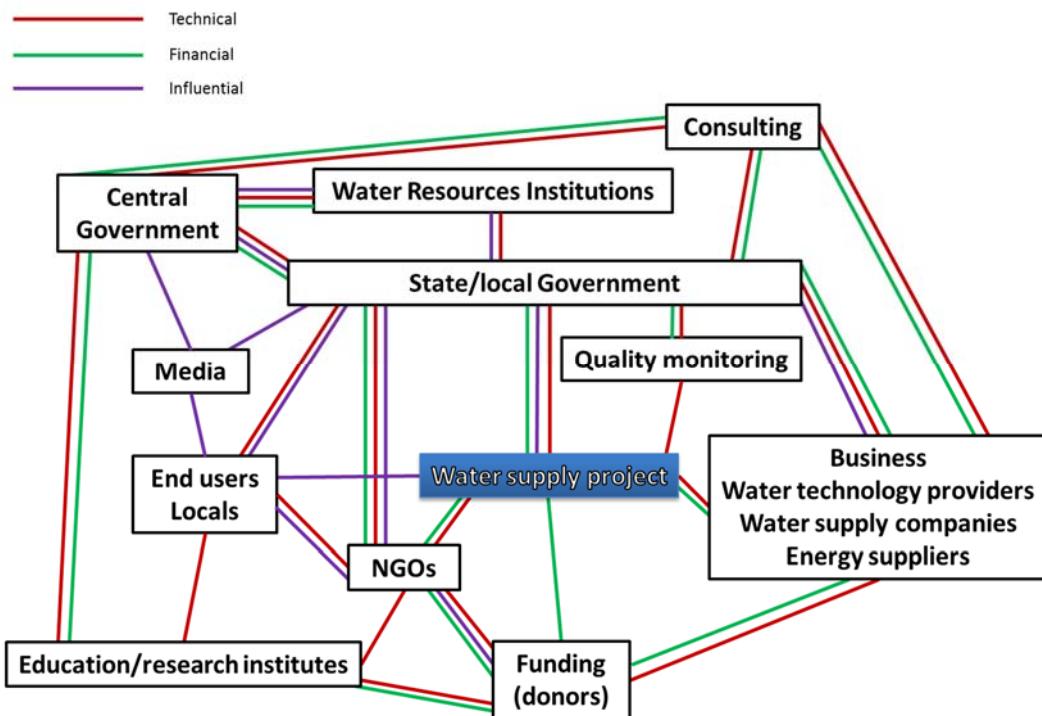
The water supply situation in rural India is complex and vulnerable. Only introducing centralised drinking water supply through multi-village schemes won't significantly improve health in many cases due to the variation of sources people use. The multi-route QMRA provides quantitative insight in the most relevant health risk. It also highlights the need for better data, especially on pathogen concentrations in contamination sources, to assess risk and support effective and efficient risk management. This is a starting point to discuss the risk based approach with Indian stakeholders and identify potential applications for QMRA in India such as prioritisation of risk reduction measures.

## WP5: Social, environmental and economical implication of Water4India

The overall aim of this activity is to ensure that the technologies that will be developed by Water4India are capable of being socially and economically adopted by intended user groups. This WP will be developed in the regional area selected in WP2, with the collaboration of local stakeholders. Specific objectives are to:

- Assess whether the technologies developed by Water4India will be accepted by the communities using them.
- Identify stakeholders in the technology and related services value chain and characterize affordability.
- Identify the social and economic constraints to widespread and long term technology adoption and develop recommendations on how these might be overcome.
- Develop recommendations on how the technologies should be introduced and scaled up within India.

The initial task for the work package was to identify the relevant stakeholders involved in the water sector in India. For water projects to be successful in the long term, it is important that social and environmental considerations form an integral part of decision making and this must happen through appropriate engagement with stakeholders across the water sector, from end users to technical decision makers and financing bodies. Stakeholder engagement not only ensures projects are appropriate for their situation through acquiring local knowledge, but also that the projects will be sustainable, by involving interested groups as part of the process and thereby enabling stakeholders to take ownership of a project and feel more invested in its success. This work package began by identifying and analysing stakeholders acting in, and influencing, the water and sanitation sectors, with a specific focus on the drinking water sector within Karnataka state Figure 8.

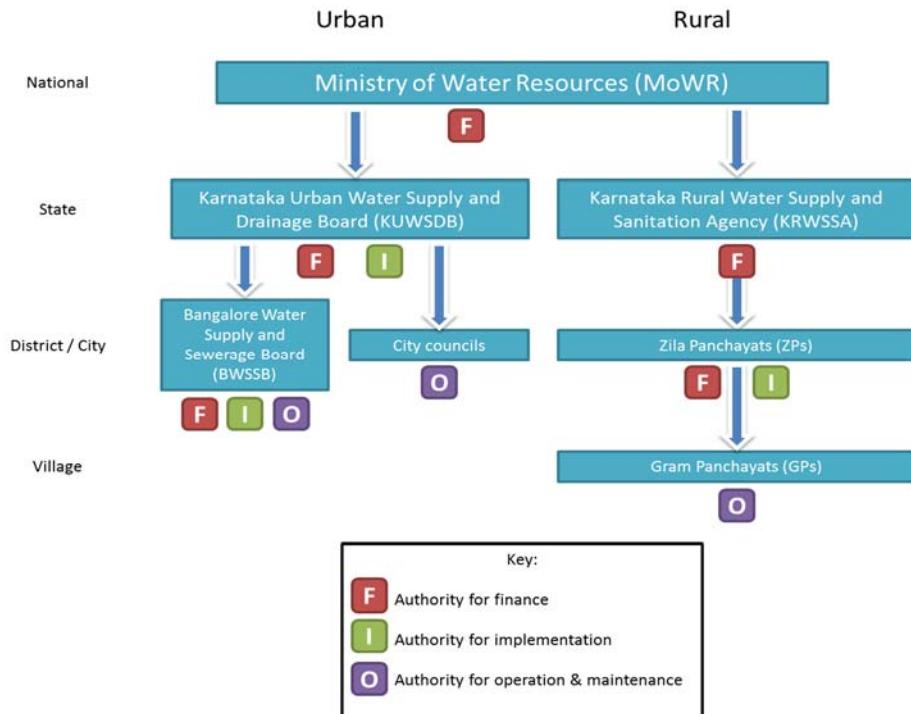


**Figure 8. Stakeholder relation map for Indian water supply projects**

The stakeholder analysis exercise revealed that local- and state-level government are the pivotal stakeholders involved in water supply projects in India. They interact with many other stakeholders, channeling finances and policies from national government and water resource institutions into local contexts, and are directly responsible for the majority of the water supply project, from conception through to financing and collecting water quality monitoring data for ongoing projects. Through setting state level water plans and priorities, they can also set the agenda for new water supply projects that business and NGOs need to react to in order to secure governmental financing for projects, whilst also having to adhere to any national standards, whilst also having direct contact with end users and locals in the area of the projects. These various connections make the state and local government a key stakeholder for water supply projects. In addition, the local and state government act as a point of contact for many of the other stakeholders, which puts them in a unique position of holding knowledge, experience, and data relating to water supply projects. The data and capacity they hold may be of huge import to learning lessons and identifying future direction, and so strong contact with this stakeholder group, and utilization of these resources, would have high value and should be explored by any groups wishing to work within the Indian water supply sector.

However, it must also be noted that local and state governmental structures can vary across the 29 states of India, with different roles and responsibilities assigned at different levels, accordingly. Therefore, knowledge of the particular structure and operation of the relevant state which projects are being planned must be acquired. For Water4India, and organogram

was compiled relating to Karnataka state, where both pilot projects were implemented (Figure 9).



**Figure 9. Organogram of decision and financial flows within Indian water supply projects**

In addition to the stakeholder analysis, a literature review was conducted to gain knowledge of the background data of economic and social aspects relating to Indian drinking water management, to provide further context ahead of the fieldwork conducted for the work package. The review cover the national water situation in India, in general, as well as a focus on Karnataka state, which was selected for the pilots of the Water4India project.

India as a whole is facing a water scarcity challenge caused by decreasing water supplies and increasing demand, a trend which is also evident within the state of Karnataka. The widening gap leaves a large portion of the water demand unmet, leading to severe water shortages because of: depleting and over exploitation of available resources; sectorial competition over water; and large water system losses, while wastewater is uncollected and / or untreated. At present, around 50% of the population is still relying on unimproved sources of drinking water and the population is exposed to high risk of contamination by both geo-genic chemical and anthropogenic pollutants. The population and the rural communities in particular are at high risk for water borne diseases from ingestion of arsenic, fluoride and other bacterial contaminants through drinking water.

The Government of India, and Karnataka state, have a clear vision and policy to state-wide improvement of the population access to safe drinking water and improved sanitation services. A new State Water Policy was drafted in line with approved action plans to support the requirement for integrated planning of water resources across various users, envisaging a sustainable and orderly process of industrialization and urbanization and urban water

management for poverty reduction and sustained human development. The intention is to improve water use efficiency in all the economic sectors to increase availability and in parallel to increase the investment in water infrastructure and technical capacity building. However, the responsibilities for water supply should be streamlined to improve coordination between the various stakeholders, involving legislative, administrative agencies, government and nongovernmental groups, local government institutions, and the private sector. Improved coordination will ensure multi-sectorial water planning, water allocation, development programs and management decisions.

The right for access to adequate safe drinking water should of course be respected, although the pervading perception within India that water is a public good, which therefore should be supplied free of charge, needs to be addressed as it is a handicap for adequate and sustainable water supply. Levies and charges need to be imposed to support the proper operation and maintenance of water supply infrastructure, as well as to avoid water wastage. In addition to the economic value, the social value of water should not be overlooked and should be considered when a new drinking water system is to be implemented. The transition from subsidized prices to a new rate of payment should be gradual and there should be a safety net for the poor communities. Access to safe water to the poorest members of the community should be ensured to meet the minimum service level through government and/or cross subsidy.

Social acceptance is a critical element in the selection and recommendation of new water treatment technologies. Technology acceptance by the community provides the basis for local participation and self-management of water supply schemes, as well as increased cost recovery through improving end-user willingness to pay. Consideration of local cultures and tradition of individually targeted communities needs to be considered in the design process, to ensure acceptance of the proposed technology. Embedding local culture, values, and language would help to interact with the community in selecting a certain technology in which they have confidence. Point-of use, decentralized and centralized systems shall be weighed against risk, culture, and threat factors, considering prohibiting and excessive costs which would pose a real barrier to adoption of alternative and preferable solutions. Especially the limited income of the rural population that works against the ability of rural households to adopt a sound alternative water system should be considered.

Once the background information, through the stakeholder analysis and literature review, had been collected, key informant interviews were conducted with experts on the India water sector, to provide recommendations to the technology providers on the perception of drinking water technologies. Respondents were selected for having many years' experience of the Indian water sector, but came from diverse backgrounds – many were Indian nationals, but some were ex-patriate workers in order to provide a different perspective. The respondents came from varied stakeholder groups, such as government, private industry, non-governmental organisations and academia.

A number of key conclusions were drawn from the survey results. There was a general perception from the key informants that current water facilities are ageing, and may pose some health risk to the population, although many communities appear satisfied with their

drinking water facilities. Complaints had been heard from the key informants regarding water supply issues, most commonly regarding water quantity and reliability of supply. The majority of respondents suggested that communities in which they had experience were satisfied with the current price they are paying for water, but the price did not reflect its true cost, with water often heavily subsidised, or in many rural areas provided without charge. Respondents felt that Indian communities would be happy to accept new technologies, but it was noted that decisions are made by state-wide water departments without community participation. There may be more resistance to the adoption of new technologies by these governmental departments. The cost of new systems was seen as a potential barrier, and full cost recovery would likely require increase water tariffs, higher than likely to be acceptable to communities (Figure 10, Table 2)Table 1.



**Figure 10. Response by key informant to the question „Do you think the community is willing to accept and willing to pay for the implementation of new drinking water facilities?“**

**Table 2. Responses to the question “If the community is not willing to accept or willing to pay the implementation of new drinking water facilities, why?”**

If the community is not willing to accept or willing to pay the implementation of new drinking water facilities, why?
Very poor communities and the perception that water is a free commodity and it is the government's responsibility to provide for this.
Yes, again it depends on economic status of the community.
The community would be willing to accept new technologies but they would not be willing to pay for them.
New technologies are feasible and the community is willing to accept them, as long as they do not depend on electricity and as long as they do not harm the environment.
Implementation costs are massive and bulky. Communities may contribute about 10% at max under the guidelines and even then this is rarely paid by communities but rather by the contractors who will do the work. As I understand it, Gol through the new NRDWP is actually moving away from community contribution for any CapEx - or at least not specifying this as a condition of new project as it had done in the Swajaldhara programme, which preceded it.
The community is willing to accept new drinking water facilities, but they will have to be convinced and educated on the savings that can be made (in terms of electricity of water) through the 24/7 supply, to accept the higher charges through metered water service (which are necessary for cost recovery).
Because coping costs are far too high in India.

Yes.
<i>There were two 'no responses'</i>

The final task of Work Package 5 was to provide recommendations on technology marketing and scale-up strategy, for the Indian water treatment technology market in general and using the piloted technologies within the Water4India project as examples. At the conclusion of the project, this report summarised the key findings of the technological and socio-economic surveys conducted on two pilot trials – one centralized system and one decentralized – and used those findings as the basis for framing a scale-up approach which could enable those technologies trialled, as well as other water treatment technologies, to successfully be implemented at scale within India.

The recommendations frame the lessons learnt from studying the Indian water sector, and specifically the case study pilot trials, into a SWOT analysis – first, providing an assessment of the opportunities and threats within the Indian water treatment sector, and secondly identifying strengths and weaknesses of the centralized and de-centralized technologies trialled, both from a technological and socio-technical aspect.

Grey and academic literature regarding scale-up strategies, with a focus on technological implementation and scale-up, were reviewed and summarised as a basis for recommending scale-up strategy with associated marketing – these again are contextualised to the water treatment technology market in India.

The findings conclude that there may well be certain specificities with respect to the different models of technology trialled in the project – the de-centralized ‘off-grid’ system and the centralized system – but there are also fundamental lessons and approaches that will be applicable to both. These are summarized in six key recommendations made at the end of the report, which should be followed to ensure successful scale-up of the technologies:

- i. Recognise that scale-up is about more than just technology
- ii. Establish and continue a learning culture
- iii. Remember the five qualities for innovation success
- iv. Develop a clear strategy for scale-up
- v. Identify market entry points to minimize risk
- vi. Develop strategic partnerships

In addition, a scale-up plan is recommended which can be followed to ensure that preparation for scale-up is comprehensive.

## WP6: Decision Support System Development

### BACKGROUND

Currently, there is an insufficient number of water treatment plants in operation in India and many of these are close to maximum capacity or falling into disrepair due to poor management (Nelson, 2008). With over 85% of India dependant on groundwater, it is vital that the water resource is managed sustainably (Taherzadeh and West, 2016). Improvement in both quantity and quality of water treatment systems are necessary. It is equally important to ensure that decentralised systems and centralised water treatment systems are used in collaboration to maximise the efficiency of the existing infrastructure. Due to the availability of a wide range of treatment technology to deliver different stages and levels of the treatment, it is difficult to find the optimal and most efficient treatment train. A myriad of factors can affect how successful a treatment plant/technology can be, and if these factors are ignored, the treatment plant/technology can become a wasted resource. Additionally, efforts are required to manage the increasing water demand and promote water efficiency.

Utilising decision support systems (DSSs) can help decision makers select the optimal technologies in different situations (i.e. to treat water and reduce consumption). To this end, WP6 was aimed to develop a number of novel decision support tools and methodologies.

### METHODOLOGY AND RESULTS

This work package was aimed at developing the following tools and methods:

- 1) **DoWET**: Domestic Water Efficiency Tool (DoWET) is a technology optioneering spreadsheet based tool to optimise and prioritize water efficiency options and evaluate their overall sustainability.
  - a) **Development of DoWET**: This required development and integration of the following elements:
    - i) **User-interface**: DoWET was developed with MS Excel 2013. The developers designed the user interface in a way that anyone with basic knowledge of using Microsoft Excel be able to work with DoWET. In the user interface, the user can input information, for example, on water user behaviour (i.e. frequency and duration of use of water using devices), hot and cold water split, required water efficiency, available budget and preference for alternative supplies (e.g. treated greywater or rainwater use).
    - ii) **Technology library**: This includes information on a range of India specific micro-components of water demand (water using activities/appliances/fixtures). Figure 11Figure 11 shows the water demand management options used in the technology library and subsequently in DoWET. The library includes information on about 300 micro-components of 8 types. The technology library contains information on the water saving potential and cost of each micro-component type.
    - iii) **Database on water use habits**: A survey on domestic water consumption was conducted in Jaipur, India. The main aim of the survey was to collect information on households' characteristics (e.g. family size, household type, number of children

and their schooling), indoor and outdoor water use activities and their respective frequencies and durations. Information was also gathered on the volume of water used in each of these activities. The survey's results were analysed by cluster analysis and ANOVA test. The survey results were used as an input to DoWET.

- iv) **Optimisation engine:** DoWET uses GANetXL for optimising the water saving options to identify technologies composites with higher sustainability. GANetXL is an add-in for Microsoft Excel that supplements the possibility of use of genetic algorithms to solve various problems with many alternatives and constraints (Savic et al. 2011).

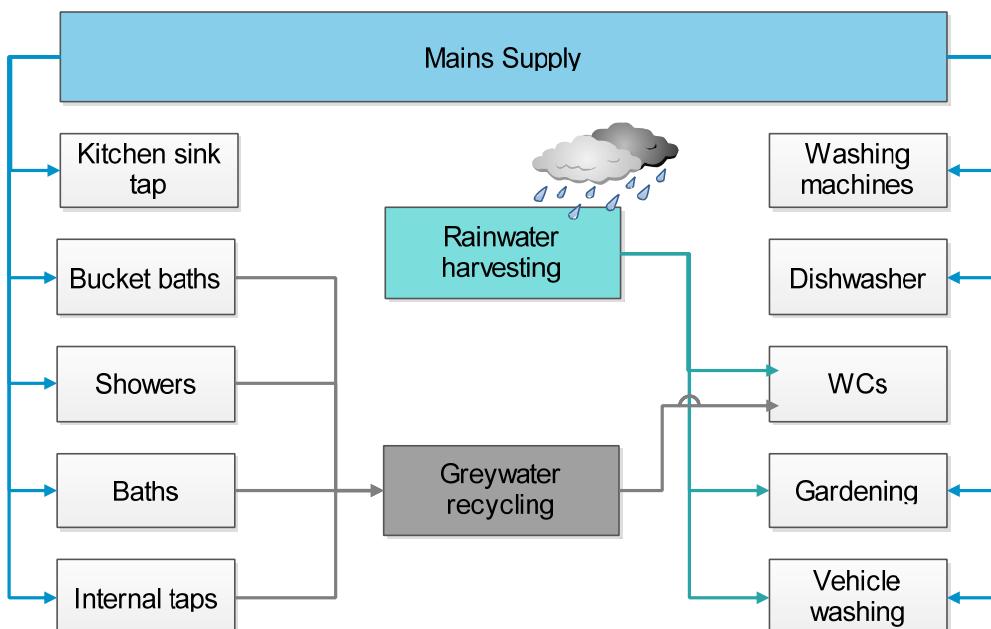
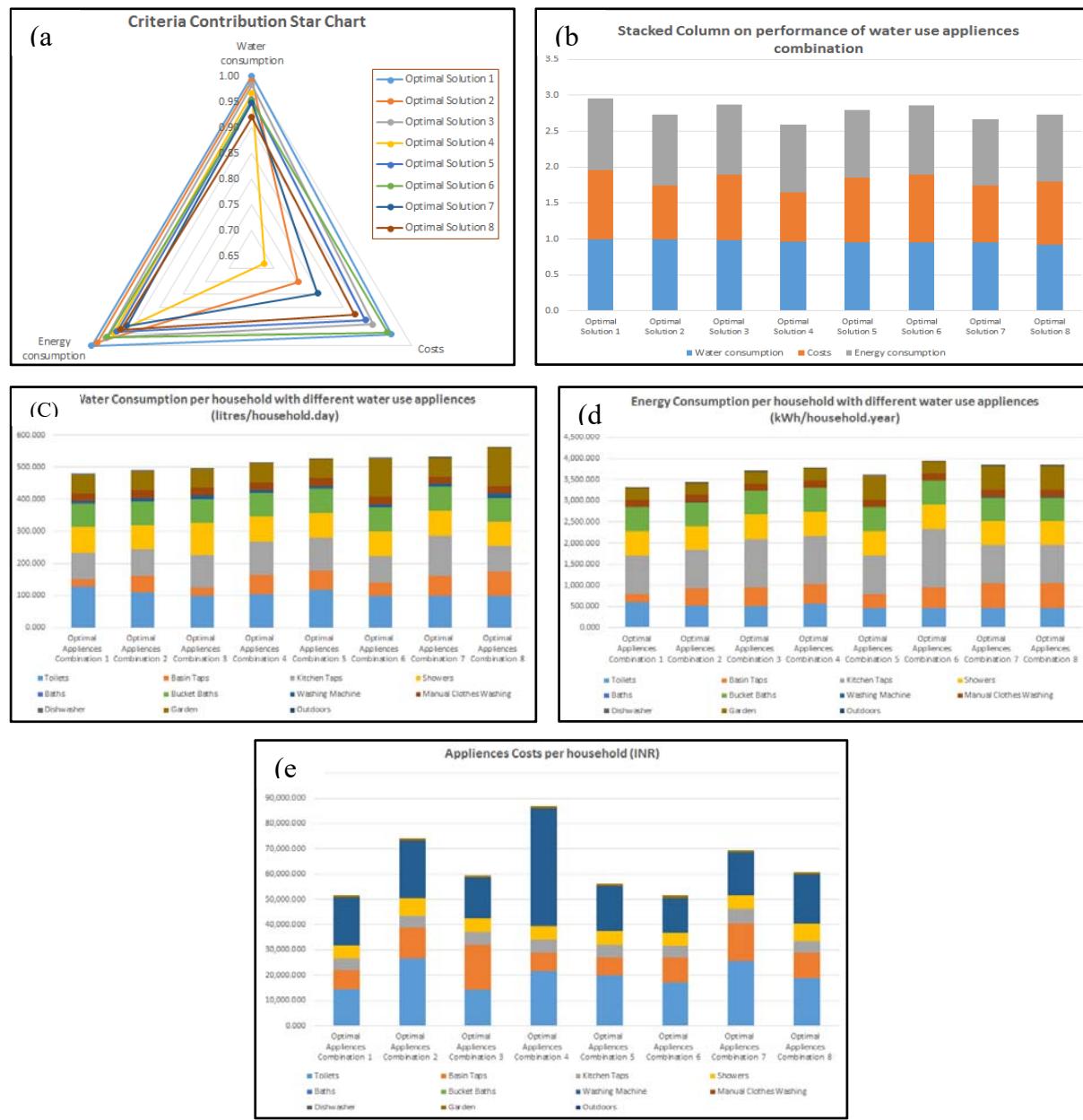


Figure 11. Possible WDM in household level (Sadr and Memon, 2016)

- a) **Application of DoWET:** DoWET was tested by running several theoretical scenarios of water demand management in different areas in India. The aim was to assess the impact of water savings, at household level, of different composite strategies (i.e. different types and combinations of water use/saving devices and alternative water supply systems) and associated energy use and cost implications.
- b) Table 3 shows the assumption made for each scenario. It also shows that which parameters are considered as variables in each scenario. The results showed that different degrees of water savings were achieved pertaining to the scenario being modelled. The cost-effectiveness and energy use also varied significantly, depending on the case study and the scenario modelled. Figure 12 shows the results in Scenario 1 (impact of house density on domestic water consumption).

**Table 3. Assumptions made for water efficiency scenarios (Sadr and Memon, 2016)**

ID		1a	1b	2a	2b	3a	3b
Scenario		House in areas with low density in Jaipur	House in areas with high density in Jaipur	House with high population (>6) in Jaipur	House with low population (≤3) in Jaipur	House in area with cold climate in Darjeeling	House in area with hot climate in Ahmadabad
Number of appliances	Toilet	2	2	2	2	2	2
	Internal taps	2	2	2	2	2	2
	Kitchen tap	1	1	1	1	1	1
	Shower	1	1	1	1	1	1
	Bath	0	0	0	0	0	0
	Washing machine	1	1	1	1	1	1
	Dishwasher	0	0	0	0	0	0
	Gardening	1	0	1	1	0	1
	Vehicle washing	Yes	No	Yes	Yes	Yes	Yes
Household type		Stand-alone	Flat	Stand-alone	Stand-alone	Stand-alone	Stand-alone
Occupancy		5	5	7	3	5	5
Desired water consumption (l/p.d)		110	110	110	110	110	110
Roof area (m <sup>2</sup> )		200	50	200	200	200	200
Cold water temperature (mains)		15	15	15	15	5	20
Annual rainfall (mm/y)		670	670	670	670	3000	800
Longest drought period (d)		90	90	90	90	60	120
Comments		The building with a roof area of 300 m <sup>2</sup> has 6 flats					



**Figure 12. Results on impact of low household density on domestic water consumption (scenario 1a): (a) performance of optimal composite strategies with respective to the objectives, (b) overall performance of optimal composite strategies considering all three objectives, (c) per household water consumption of the best 8 optimal composite strategies with the break-down water consumption of all appliances, (d) per household energy consumption of the best 8 optimal composite strategies with the break-down water consumption of all appliances, (e) per household costs of the best 8 optimal composite strategies with the break-down water consumption of all appliances (Sadr and Memon, 2016).**

2) **WETSUiT**: WatEr Treatment decision SUpport software Tool (WETSUiT) is a water purification technology selection tool which is able to identify optimal treatment trains and small scale packaged treatment systems.

- a) **Development of WETSUiT**: This comprises the following interconnected components:
  - i) **Graphical user interface**: This was built using Rad Studio C++ Developer and facilitates the processing of the user defined context information for which water treatment is required (e.g. system scale, raw water source and quality, budget and availability level of skills and power supply). WETSUiT is a multi-device application which can be run on any MS Windows, Android, and IOS devices. WETSUiT contains a number of pages and tabs including Context definition, Water sources, Criteria/Objective selection, MOO Results, MCA Results, and Technology (solution) performance for contaminants removal. In total, performance was assessed for 10 key water quality parameters.
  - ii) **Technology library**: This contains information on about 30 unit processes and 35 packaged water treatment systems and their sustainability indicators. Both classes of treatment systems are evaluated against similar criteria and indicators. Each technology or unit process occupies one line/row of the table in the databased which includes information on various aspects of the technology under consideration.
  - iii) **Optimisation engine**: This is applied to develop optimal treatment trains using algorithms based on Multi Objective Optimisation (MOO). MOO evaluates the fitness of each solution in relation to an entire population of candidate solutions.
  - iv) **Solution evaluator**: This facilitates evaluations based on both Multi Criteria Analysis (MCA) and MOO, and shows performance for each candidate solution (water treatment technologies) with respect to each of the evaluation criteria. Figure 13 is a flow chart showing how these components are interlinked.
- b) **Application of WETSUiT**: WETSUiT was applied to several theoretical scenarios of water treatment in both urban and rural areas in India. These scenarios were divided into two different categories:
  - i) **Centralised water treatment trains**: Two centralised scenarios (Srirangapatna and Bilikere) underwent the MOO and MCA and 13 evaluation criteria are utilised for these two centralised scenarios. Figure 14 illustrates the results obtained by WETSUiT in Scenario 1 (Srirangapatna).
  - ii) **Decentralised water treatment packages**: Two scenarios have been considered to evaluate decentralised water treatment packages: (1) Selection of decentralised small-scale system for an emergency situation, and (2) The effect of income in an urban household package selection.

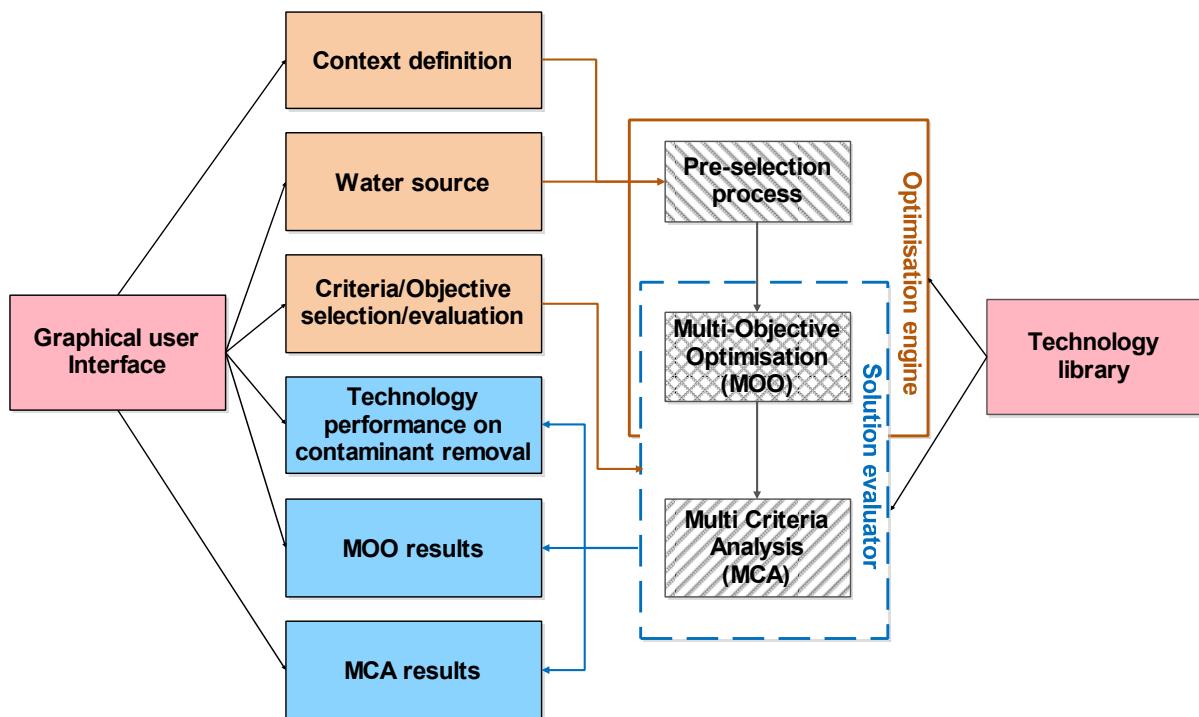


Figure 13. Overview of WETSUIT Structure and main components of this tool (Sadr et al. 2015)

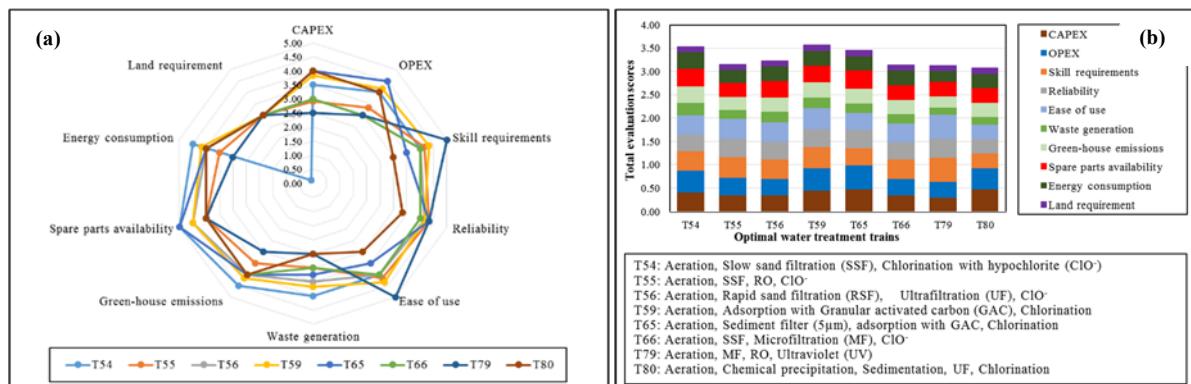
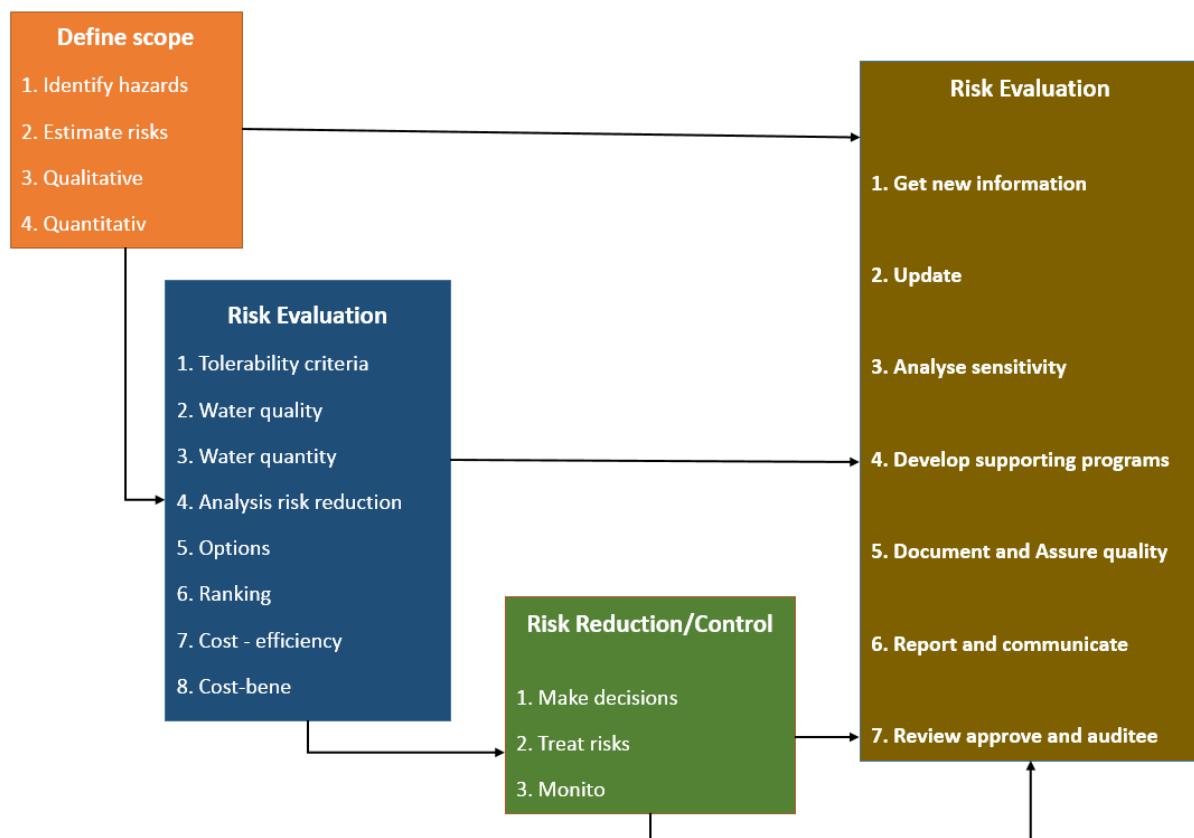


Figure 14. (a) Criteria/objective contribution star chart for water treatment systems in Srirangapatna, (b) Stacked column on performance of water treatment systems in Srirangapatna (Sadr et al. 2015)

- 3) **PRA methodology:** A Probabilistic Risk Assessment (PRA) methodology (Figure 15) was proposed to identify uncertainties associated with input data and mitigate its impact on decision quality for the design and implementation of water management projects. Based on the outcomes of this task, water agencies using PRA can identify potential risks which may impair production, reliability, human health, increase cost, delay process &

production & change customer preferences and expectations. The PRA was developed to cover the following steps:

- Development, construction and application of a prototype PRA model addressing the related uncertainties in water supply, comprising social, environment and technology.
- Incorporation of uncertainty factors as inputs to the prototype PRA where the defined parameters are uncertain.
- Accounting the presence of multiple factors whose competing influences affect the preference of the decision makers.
- Integration of the PRA with a decision tree and Bayesian updating techniques to evaluate the value of additional information for decision making.



**Figure 15. Main components of the generic framework for integrated risk analysis in water safety plans (Shiva, 2015)**

The PRA was also tested on a rehabilitated and expanded water system in Thirthahalli, Karnataka State.

## CONCLUSIONS

Work Package 6 was aimed at developing a number of decision support tools and methods. Domestic Water Efficiency Tool (DoWET) was developed and tested by running a number of

scenarios of water demand management in the contexts of India. In order to improve the quality of the tool database, a domestic water consumption survey was carried out in Jaipur. It was concluded that although changing water use habits of any city dwellers seems to be a long and complex process, it would substantially reduce the household water consumption. In addition to that, several water saving devices/micro-components can be adopted in households to improve the domestic water efficiency.

The prime focus of this work package was on the development of WETSUiT, which uses both Multi-Objective Optimisation (MOO) and Multi-Criteria Analysis (MCA) for the optimal selection of treatment solutions. The tool was tested using a number of scenarios with a view to demonstrate the computational functionalities and various features the tool offers. The reliability of the solutions generated by the tool is very much depended on the input data quality in the technology library.

The final focus of WP6 was on the development and implementation of Probabilistic Risk Assessment (PRA) methodology. The key finding of this focus is that the PRA application can support the identification and characterisation of potential risks which may impair human health, increase cost, delay process and production and change customer preferences and expectations.

## WP7: Technological deployment and validation of the selected solutions in India

### BACKGROUND

Work Package 7 aimed at demonstration and comprehensive validation of the developed set of solutions in selected communities with potential for transferability to other locations in India. The proof of concept included the application of the frameworks and Decision Support System (DSS) and the implementation of proposed technical solutions in selected sites facing different water challenge situations. The Water4India Project had chosen the state of Karnataka since it features many water supply challenges typical in India. These include source water quality and quantity, unstable and irregular supply of water and energy, low percentage of piped water supply, and large distance to public water tap. Water4India focused in particular on improved water quality since it has become a major issue in many parts of India. In the Water4India case study region Karnataka state, the drinking water supply of most urban local bodies (200 out of 213 cities and towns) base on surface water which is treated in centralized water treatment plants. It is likely, that the conventional treatment process in these plants, i.e. coagulation-sedimentation-sand filtration and chlorination cannot efficiently remove the contaminants of concerns, i.e. *Cryptosporidium*, *Giardia*, heavy metals or pesticides. Moreover, with the ever-increasing migration to cities, the construction of centralized water treatment and supply infrastructure can hardly keep pace resulting in intermittent water supply of a few hours a day and leaving around 20% of urban households without piped water connection. Usually, at the outskirts of the cities as well as in rural areas people continue to rely on groundwater sources from bore wells or open wells. Almost 40% of households in Karnataka state use groundwater sources showing excessive concentrations of fluoride, arsenic, iron, nitrate and salinity and often the only countermeasure is to close the affected wells.

The overall aim of the Water4India project was to find cost-effective water treatment and monitoring solutions to contribute to a solution for the critical Indian water situation. Two typical cases for small scale water supply were selected: a small town in rural Karnataka with a population of 15 000 inhabitants and an informal settlement in Belgavi district with a population of about 600 people.

### METHODOLOGY AND RESULTS

**Decision Support System validation:** Based on the results from WPs 2 to 6, the developed DSS was applied in order to identify the most suitable solution based on site specific characteristics and main water challenges of the selected communities.

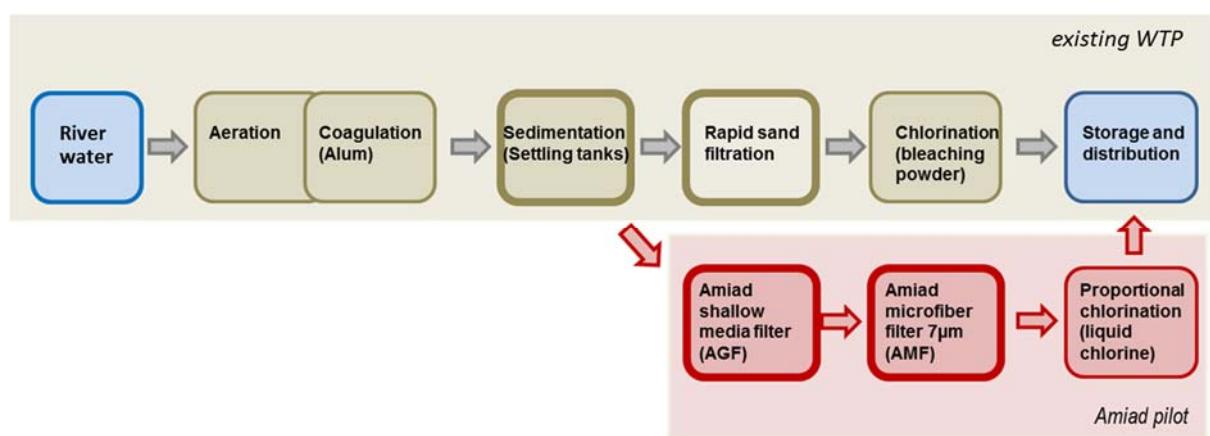
Case study 1: Like many of Karnataka's cities and towns, the water supply scheme of the case study town bases on surface water from a perennial river treated in a conventional water treatment plant with the following treatment train: aeration – coagulation with alum – sedimentation rapid sand filtration – chlorination with bleaching powder – storage and distribution. The treatment plant dates back to the 1950s with extensions in the 1990s and

2010s. Major treatment challenges arise from the highly variable raw water quality in particular high turbidity reaching values above 100 NTU during monsoon season. High turbidity water and disproportional dosing of alum and chlorine are considered as major limiting parameters in the existing treatment process. The existing water treatment plant lacks a proper dosage and control system as well as monitoring of the plant performance. The operators receive no feedback from the analytical results produced in the central district lab - a situation often encountered in small water treatment plants.

Case study 2: The second case looks into supply of drinking water to a settlement which does not have public water supply. The Kanbargi settlement located at the outskirts of Belagavi City Corporation in Northern Karnataka. Groundwater was identified as the available local water source. Since supply of electricity is also unreliable the water treatment plant should run off-grid.

**Technical concepts and implementation:** Based on the aforementioned assessments the technical solutions were tailor made to improve the respective water treatment and supply situation most efficiently.

Case study 1: In June 2015 at the beginning of monsoon, a microfiber filtration system (Amiad Water Systems) was integrated into the centralized water treatment plant to replace the rapid sand filtration. The AMIAD system was designed with the treatment objectives to remove turbidity and total suspended solids to improve consumers' acceptability and to achieve a 3-5 log removal of pathogenic microorganisms like Cryptosporidium, Giardia or helminths as well as smaller pathogens like bacteria and viruses. The intake water comes from the sedimentation pond at 90 m<sup>3</sup>/h and the pilot is composed of low bed media filters (pre-filtration unit) followed by a fine filtration unit with 7 µm AMF 370K filter and proportional disinfection with liquid chlorine.

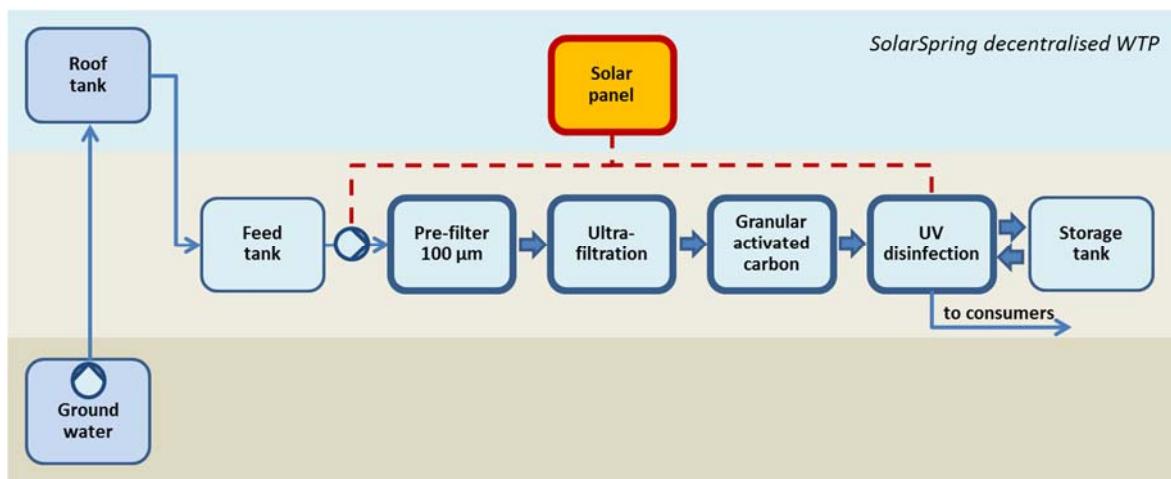


**Figure 16. Treatment train for upgradation of the existing conventional water treatment plant case study 1**

Case study 2: A solar-driven ultrafiltration water treatment plant (SolarSpring GmbH), as a decentralized stand-alone treatment concept, has been installed during October 2015 in an orphanage at the outskirts of Belagavi ('Belgaum') City Cooperation, Belagavi District, Karnataka. The water is distributed to the orphanage (60 children), to a nearby governmental

primary school (400 students) and further serves also as water supply to the near-by Kanbargi informal settlement (currently around 600 persons). For their supply the treated groundwater is filled into 20 L containers and provided to the community at a price of 1 INR/L ('water kiosk' concept). The water treatment plant has a capacity of 1'200 L/hour.

The SolarSpring treatment plant receives the raw water from an aquifer about 40 m below ground, which is pumped up to a roof tank and from there conveyed to the feed tank by gravity. The treatment train features a multi-barrier system consisting of a Multibore UF hollow fibre membrane unit followed by a GAC filter and an UV disinfection unit. The concept provides a safe barrier to pathogens down to the size of viruses (LRV = 4-5) and safe removal of adsorbable compounds such as trace organics. Chlorine-free disinfection is applied to achieve high consumer acceptance. A big advantage of the treatment scheme is its independency of electrical infrastructure which makes it implementable in many remote locations where power supply is erratic, or accessibility to grid is complex and expensive.



**Figure 17. Treatment train of the solar powered decentralised water treatment plant case study 2**

**Monitoring concept:** Both pilot systems are equipped with high end monitoring analysers and on-line monitoring systems which ensures a constant performance evaluation of physical, chemical and operational system parameters. Both systems allowed wireless remote control and monitoring via e.g. GPRS communication.

In the Amiad pilot unit (case study 1) the following parameters were measured online: Turbidity of influent (after settling tanks) and turbidity after microfiber filtration (care is needed not to include fine air bubbles), pressure at the inlet and outlet (to determine the pressure loss), as well as free chlorine after chlorination, temperature, and flow rates. Additionally, the local operator filled out daily manual monitoring reports of turbidity values. Every third month a visiting operator from Amiad conducted additional performance tests on-site with different testing goals.

The performance and operation of the SolarSpring plant (case study 2) was monitored using several online monitors: Pressure before and after pre-filter and UF, flow rates, and transmission at the UV reactor (disinfection performance). The status and operation of the plant was continuously logged and the data transmitted. Regular storage on a micro SD card

served as back-up. Systematic microbiological analyses were undertaken for the feed and product water in local laboratories to ensure the supply of safe drinking water. Additionally, H2S-tests on-site were applied for monitoring of *E. coli*.

**Performance evaluation:** The Amiad pilot unit was able to produce very stably drinking water quality keeping turbidity mostly below than 1 NTU despite extremely variable raw water conditions through the year with raw water turbidity exceeding 200 NTU during monsoon. After almost one year of continued operation, filter condition was good with no malfunction, leaks or breakage observed. The Amiad pilot outperformed the existing rapid sand filtration where turbidity values up to 22 NTU were measured while the maximum turbidity in the product water of the Amiad pilot was 1.8 NTU (detected on one day). Further optimisation of the system performance would have been possible through improved alum dosage which was not part of the piloting. Parallel onsite tests revealed that safe removal of protozoic oocysts (*Giardia* and *Cryptosporidium*) can be achieved through installation of a 3-µm thread filter instead of the 7-µm type used in the pilot. Overall the Amiad pilot was able to safeguard compliance with the Indian DW standards.

The SolarSpring water treatment plant has operated stably after some delay with the start-up. The water analyses (including 13 chemical parameters and 2 microbiological parameters) carried out in external labs during the piloting confirmed full compliance with the IS 10500 along the measured parameters. Due to the good groundwater quality the UF-system had only minor effect on turbidity. Chemical water parameters were already in the raw water not critical. For the microbiological quality, most of the water analyses from the employed commercial labs have shown that there was neither a contamination in the raw water nor a contamination in the product water. However, manual tests onsite showed contamination with coliforms in the feed which were removed by the UF system. Overall finding a reliable lab proved to be very challenging.



**Figure 18. (Left) Purified water from the SSP UF plant vs. water from slum tap. (Right) people collecting water from the SolarSpring UF plant**

**Socio-economic aspects:** The study used an inductive mixed-methods approach, including observation, quantitative surveys and qualitative surveys, to investigate the acceptability of the treatment systems and their product water to the end-user beneficiaries, and to determine the sustainability of the required O&M tasks on the local staff responsible for the systems. In Belgavi, four surveys were conducted amongst various stakeholders in the water supply system to the study site. In small town of case study 1, a survey relating to ease of operation and maintenance tasks was conducted with the operator of the Amiad system.

The studies found there was generally good acceptance of both the new technologies introduced and the water they produced. Beneficiaries demonstrated a preference for the new treated water over their current water sources, and in the case of Kanbargi settlement, Belgavi, indicated a willingness to pay for the treated water even though a free public supply was available close to their household. However, risks were identified associated with the distribution systems at both sites, which threaten to negate the advantages of the new treatment technologies – both for end-user acceptance, where many beneficiaries consider quantity and reliability of supply to be more important than water quality, and for the quality itself, as recontamination in a distribution system will reduce the effectiveness of the initial treatment.

Regarding the ease of use of the technologies for operation and maintenance tasks, it is recommended an emphasis is placed on appropriate and comprehensive training of the local staff, to ensure as much of these procedures as possible can occur at the local level. Where possible, a group of staff should be trained, so that they can provide support for each other, but also safeguard against staff turnover and the subsequent loss of capacity. A local presence is important for both technical support and supply chain management.

## CONCLUSIONS

- The deployment phase demonstrated successfully the good and robust performance of the selected technologies. The systems were able to produce drinking water compliant with the Indian DW standards.
- The onsite monitoring concepts proved to be an important component of safe water supply since local analytical labs are often not accessible in remote locations and the data reliability is questionable due to several factors.
- The operation of the treatment plant requires dedicated and skilled staff on-site, as even with sophisticated monitoring, broadcasting of the information is challenging. That on top of power outage, which occurred on a daily basis (case study 1), leads to the need of human intervention and manual recording of results.
- Introduction of new technologies necessitates a local supply and maintenance network and counterparts/operators with full commitment to harvest the advantages of improved performance.

It is important for the success of new technologies, both in their adoption in the Indian context and in their effectiveness in improving public health, that they are introduced alongside robust distribution systems. Consumers have concerns over the quality of public water supply and therefore often use home treatment units to polish the already treated water.

## 4 Potential impact, dissemination activities and exploitation of results

### OVERALL IMPACT

Water is an essential resource for life and good health. Access to safe water should be a right and not a privilege but unfortunately 1 in 10 people lack access to safe water<sup>1</sup>, the outlook worsens when considering the rural water systems, a review in eight countries from Africa, South Asia and Central America found an average water project failure rate of 20 – 40 percent<sup>2</sup>.

Particularly in India the situation of drinking water and sanitation is very difficult and great efforts are being made by the central government and the international community to overcome this so worrisome crisis. The aforementioned facts are just a minimum sample of all the findings about safe water shortage that the project obtained through its research activities.

The Water4India project emerges from the necessity to change a water purification system which does not produce enough drinking water in appropriate quality to supply the Indian population. Given this problem, the goal of the project is to find technologies which can be applied to the current circumstances in India in order to improve the conditions, considering available resources to produce fresh drinking water for the population.

### COMMUNITY APPROACH

The consortium agreed at an early stage that the project will test the purification systems in a “rural area” and for that purpose selected two case studies in rural communities in the region of Karnataka: Thirthahalli and Belgaum. Both pilots started to operate in the second semester of 2015. It is worth to highlight that start working in rural India was an important challenge for Water4India from all points of view. Facing cultural differences, being the language one of the biggest barriers, was one of the most difficult obstacles to overpass. However, step by step the consortium was able to adapt itself to the Indian environment.

In terms of social labour it was a very interesting and gratifying experience. Two communities could benefit from the case studies and have access to safe water for free. Furthermore, both communities were able to learn more about healthy habits for safe water access thanks to the dissemination plan of the project in which awareness material for local users/families and school children was developed.

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<sup>1</sup> 1. World Health Organization and UNICEF Joint Monitoring Programme (JMP). (2015) Progress on Drinking Water and Sanitation, 2015 Update and MDG Assessment.

<sup>2</sup> 4. Lockwood and Smits. (2011). Supporting Rural Water Supply. Moving towards a Service Delivery Approach



As social approach, the Belgaum case was particularly of relevance due to the characteristics of the community involved. Working hand in hand with a local NGO (Mahesh Foundation) it was possible to supply water for an Orphanage, a neighbouring school and a neighbouring households.

In general the acceptance form the community was good, if one considers that scepticism and rejection to new technologies do exist.

## **SOCIO-ECONOMIC APPROACH**

From a socio-economic point of view, a greater impact can be achieved thanks to the versatility of the DSS tool and in general to the versatility of all project outputs. From the beginning of the project, the idea of adapting the project results to any other developing countries has been crucial. Important data and analysis of other developing economies have been taken into account in order to expand the horizons of the project beyond India.

DoWET application, WETSUiT and all dissemination materials developed within WP8 can be easily adapted to other regions facing clean drinking water procurement problems.

## **OVERVIEW OF DISSEMINATION**

The project carried out a vast number of dissemination activities to reach as wide an audience as possible and have the maximum impact as possible. This included:

- Participation in and presentation at conferences, workshops, seminars and trade-fairs within Europe and internationally, to make the project visible to the widest audience possible. The following events were attended by the project partners from September 2012:
  - IWA Water Safety Conference, September 2012, Kampala – Uganda
  - 38th WEDC International Conference, July 2015, Loughborough University – UK
  - Water Efficiency Conference 2015, August 2015, Exeter – UK
  - Euromembrane, September 2015, Aachen – Germany
  - 18th International Symposium on Health-Related Water Microbiology, WaterMicro2015, September 2015, Lisbon – Portugal
  - International Conference on Challenges in Environmental Science & Engineering, September 2015, Sidney – Australia
  - IWA Water and Development Congress Exhibition, October 2015, Amman – Jordan
  - IWA Micropol & Ecohazard Conference, November 2015, Singapore
  - 1st International Conference & Exhibition of Chemical Engineering CCE-16, January 2016, Pakistan

- Innovations in Sustainable Water and Wastewater Treatment Systems (ISWATS), April 2016, Pune – India
  - Hannovermesse, April 2016, Hannover – Germany
  - Presentation at Imam Khomeini International (Iranian University), May 2016, Iran
  - Presentation at Chamran University (Iranian University), May 2016, Iran
  - Presentation at Sharif University of Technology (Iranian University), May 2016, Iran
  - The 12th International Conference on Hydroinformatics, August 2016, Incheon - South Korea
  - 13th IWA Specialized Conference on Small Water and Wastewater, September 2016, Athens – Greece
  - 16th Aachener Membran Kolloquium, November 2016, Aachen - Germany
- 
- Release of technical papers and publications by the project partners describing the work and results of the project in targeted journals and conferences:
    - Yehuda Shevah, "**Water scarcity, water reuse, and environmental safety**", Pure and Applied Chemistry, Vol. 86/Issue 7, pp.1205-1214, 2014
    - Heinz Rüdel, Cristina Díaz Muñiz, Hemda Garellick, Nadia G. Kandile, Bradley W. Miller, Leonardo Pantoja Munoz, Willie J. G. M. Peijnenburg, Diane Purchase, Yehuda Shevah, Patrick van Sprang, Martina Vijver, Jos P. M. Vink, "**Consideration of the bioavailability of metal/metalloid species in freshwaters: experiences regarding the implementation of biotic ligand model-based approaches in risk assessment frameworks**", Environmental Science and Pollution Research, Vol. 22/Issue 10, pp. 7405-7421, 2015
    - Seyed Sadr, Fayyaz Memon, Arpit Jain, Shilpa Gulati, Andrew Duncan, Wael Hussein, Dragan Savić, David Butler, "**An Analysis of Domestic Water Consumption in Jaipur, India**", Science Domain International, Vol. 6/Issue 2, pp. 97-115, 2016
    - Benedikt Aumeier, "**Evaluating water purification at household level in India**", Water Science and Technology, in process
    - Benedikt Aumeier, "**Temperature Enhanced Backwash**", Water Research, in process
    - P. Cruddas, S. Linneck, A. Parker, P. Jeffrey, "**Socio-economic factors influencing water source and treatment technology preferences in India**", Water Science and Technology: Water Supply, in process
    - Seyed MK Sadr, Fayyaz A Memon, Dragan Savic, "**Application of Novel Domestic Water Efficiency Tool in India Urban Areas**", Urban Water Journal, in process
    - Seyed MK Sadr, Fayyaz A Memon, Dragan Savic, "**Selection of Drinking Water Treatment Technologies in India by WETSUiT Decision Support System Tool**", Environmental Modelling and Software, In process

- Seyed MK Sadr, Fayyaz A Memon, Dragan Savic, "**WETSUiT: A Novel Approach for Selection of Drinking Water Treatment Technologies in India**", Environmental Modelling and Software, in process
- . Zach-Maor, E. Shpitzer, P. Smeets, L. Breitenmoser, C. Kazner, "**Thread filtration for drinking water production from highly turbid surface water**", Water Research, in process
- Gross, T. et al, "**Assessing impacts of multi-sectoral drivers and pressures on downstream drinking water resources in the Indian Krishna Riverbasin using DPSIR and SWAT**", Science of the Total Environment, in process
- Platter, J. et al, "**Fluoride removal from groundwater using direct contact membrane distillation (DCMD) and vacuum enhanced DCMD (VEDCMD)**", Separation and Purification Technology, in process
- Constant update of the Water4India project website for active and timely presentation of the project results, announcement of forthcoming events, and dissemination. The following dissemination material was prepared and made available for download on the project web-site:
  - Project poster
  - Project presentations
  - Featured events
  - News
  - Publications
  - Public deliverables
  - Water sector related news
- Dissemination through the social networks. In order to make the best diffusion of the results and mission of the project, a Facebook account (<https://www.facebook.com/Water4India-1004520032916006/>) has been constantly updated, with discussions and news on the project development.

## DISSEMINATION MATERIAL

Besides the common dissemination channels, awareness material for stakeholders has been developed in order to spread the Water4India project results. It has been divided into three different interest groups:

- Awareness material for decision makers: "Compendium On Drinking Water Systems and Technologies from Source to Consumer" - within the Water4India project drinking water supply systems in rural and urban India have been assessed and evaluated for their strengths and weaknesses. This document presents parts of these findings in form of a concise and well-structured overview of relevant drinking water systems and technologies in developing countries, particularly India.



The compendium targets local decision makers in India and other developing countries as well as local and international experts, engineers and practitioners. The compendium describes 8 typical drinking water supply schemes given different water sources and water qualities. The system descriptions provide information about all technological steps from source exploitation to household water treatment and storage. Therefore, the water treatment and supply systems are disaggregated in their main components, namely:

- Water source
- Water intake structures
- Water abstraction technologies
- Water treatment technologies
- Means of distribution & storage, and
- User safety (treatment options on household level).

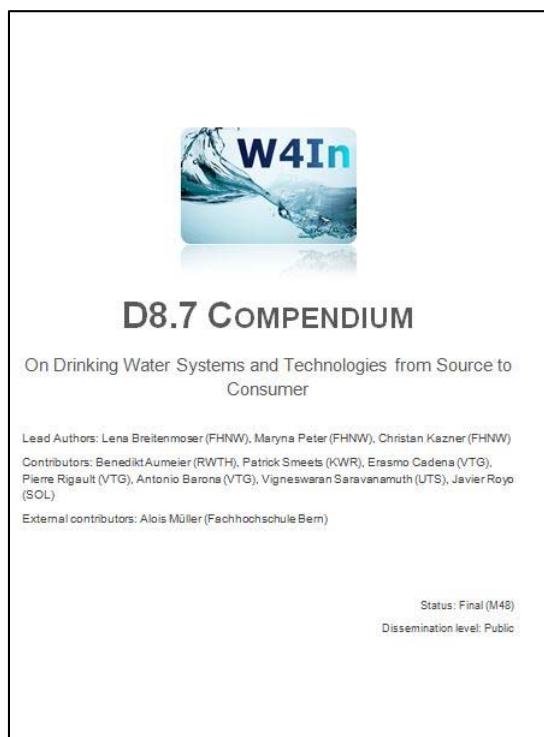


Figure 19. Compendium Cover Page

- Awareness material for local users/families: This material aims to support sustainability of water treatment technologies by improving awareness in local Indian communities. A special focus on the position of women towards water and their important involvement in obtaining the resource has been made. In the objective to reach a maximum of families in the Indian community, the pedagogical materials developed in the frame of the Water4India project have been chosen as follow:

- Three Stories
- One Booklet
- One Activity Booklet
- One Poster



**Figure 20. Poster - summarizing medium**

- Awareness material for education: Deliverable 8.8 is an Educational website material for children awareness tool targeting both India and the EU, has as a main purpose the creation of interactive educational materials for children which will help them understand the importance of hygiene and sanitation. These materials are then published and promoted on the Water4India website (<http://water4india.eu/w4i-e-learning-tool/>). The biggest challenge of this task was to develop educational material in relation with the DSS for above preliminary school students. Therefore, the developed methodology should be sophisticated enough to provide important information, correspondingly should be attractive and interesting to students. Also, contents and teaching strategies must undergo re-purposing, in order to fully exploit the new technologies, adapting to each learner profile. As an initiative, the idea of developing an e-Learning platform seems the most effective. Ensuring usability is one of the main challenges of e-learning systems developers. The following points have been kept in mind when designing the Water4India e-Learning tool:

- To be interactive and provide feedback
- To have specific goals
- To motivate, through communicating a continuous sensation of challenge
- To provide suitable tools
- To avoid any factor of nuisance interrupting the learning stream



**Figure 21. Login page of the E-Learning**



**Figure 22. Course N° 1: Different water sources, water contaminants and water treatment methods**



**Figure 23. Course N° 2: Water conservation (water calculator and good practices to reduce water consumption**

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## 5 Address of the project public website and relevant contact details

### WEBSITE

The website was launched by SOLINTEL at month 5 and was fully renovated in month 32. It has been constantly updated, improved and enhanced with news, events, links, public deliverables, etc. and information on project development. The address of the official project webpage is: <http://www.water4india.eu/>

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