Final Report Summary - SAPH PANI (Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India)

Executive Summary:
Saph Pani was an India-EU collaborative project with a duration of three years. The project aimed to improve natural water treatment systems such as bank filtration (BF), managed aquifer recharge (MAR) and natural treatment systems (NTS) for wastewater treatment (e.g. constructed wetlands) in India by building on a combination of local and international expertise. An enhancement of water resources and water supply, particularly in water stressed urban and peri-urban areas was targeted. The means to reach this impact was to strengthen the scientific understanding of the performance-determining processes occurring in the root, soil and aquifer zones of the relevant regions and consider the removal and fate of important water quality parameters such as pathogenic microorganisms and respective indicators, organic substances, nutrients and metals. The consortium studied the three technologies on a total of nine sites in
A good understanding of bank filtration performance as a function of operation and design was established. The applicability of technology was extended through an assessment of flood risks and development of flood-proof designs and other measures. A survey of other existing sites broadened the experience base and allowed identification of potential new BF sites and the characteristics of such sites. Special attention was given to the polluted waters (nitrogen species) in Delhi and the adjoining aquifers, representative of the conditions in the Gangetic plain. The specific cost of production was determined to be less than 0.1 €/m³, a factor three lower than surface water abstraction followed by conventional treatment.

Based on field results and modeling, MAR performance was reliably quantified, in particular for a percolation pond in a hard rock setting and a check dam in alluvial setting. Up to now limited data on MAR influence on quality was available and the project gave new insights, for example with regards to geogenic fluoride contamination, pathogen die-off, organic pollutant elimination and dilution effects.

A catchment with a natural peri-urban wetland was comprehensively described (hydrology, water quality) and modeled which gave new insights in the cleaning capacity and options for improvement of the situation of the local farmers. On the national scale a complete inventory of Indian public NTS for wastewater treatment was performed. 41 structures representing five different technologies (horizontal sub-surface flow constructed wetlands, duckweed ponds, waste stabilization ponds, polishing ponds and Karnal-type constructed wetlands) were analysed on-site. Also pilot constructed wetlands trials were performed and the knowledge gained will facilitate planning and designing of NTS structures for wastewater treatment including post-treatment to enhance potential for recycling and reuse.

Current pre- and post-treatments for NTS in India and the critical water quality parameters of concern were determined. The partner knowledge base together with lab and field studies allowed us to derive recommendations for pre- and post-treatment options for different uses. Also, a matrix to select appropriate treatment was prepared based on data on cost and elimination capacity. It can be used by designers and planners for preliminary selection of NTSs and associated pre- and post-treatment systems. Human health risks, economical and institutional viability and social risk acceptance were assessed on selected project sites and recommendations and sustainable business models resulted. One example is NTS for wastewater treatment managed by local communities providing both irrigation water and fodder for cattle and thus allowing an increased income.

The project resulted in around 30 articles in scientific journals and the Saph Pani Handbook presenting an overview of the most important findings and striking success stories of the project. Results were disseminated through a project website, newsletters, leaflets for the general public, 4 targeted courses, practitioner meetings and over 40 events, culminating with the Saph Pani final conference with attendance of the Indian Minister of Water Resources, over 100 invited scientists, senior level policy and decision makers and presentations also from other current EU-India projects on NTS.

Project Context and Objectives:

India has 18% of the world’s population, 1.3 billion people, but access to only 4% of world’s fresh water resources. Climate change causing a frequent failure of monsoons coupled with limited surface water resources has led to an increased dependence on groundwater. Today, 70% of India’s irrigation needs and 80% of its domestic water supplies come from groundwater. This practice has led to rapidly declining groundwater tables in most states in India and is no longer sustainable. Urbanization and increasing population has led to an encroachment of urban areas onto wetlands, swamps and floodplains of rivers.
The population has led to an encroachment of urban areas onto wetlands, swamps and floodplains of rivers. The people living in these areas generally have access to neither traditional potable water supply systems nor adequate sanitation facilities.

The Saph Pani project aimed to improve natural water treatment systems such as bank filtration (BF), managed aquifer recharge (MAR) and wetlands in India by building on a combination of local and international expertise. The project targeted an enhancement of water resources and water supply particularly in water stressed urban and peri-urban areas in different parts of the Indian sub-continent. The objective was to strengthen the scientific understanding of the performance-determining processes occurring in the root, soil and aquifer zones of the relevant regions and consider the removal and fate of important water quality parameters such as pathogenic microorganisms and respective indicators, organic substances, nutrients and metals. The hydrologic characteristics (infiltration and storage capacity) and the eco-system functions were also to be investigated to strengthen the local or regional water resources management strategies (e.g. by providing buffering of seasonal variations in supply and demand). The socio-economic value of the enhanced utilisation of the treatment and storage capacity of natural systems was to be evaluated taking into account long-term sustainability and comprehensive system risk management.

The project was organized in work packages dealing with (river) bank filtration, (R)BF (WP1), managed aquifer recharge, MAR (WP2), natural treatment systems, NTS, for wastewater (WP3), pre- and post-treatment (WP4) as well as system modeling (WP5) and integrated assessment (WP6). Dissemination and training (WP7) were planned as well as project management (WP8). One of the main goals was to link the work package activities with the case study sites in different parts of India namely:

- Haridwar, Srinagar, Uttarakhand. RBF sites north of the Gangetic plain with good surface water quality.
- Nainital, lake bank filtration site with moderate water quality.
- Delhi, RBF site with poor water quality.
- Raipur, site with limestone and potential for MAR from existing lakes (Talabs)
- Chennai, Tamil Nadu, metropolitan site with MAR from check dam, percolation pond and temple tank on sediment.
- Maheshwaram, Telangana, rural site with MAR from percolation pond in hardrock setting.
- Mumbai, Maharashtra, engineered wetland.

The overall project objective can be broken down in a number of goals for the different work packages: WP1 had the overarching goal to enhance the understanding and performance of bank filtration (BF) systems, particularly to cope with extreme hydrologic fluctuations such as monsoon floods and varying pollutant loads in surface water in urban areas in India. To achieve this goal the project partners were to focus on four objectives:

- analyse the performance of the existing BF schemes in urban areas in India specifically focusing on the Saph Pani BF case study sites of Haridwar, Srinagar and Nainital in the state of Uttarakhand in north India and at the BF site in Delhi
- analyse the system design and capacity of the BF schemes, the evaluation of their removal of organic pollutants and coliform bacteria by BF
- conduct a risk evaluation addressing sustainable operation and the removal of coliforms and turbidity during floods at the Haridwar and Srinagar BF sites
- develop technical elements for the improvement of flood protection for BF sites in India using the
• develop technical elements for the improvement of flood-protection for BF sites in India using the Srinagar BF site as a basis.  
• develop remediation concepts for BF in aquifers contaminated with inorganic nitrogen species  
• determine the economic viability of BF including post-treatment options

WP2 had the goal to improve the understanding of processes determining infiltration and removal capacity of different MAR systems in urban and peri-urban settings in India (including soil-aquifer treatment). It focused firstly on pilot site construction and/or upgrade of existing sites as well as sampling of water and geology. The intense field work was supposed to be accompanied by reviewing of literature and other sources of information. Experimental measurements of quality and quantity of recharged water and hydrological properties on the study sites (Chennai check dam, Chennai temple tanks, Chennai percolation pond, Maheshwaram percolation pond, Maheshwaram dug well and Raipur site) should be consolidated, including a cross case analysis with future scenarios and climate change. The results from some sites should also feed into post-treatment assessment (WP4), modeling (WP5) and sustainability assessments (WP6).

WP3 strived to develop and implement suitable eco-centric technologies to achieve wastewater treatment and reclamation with the help of constructed wetlands, (CWs) and other NTSs. To reach this goal the project partners during the first 18 months planned a national survey and assessment of CWs and other NTSs to select case studies for further in-depth evaluation. Acquiring the knowledge base required for planning, designing, constructing, operating and maintaining of horizontal sub-surface flow constructed wetland (HSSF-CW) was a major focus. Accordingly, a multi-pronged experimental and modeling approach was planned with studies on media and vegetation and kinetics using in lab and pilot scale. For this, a pilot-scale CW treatment facility was to be constructed. The Musi river wetland/SAT site planned the establishment of a conceptual model of the site and extensive measurements of hydrology and water quality in the micro watershed for later numerical modeling with WP5. Finally, recommendations were to be articulated leading to: improvement of treatment efficiency, incorporation of reuse-oriented post-treatment and strategies for implementation at several locations and at large-scale.

WP 4 was a crosscutting work package focusing on upgrading the “treated water” produced by different natural treatment systems for different intended applications (non-potable use, potable use and reuse) through tailoring mostly conventional post- (and pre-) treatment. To reach this goal the project partners planned to:  
• collect baseline data on water quality from selected natural treatment systems and subsequent post-treatment systems by conducting an extensive literature review and some field data collection  
• identify critical water quality parameters of concern for different types of natural treatment systems in India  
• conduct laboratory studies on different aspects of pre- and post- treatment at different partner institutions and conduct field sampling for selected water quality parameters at case study sites  
• derive recommendations for post-treatment options  
• analyse the removal efficiencies of conventional pre- and post-treatment methods applied to NTSs and develop a general framework and matrices for selection of pre- and post-treatment for different natural treatment systems

WP5 should potentiate the knowledge and techniques gained in the first three work packages with tools including simulation methods for the design, implementation and planning of improved natural water treatment systems to enhance the water supplies in Indian urban centres. The main objective was to
treatment systems to enhance the water supplies in Indian urban centres. The main objective was to
demonstrate the utility of flow, transport and reactive transport modeling approaches to:
• improve the understanding of NTSs
• to simulate with success the observed processes
• to predict impacts of implementation of NTS on water quality and quantity on site to catchment scale
• to optimize NTS systems
To reach this goal the project partners planned to collect the necessary model-specific background data
for all selected demonstration sites, to establish conceptual models of flow and transport, to conceive
numerical models and through continuous exchange with WP1, WP2 and WP3 control and refine the
models in an iterative process.

WP6 was to complement the technical components of other work packages through investigations on the
overall environmental and financial sustainability of the natural treatment systems. In addition, knowing
that institutional and social factors are often decisive for successful technology adoption, an integrated
assessment of all relevant aspects was to be carried out. First, an initial sustainability appraisal of
currently existing natural treatment systems was planned to highlight the current SWOTs of natural
treatment systems in India and guide the following more detailed sustainability assessments on the Saph
Pani study sites, covering health risks, economic aspects, institutional ones as well as social risks.
Building on this work, stakeholder and policy workshops were planned and policy recommendations as
well as integrated management plans were to be elaborated. Finally, WP6 aimed at compiling technical
recommendations arising from other work packages.

WP7 was principally responsible for providing the basis for a more wide-spread application of natural
water treatment systems in India through dedicated dissemination of project results and facilitation of
training activities. To reach this goal the project partners should, in harmony with an overall Saph Pani
communication strategy, launch the project website, produce project newsletters and organize courses on
the studied NTS. Meetings for practitioners were also planned as well as exploration of potential use of
project results in existing education. The Saph Pani final conference should present the outcomes and
allow exchange with stakeholders to promote ownership and roll-out. The knowledge and success stories
gathered on natural treatment systems in the Indian context should be published as the Saph Pani
Handbook.

Project Results:
2 Main S&T results/foregrounds
2.1 WP1 Bank filtration in urban areas under varying pollutant loads and flood situations
The environmental and human health benefits of obtaining improved water quality and sustainable quantity
by bank filtration (BF) compared to direct surface water abstraction were elucidated through the analysis
of field data pertaining to water quality (total and thermotolerant coliforms; major ions; trace elements;
dissolved organic carbon, DOC; organic micropollutants), hydrogeology (including the isotopes δ2H and
δ18O), hydrology, system design, techno- and socio-economic parameters that were collected from the
BF case study sites of the Saph Pani project.

2.1.1 Performance, limitations and removal efficiency of pollutants by BF systems with surface water
having varying pollution loads
BF was studied on three Generally in hill and sub-montane areas in Uttarakhand, with relatively good
BF was studied on three Generally in hilly and sub-montane areas in Uttarakhand, with relatively good surface water quality, the main parameters of concern for BF are the breakthrough of pathogens and turbidity. The main water quality results of BF well-water at case study sites in Uttarakhand were:

- Frequent (Haridwar) to occasional (Srinagar & Nainital) presence of thermotolerant coliforms, but in relatively low concentrations such that disinfection by chlorination of abstracted water from BF wells suffices as post-treatment
- In Haridwar, Escherichia coli O157:H7 were below the national diarrhoeal incidence and meet the health target used in the risk assessment
- Inorganic chemicals and salinity lie within guideline values, except nitrate in Srinagar
- Low (mostly <1 mg/L) DOC and low risk of disinfection byproduct formation
- Only 2 (Haridwar & Srinagar) to 5 (Nainital) pharmaceutical organic micro-pollutants (OMPs) out of 54 screened were detected in surface water and two BF wells in very low concentrations

Thus the BF systems abstract high quality water such that only disinfection is required as the final post-treatment step. Based on the collected data, a comprehensive staged investigation to assess the risks from 12 hazards to human health and the environment was conducted for Haridwar, and subsequently used as a basis to derive a general risk-based assessment and management framework for BF sites in India. Subsequently, the highest risks from untreated ground and surface water were identified mainly with pathogens and turbidity and in some case with iron, manganese, total dissolved solids and total hardness.

Using the BF system in Haridwar as an example, a water safety plan was developed to include potential risk management procedures to minimize pathogen-related risks. To achieve this, the BF systems need to be equipped with a robust disinfection method. The investigations also highlighted the need for the implementation of well-head and catchment protection zone measures in order to prevent contamination of ambient groundwater and bank filtrate from anthropogenic activities.

Stable isotope values for the BF well in Srinagar showed that the water is predominantly bank filtrate, but numerical groundwater flow modelling results indicate that the travel time and flow path of the bank filtrate is relatively long (≥2 years), with the bank filtrate mostly originating upstream of the site at the start of a meander in the river. There are zones of exposed bedrock in the region which were found to readily leach nitrate into water, suggesting that these rocks could be the origin of nitrate contamination. Groundwater flow modelling investigations show that the total abstraction of water by BF from the site would have to be substantially increased in order to lower the nitrate concentration in the well water naturally by mixing. This measure would also meet the increasing demand for drinking water of Srinagar and neighbouring towns. Similar to Haridwar, the BF system in Srinagar needs to be flood-proof, have a robust disinfection system and needs to consider catchment and well-head protection measures. Additionally, the research highlighted the importance of thorough investigation and selection techniques for the identification of suitable BF sites.

The investigations in Nainital showed that the proportion of bank filtrate abstracted by various BF wells is not determined by the distance from the lake. Wells located within 15 m of the lake abstract ~80% bank filtrate almost throughout the year. Some other wells located closer to the lake, abstract >50% bank filtrate during non-monsoon seasons but mostly groundwater during the monsoon season. Possible causes for such unusual hydrology are inhomogeneities in the aquifer made of landslide debris and the presence of the Naini fault very close to the well field. The water quality of the lake was moderate to reasonably good. The BF wells were largely free of coliform except for occasional contamination in individual wells in summer months. The results indicated that contamination came from localized sources around the wells and not from the bank filtrate. Some OMPs such as cotinine, diuron, phenazone, theophylline and...
and not from the bank filtrate. Some OMPs such as cotinine, diuron, phenazone, theophylline and sulfamethoxazole were found in the lake water, but only sulfamethoxazole was found in the 5 wells tested in very low concentrations, thus indicating the good removal ability of OMPs by BF.

2.1.2 Risk-evaluation for BF operation during floods

The risks from floods (monsoon) were systematically identified for the Haridwar and Srinagar BF systems through site-audits, water level measurements and bacteriological indicator (total coliforms and E. coli) investigations in the field and laboratory (column experiments) and tracer tests on a caisson well in Haridwar. The highest ever recorded flood event in September 2010 in Haridwar and the unprecedented flood of June 2013 and extreme flood of August 2011 in Srinagar, were used as reference flood events. The risks identified as a result were mostly associated with the location of the BF wells and their designs resulting in direct contamination, inadequate existing flood protection measures for some wells, failure of the main power supply and insufficient contingency measures. Results from comprehensive field and laboratory column investigations indicated that the breakthrough of coliforms can be attributed to the seepage of flood water from above ground through the previously upper unsaturated aquifer, short circuit of the flood water along the annulus between the casing of the well and the aquifer, or a breakthrough of coliforms due to increased bank filtrate flow velocity accompanied with very short travel time. Tracer tests confirmed the possible seepage of surface water along preferential flow paths (such as along or through cracks / fissures in the caisson wall). The shallow depth to the groundwater table may result in shorter travel times for the potentially contaminated water from the surface to arrive in the well.

Within the framework of a general flood risk management plan derived for BF sites as part of the project, the most important aspect is to ensure adequate disinfection at all times. This can only be achieved if a back-up power supply is permanently available. Furthermore, disinfection measures should be installed at certain points along the drinking water distribution network in order to guarantee a residual chlorine concentration of 0.2 mg/L. In the event of an extreme flood, more elaborate long-term measures have to be introduced such as online monitoring of DOC and bacteriological indicators, inline-electrolysis, sealing of surfaces near the periphery of wells in Haridwar with clay, construction of dykes to prevent direct contamination to flood-prone wells and construction of new flood-proof wells (e.g. in Srinagar). Consequently, the criteria to flood-proof BF wells include, considering the availability of local materials and site-specific conditions:

- the protection of the well against external factors and trespassing by unauthorised persons
- prevention against pollution of groundwater through the well, prevention of rapid seepage of rainfall-runoff by providing adequate drainage measures
- low maintenance costs and use of non-toxic materials resistant to chemical corrosion and biological degradation and easy access to the well for authorised persons.

2.1.3 Development of remediation concepts for BF in aquifers contaminated with inorganic nitrogen species

This study was performed at the case study site in central Delhi, where the Yamuna River water has a high pollution load due to discharge of untreated sewage. The Yamuna water quality at this site typically reflects the quality of an extremely polluted river in India, especially as found between Delhi and Agra (200 km downstream). Ammonium is a typical domestic wastewater parameter and infiltrates into the aquifer where it does not move with groundwater velocity but is strongly retarded. The transport and fate of this contaminant was studied to predict the future development of ammonium concentrations at a well field for drinking water production in central Delhi. Recommendations for the future use of the aquifer were...
Drinking water production in central Delhi. Recommendations for the future use of the aquifer were developed. To address this, a substantial number of water and sediment samples were taken at the field site and analysed for nitrogen species, main ions, trace elements and NH4-N isotopes. Several samples were analysed for bacteriological indicators and some samples were analysed for organic trace elements. The borehole and Yamuna riverbed sediment were analysed for their grain-size distribution, cation exchange capacity and organic matter content (loss on ignition). Clay mineral analyses were conducted with some samples. Laboratory column experiments under suboxic, anoxic and oxic conditions were conducted with the sediments to study the transport of ammonium in the aquifer material. The consequent hydrogeological characterisation of the saturated part of the aquifer indicated the presence of mainly two layers comprising medium sand, and gravel made up of calcereous nodules (kankar). The highest ammonium concentrations were found in the sampling points in the medium sand at a distance of 250 m to the river. The ammonium from the river had just reached the first production well 500 m away. The two layers show distinct characteristics in lab experiments. In both layers cation exchange is the main process determining the transport. Degradation or fixation of ammonium was not observed. It took about 10 - 12 flushed pore volumes to reach a 100% ammonium breakthrough in the sand while it took 30 - 35 pore volumes in the kankar. Similar results were obtained when flushing out the ammonium. Some degradation or fixation of ammonium was observed in the sediments of the unsaturated zone. It is recommended that the focus should be on setting-up a post treatment without installing remediation measures, which are very cost intensive. The post-treatment should be designed specifically for the wells in the floodplain aquifer. Biological nitrification filters or zeolites could be adequate options for conditions to be met in Delhi.

2.1.4 Determination of the economic viability of BF
The indicative cost per cubic meter of drinking water produced by BF and groundwater abstraction in Haridwar, and BF and surface water abstraction followed by conventional treatment in Srinagar, was derived and compared. Furthermore, in order to relate the costs and benefits in a broader context and for greater representativeness, this information was supplemented with water quality (>150 samples) and design information of existing and potential BF systems operating under diverse hydro-climatic conditions in around 24 additional locations in the states of Bihar, Jharkhand, Andhra Pradesh, Madhya Pradesh, Gujarat and the city of Jammu.

The indicative production cost of drinking water in Haridwar and Srinagar by BF was calculated at 0.09 and 0.06 €/m3, respectively. These production costs are considerably lower than indicative cost of direct abstraction of surface water followed by conventional treatment (0.32 €/m3). The indicative drinking water production costs by BF for Haridwar and Srinagar also lie within the range reported in literature for a feasibility study on BF for five locations in Africa. The main health benefit of BF in Srinagar and Haridwar is the removal of total thermotolerant coliforms of 2.1 to 4.4 log10 that is attributed to relatively superior surface water quality and suitable hydrogeological conditions. The main environmental benefit lies in the year-round uninterrupted abstraction by the BF wells on account of their siting between surface water boundaries (Ganga R. and Upper Ganga Canal) that ensures a sustainable recharge of water to the wells. In general, when the source water quality and local hydrogeological conditions are favourable, BF is the most cost-effective method of water treatment for developing countries requiring no or minimal post-treatment.

A survey of potential and existing Indian BF sites was performed. The Yamuna River water at BF sites...
A survey of potential and existing Indian BF sites was performed. The Yamuna River water at BF sites between Delhi and Agra was observed to have the highest organic pollution (concentration of DOC and OMP) in comparison to other BF sites in Uttarakhand where DOC and OMPs were found to be very low or were below the detectable limit of 1 ng/L for OMPs. Nevertheless, the concentrations of some OMPs in the BF well water in Delhi and Mathura were 13 - 99% lower while others were not detected, and DOC was 50% lower, than river water.

The removal of DOC and some OMPs by BF is considerably higher compared to direct surface water abstraction and subsequent conventional treatment (e.g. in Agra and Mathura). For the BF system in Mathura, the main benefit of BF lies in the cost-effective removal of colour, UV-absorbance and thermotolerant coliforms. These are removed by around 50% and BF is thus a vital pre-treatment step to the necessary post-treatment by aeration, filtration and disinfection. Furthermore, compared to the direct abstraction of river water followed by conventional treatment in Mathura, the BF system reduces or eliminates the need for pre-oxidation or pre-chlorination that would otherwise add to the treatment costs. At most BF locations in Uttarakhand, Jharkhand, Andhra Pradesh, Bihar and Jammu, surface water quality is generally good with respect to all inorganic parameters, although bacteriological indicators are present in highly variable numbers. The BF sites in Uttarakhand are mainly advantageous due to the very high removal of bacteriological indicators and turbidity especially in monsoon.

The design and location of the radial collector wells in Jharkhand and Andhra Pradesh within the riverbed ensures the year-round abstraction of water, even during the pre-monsoon when very low to negligible surface water flow is observed. Accordingly, as a result they are less prone to the seasonally shifting river courses compared to surface water abstraction structures. However, the travel time of bank filtrate for such riverbed radial collector wells is too short and thus breakthroughs of pathogens and turbidity occur in high numbers especially in monsoon and the removal of organics is also lower. One advantage at these locations is that the surface water itself has relatively low concentrations of DOC and OMPs. Iron and manganese can also occur in the abstracted water from such systems. Thus the bank filtrate subsequently undergoes post-treatment comprising aeration, flocculation, rapid sand filtration and disinfection. In some coastal and peninsular (hard rock) areas of India (Jharkhand, Odisha, Andhra Pradesh and Tamil Nadu), BF is the only viable means of obtaining water compared to direct surface water or even groundwater.

2.1 WP2: Managed Aquifer Recharge and Soil Aquifer Treatment

Three different MAR case studies were performed at three different sites – Raipur, Chennai and Maheshwaram - located in different regions of India, with varying natural conditions and objectives. The aim was to determine the quantitative efficiency and water-quality effects at MAR test-sites in order to be able to derive recommendations for further targeted implementation of MAR in the regarded regions as well as generally in India.

2.1.1 Potential of storm water infiltration from existing lakes and ponds into an extensively exploited urban aquifer and its effect on groundwater quality in Raipur

The case study Raipur focussed on Telibandha lake area and Telibandha area, at which field investigations including the analysis of climatic, hydrologic, topographic, geologic, hydrogeological, and water quality data were carried out with the following objectives:

- to assess the storm water infiltration potential and its effect on groundwater quality
- to derive recommendation of measures to enhance lake water quality and improve the infiltration capacity of existing talabs (lakes)
In addition, this case study provided recommendations for carrying out geophysical studies to delineate the subsurface geology and groundwater potential zones. The results were documented in project deliverables and also presented to the Raipur Municipality in September 2014.

The analyzed data helped in identifying the potential of the sites for implementing MAR schemes. Generally, both, the Telibandha Lake and the Telibandha area, have a high potential of surface runoff generation from rainfall occurring in their respective catchments. The average annual rainfall of the Raipur city area was found to be about 1200 mm, of which 85% is received during monsoon months (June-September).

The geological formations at both sites pose constraints for MAR implementation because of the limited self-purification potential of the thick limestone formations.

The water quality at the Telibandha lake site indicated a contamination by bacteriological parameters, turbidity and COD, which exceed the permissible limits of drinking water standards prescribed by the BIS (10500:2012).

The cumulative quantity of water balance components of the lake show that during monsoon months Telibandha Lake receives a high amount of surface runoff, a large quantity of which spills over from the lake without potential uses. Retaining monsoon surface runoff could thus help purify (by dilution) the contaminated lake water. Only when the lake was clean can recharge of lake water to the underneath aquifer be considered, conserving surface runoff and augmenting groundwater resources for subsequent recovery.

Both identified catchments and proposed sites have a good potential of surface runoff generation. By constructing suitable conservation structures, such as check dams, surface runoff can be stored. The infiltration of the ponded water could theoretically be facilitated by providing recharge shafts connecting the recharge pond to the underlying limestone formation. However, maximum precautions would be necessary in order to avoid mixing of domestic sewer drains to the recharge pond water. At current stage infiltration from the talab to the main aquifer is not recommended.

2.1.2 MAR for coping with sea-water intrusion and groundwater over-exploitation in an aquifer used for drinking water production in Chennai

The objective of the work in Chennai was to quantify the impacts of managed aquifer recharge (MAR) structures like check-dams, percolation ponds or temple tanks on improving the groundwater availability in the Arani and Koratalaiyar (AK) river basin. This was done by undertaking assessment of MAR for coping with seawater intrusion and groundwater overexploitation on the basis of extensive field investigations and by developing recommendations and management plans for implementing MAR systems that utilize excess monsoon water to counteract seawater intrusion in Chennai. The results were the basis for the set-up of a regional scale model of the AK-river basin in WP5.

At three different test sites field investigations consisting of regular water level measurement and sampling for hydrochemical and microbiological analysis were carried out at:
- a check dam located near Paleshwaram village across the Arani river north of Chennai
- a percolation pond located north of Chennai 4 km off the coast close at Andarmadam, Thiruvallur district of Tamil Nadu and
- four temple tanks within the city of Chennai.

The efficiency of the check dam at the AK aquifer to improve the groundwater quality and usability was...
The efficiency of the check dam at the AK aquifer to improve the groundwater quality and usability was assessed using electrical conductivity and groundwater level measurements. Based on these measurements, the region positively influenced by this recharge structure could be delineated. Trace organics’ analysis of eight chlorinated pesticides in six bore wells in Chennai detected only Atrazine in low concentrations (ng/L).

Groundwater in an area of 3 km² around the check dam is having electrical conductivity similar to that of the water in the check dam and groundwater level in this region has risen by about 1.5 m after construction of the check dam. Recharge from the check dam was estimated to be about 1.12 Million cubic meters from 2011 to 2012. Thus, the availability of water for irrigation purpose in this region has increased after the construction of the check dam.

The percolation pond was almost completely filled from September 2012 to February 2013. Afterwards, the water level gradually decreased from February 2013 until it was empty in May 2013. Clogging was found to be a major problem and was investigated in an experimental set-up in the laboratory. The discharge was found to be greatest immediately after the commencement of the test and then it gradually decreased until reaching a constant rate. In areas where the soil particles are fine, the clogging of finer suspended particles in the runoff water will be a cause of reduced infiltration. But this can be managed by conventional scraping of the bottom of the pond after drying. Even though infiltration rate decreases in due time, a considerable quantity of water will be recharged into the aquifer. This can further be improved by the construction of recharge shafts at the pond bottom, so that the pond water will be directly recharged into the deeper aquifer.

Overall, the construction of percolation ponds is most feasible in areas where the depth to the water table is more than 3 m, the aquifer is unconfined and the soil is characterized by high permeability.

The temple tank study in urban Chennai indicates that the water in the investigated temple tanks may interact with the groundwater on site. Additional investigations are necessary to further characterise the tank infiltration potential. These investigations may include:

- Seasonal water table maps around the temples
- Hydrochemical characterisation of native (not influenced by tank infiltration) groundwater upstream from tanks
- Water balance calculations of tanks

2.1.3 Percolation tanks to enhance recharge and groundwater quality in over-exploited hard-rock aquifers in Maheshwaram

Investigations aiming at understanding MAR processes in hard-rock environments were carried out at two test sites: i) a percolation pond “Tummulur tank” and - due to a lack of suitable sites within the Maheshwarem watershed - ii) a defunct dug well located on the NGRI campus in Hyderabad.

At the test site “Tummulur tank” water level monitoring, slug tests, GPS-tracking of the tank area as well as sampling for hydrochemical analysis (main ions, stable isotopes) were carried out on a regular basis. The results were used to calculate a water budget, which show a high variability in the infiltrated water from 12'000 m³ in 2012 monsoon to 229'000 m³ for the 2013 monsoon. Thus, the tank clearly enhances groundwater availability during rainy years (when rainfall and aquifer replenishment are naturally above average), but cannot be considered as a solution to bridge groundwater availability during dry years when aquifer replenishment is low.

Due to the existence of different vertical and horizontal flow paths which were identified by hydraulic tests and hydrochemical observations, the geological structure might create inequity between farmers during
and hydrochemical observations, the geological structure might create inequity between farmers during recovery of water: In the Tummulur case in 2012 only 2 farmers appear to pump 53 to 88% of the stored water for years of low rainfall, while other farmers with boreholes at similar distances to the percolation tank do not benefit at all.

Percolation tanks’ impact on water quality is usually considered positive, since it is supposed to dilute contaminants. However, in the case of geogenic contaminants such as fluoride, the infiltration of water with a different chemistry may change equilibriums and may release fluoride in the aquifer. The results indicated that fluoride concentrations in the observation wells do not decrease after the monsoon showing the fluoride content evolution complexity, i.e. an input of fresh water does not lead to its decrease. This percolation tank assessment showed that those structures may be, under certain conditions (i.e. above average monsoon) a possible solution to enhance groundwater availability, but have limited impact during average monsoon years. Consequently, percolation tanks must be carefully planned and guidelines should be defined for assessment and management.

In crystalline rock aquifers, flow is constrained by the fracture network, i.e. distribution of fracture length, orientation, density and connectivity. Investigations show that the storage decreases drastically with depth and that the deepest fractures may have a semi-confined behaviour. For example, during pre-monsoon the conductivity profile is constant. When recharge starts, the borehole appears to combine two separate water bodies: the upper part of the profile seems to be diluted by rainfall and surface water (decrease of electrical conductivity); while in the deepest part, the conductivity is higher. The water with elevated conductivity comes from the deepest parts of the aquifer and/or zone of salinization. Local or regional changes in pressure gradient may mobilise different productive zones or fractures.

The investigations at the dug well site included rainfall analysis, determination of vadose zone hydraulic properties (infiltration tests, soil moisture measurements, soil sampling etc.), time lapse resistivity measurements, compilation of groundwater level and flow maps and the evaluation of existing data. The stabilized infiltration rate at three locations measured using double ring infiltrometer showed that the infiltration rate varied from 2.04 to 6.3 m/d. Mean natural recharge from rain fed sites is about 7 % of the effective seasonal rainfall. Laboratory permeability measurements carried out using constant head permeameter showed that the saturated permeability varied from 0.028 m/d to 0.395 m/d. Field observations showed that storm intensities greater than 20 mm/hr generated significant surface runoff. The unsaturated zone of the granitic terrene was investigated and analyzed using comparatively simple approaches such as geophysical analytical methods like Time Lapse Electrical Resistivity Tomography and soil moisture measurements.

As monitoring within the dug wells showed, the recommended site for the rain garden as recharge structure to improve local water management proved to be suitable to enhance recharge in terms of water level rise and contaminant dilution.

2.1.4 General aspects of MAR in India

The objective of this task was to link the site-specific investigations conducted at test sites in Raipur, Chennai and Maheshwaram to previous research and experience in India as well as to generalize the outcomes to recommendations for India on national scale. In a first step available scientific publications and reports on MAR in India were analysed for technical aspects associated with MAR, discussing the state-of-the-art with respect to the techniques used and to the amount of water being artificially recharged. The results were documented in a report and were the basis for field investigations carried out at the three case studies.

Analysis of available literature shows that aquifer recharge is practiced to a large extent and since a long
Analysis of available literature shows that aquifer recharge is practiced to a large extent and since a long time to recharge the groundwater and assure access to water all year. Experience with structures and groundwater management was developed in and adapted to the various climatic and hydrogeological situations, which is reflected by their variety and their presence at many historic sites. Although MAR might contribute significantly to groundwater replenishment on catchment scale its efficiency is highly variable and very site-specific. Information was found to be lacking on the actual number of MAR structures in India as well as quantitative scientific evidence for both positive and negative performance of MAR interventions. Fields for further research and development were found to be operation and maintenance plans to ensure stable long-term performance, the potential positive and negative effects of MAR interventions on water quality as well as field data on mixing ratios between naturally and artificially recharged water, travel times and redox conditions.

In the final phase of the project, the activities within this task concentrated on a cross-case analysis integrating the scientific results of the three case studies, comparing them and developing transferable recommendations for MAR implementation in India. A comparison of the results of the scientific investigations done in the three case studies Chennai, Maheshwaram and Raipur indicates that managed aquifer recharge structures play a considerable role in the management of aquifers, even though the performance of the structure ultimately depend on hydrogeological characteristics of the area, the availability of rain fall and periodic maintenance. In the Chennai case study, the effect of the investigated check dam is significant in improving the groundwater quality of the aquifer and in augmenting the groundwater level in the surrounding area. The concentration of microorganisms like E coli in the aquifer could be reduced by the effect of a check dam to an extent. The percolation pond constructed as a part of the Chennai case study could improve the aquifer potential in a local sale, even though the efficiency of the pond was reduced over time by the problem of clogging at the bottom of the pond. Any way such structures are economically feasible to manage the aquifer and the effect will be significant in geologically suitable areas. In the case of Maheshwaram, the investigated infiltration pond can be efficient to recharge water in case of high rainfall but have negligible impact on groundwater replenishment in case of low to average monsoon. In case of Raipur study, the limited cleaning capacity of the aquifer materials limits the infiltration of lake water. Generally, MAR structures impact on the nearby aquifer, even though, selection of site needs more attention for the effective practice of managed aquifer recharge structures.

2.2 WP3: Constructed wetlands and other natural treatment systems for wastewater treatment

In the light of shortages of water in several parts of the World (including in Asia), communities are searching for the alternatives which would augment their water resources. In that context, clearly, the engineered constructed wetlands (CWs) and other natural treatment systems (NTSs) have attracted attention of environmental engineers and scientists because these technologies are capable of treating sewages and wastewaters at phenomenally low operation and maintenance (O&M) costs as well as low power requirements. Consequently, they are favourably looked up to in the countries, which have the natural advantages of tropical climate and warm weather. The engineered variants of CWs and other NTSs were investigated thoroughly in Saph Pani because the peri-urban and small communities seem to be willing to own and operate their wastewater treatment systems based on these eco-centric approaches.

2.2.1 Assessment of the potential of existing CWs and other NTSs for wastewater treatment and reuse across India

The overall aim of the assessment task was to survey the existing engineered CWs and other NTSs across India and to select some illustrative examples to investigate the reuse potential and social...
across India and to select some illustrative examples to investigate the reuse potential and social relevance. At the outset, IIT Bombay undertook the exercise of assessment of publicly operated wastewater treatment plants (WWTP) that were based on engineered CWs and other natural treatment technologies. Based on this compressive study, gaps in understanding of the current state of art as well as strategies for achieving improved performance of CWs and other NTSs were articulated – especially focusing the potential for recycling and reusing of treated effluents.

Currently, in India, substantial efforts are being made to provide WWTPs in smaller communities incorporating the low-cost and eco-centric technologies. However, not all the facilities are working satisfactorily to meet the design and regulatory expectations. Typologies of the reasons behind their failures and successes were articulated. It was hoped that this assessment would prove to be helpful for the planners and implementing agencies in the developing countries including India in meeting the challenges of wastewater treatment in the years to come.

In a second stage, five technologies practiced at various locations in India were selected for site assessment, namely: horizontal sub-surface flow constructed wetlands (HSSF-CWs), duckweed ponds, waste stabilization ponds, polishing ponds and Karnal-type constructed wetlands for on-land disposal of sewages. During the detailed assessment, 41 STPs based on engineered natural treatment technologies were surveyed between December 2011 and June 2014. Out of the 41 selected STPs, 23 plants had waste stabilization ponds, three plants had duckweed ponds, seven plants had PPs and eight plants employed either HSSF-CWs or Karnal-type constructed wetlands. In addition to collecting the technical data, views of the personnel related to the difficulties faced in routine and episodic O&M were also recorded. This assessment highlighted some of the more intricate and counter-intuitive lessons which can potentially be used for upgrading of technologies and effectiveness of NTSs in the Indian context as well as for articulation of policy and regulatory reforms in India.

Further, the various NTSs studied in this research were classified; on the basis of published reports and literature as well as the insights developed in the project. Based on these perspectives, the five typologies of classification were proposed, namely: [1] classification based on gainful utilization of runoff and effluents, [2] classification based on goals and intentions, [3] classification based on treatment principles, [4] classification based on terrestrial versus aquatic systems and [5] classification based on the preferences of benefactors.

2.2.2 Identification of strategies for enhancement of the potential of shortlisted constructed wetlands and other natural treatment systems

Poor treatment and disposal of sewages as well as the loads brought in by the so-called non-point source pollution emerging from farm runoff and non-sewered urban and rural drainages has posed a severe challenge of contamination of surface and sub-surface waters in India. The soil aquifer treatment, especially the engineered CWs as well as managed aquifer recharge and river bank filtration have been concluded to be the useful and relevant candidate technologies having the eco-centric character and competencies for addressing some of the critical problems of aquatic contamination.

Experiments were conducted in laboratory CW-Reactors (in batch mode) by charging 24 liters of raw settled sewage from IIT Bombay Campus in each reactor. Box-type open crates (material of construction: PVC) were typically used for holding 0.0576 m³ volume of randomly packed media in the reactors. The initial and final concentrations of 5-day biochemical oxygen demand (BOD5), chemical oxygen demand (COD), ammonia nitrogen (NH4-N) and ortho-phosphate were determined in every batch degradation experiments in the laboratory CW-reactors. The removal efficiencies for targeted pollutants in different laboratory CW-reactors were analyzed and interpreted in the context of vegetation in the reactors and the
laboratory CW-reactors were analyzed and interpreted in the context of vegetation in the reactors and the associated media. Finally, the rate constants were estimated by interpreting the experimental data to gain insights into the kinetics of reactions that represented removal of pollutants in the HSSF-CW.

The oxygen mass transfer coefficient due to diffusion was estimated in simulated laboratory conditions using physical absorption method (equal to 0.0140 m/h). It was estimated experimentally by three well-mixed reactors of three different interfacial areas. Further, the values of oxygen transfer coefficient due to convection (equal to 0.0115 m/h) and due to plant roots (equal to 0.021 m/h) were used from literature and the three components were combined to estimate the overall oxygen mass transfer coefficient equal to 0.047 m/h in the constructed wetlands.

Based on the learnings from the research conducted in the Saph Pani Project, the following six-pronged strategy is proposed:

1. Reuse oriented technological options for treatment of sewages and up-gradation of contaminated ambient waters for the purposes of agriculture, process industry as well as uses in recreation and groundwater replenishment were favored for public investment in the recent times.
2. Merely compliance-driven investments are being seen as ecosystem damaging and wasteful. It is concluded in this research that the most appropriate sewage treatment system in India could incorporate excellent primary treatment unit followed by secondary treatment unit based on NTS.
3. Further, depending on the reuse option prescribed by the community; a high-class tertiary unit followed by disinfection should also be combined with the NTS so that treated wastewater can be gainfully reused.
4. The engineered CWs in conjunction with adequate primary treatment and suitable tertiary treatment present the possibilities of producing treated effluents of rather high quality. Such treated effluents can be used for irrigation, gardening and even for recharging into contaminated urban lakes and ponds.
5. In addition, the CWs are simple to operate and can be easily combined with cultivation of fodder, production of recyclable water, production of fuel, timber for pulp and paper industry as well as up-gradation of lake or river ecosystem and develop habitats for fishes and birds.
6. Strengthening institutional arrangements and financial provisions, which are conducive for incorporating engineered CWs in STPs as well as motivating community to own and operate such decentralized systems, is going to be a task to be addressed by the municipalities in the years to come.

2.2.3 Assessing the efficiency and sustainability of wetlands and SAT for wastewater treatment and use for irrigation (Musi river case study, Hyderabad)

Water sampling and data analysis were completed to assess the long-term impacts of wastewater irrigation on the groundwater and the treatment capacity of the soils (SAT potential).

In the Musi River, salinity and conductivity (EC) generally increased downstream of the river. The Total Dissolved Solids showed variable results over time and indicated a decreasing trend during the monsoon, attributed to the combined effect of dilution from rainfall and runoff water. BOD levels were lower than what was reported in previous years. The major ions (sodium and chlorides) that contribute to salinity, did not vary significantly in the pre- and post-monsoon samples, however, values were indicative of anthropogenic influences. The wetland sample showed a greater variation in its constituents compared to the irrigation canal water.

Ground water quality studies showed a strong spatial variability in groundwater chemistry (i.e. mineralisation, long term wastewater irrigation, agriculture run-off etc.). Two poles of EC were visible, along the north south gradient of the micro-watershed, one representative of freshwater and the other influenced by canal water return flows. In some samples the EC was even higher than raw canal water.
Influenced by canal water return flows, in some samples the EC was even higher than raw canal water, most likely due to re-concentration by evapotranspiration processes. Chloride, nitrate, and sulphate concentrations decreased under the influence of rainfall. Fluctuations in the fluoride concentrations were minimal. More than half the well samples tested positive for pesticides. The salinity hazard (Wilcox diagram) was high which indicates that the water was not suitable for sustainable irrigation.

The water flow pathway, which is mainly from north to south during high water level conditions, appears to suggest that SAT processes might be occurring, however, not to an appreciable degree. The terrain, and local level activities consistently influence the groundwater quality, and the SAT may not be sufficient to improve the water quality for irrigation.

Electrical resistivity tomography (ERT) was carried out in the study area during June and July 2013 to delineate the deposition of the subsurface lithological layers and saturated thickness. A total of 17 ERT profiles were carried out at 11 different locations to capture the various stages of weathering processes. A continuous ERT profile line of 1.62 Km distance was chosen to decipher the spatial variations of regolith (saprolite) thickness and saturated zone, and also to determine subsurface contamination from north to south orientation up to the Musi River. In addition to the long profile line, the ERT investigations were also performed at other locations in the proximity of observation wells. Detailed information encompassing site geology, geomorphological and hydروgeological conditions at each ERT profile was noted down during the ERT investigations which were useful in the geophysical image interpretation.

Based on the hydrodynamic monitoring, hydraulic tests, hydro-geophysical surveying, land use data, a conceptual model for flow and transport was developed.

2.2.4 Implementation of pilot-scale constructed wetland

IIT Bombay established and implemented a pilot-scale horizontal sub-surface flow constructed wetland (HSSF-CW) for investigating some of the significant issues associated with design, operation and maintenance of engineered constructed wetlands. This is one of the unique features of the experimental research conducted in Saph Pani.

In order to assess the influence of operational parameters, a group of experiments were conducted using the pilot-plant of HSSF-CW. The parameters taken into consideration included: effective reaction time in wetland bed, depth of water column, recirculation of wastewater, dry periods in-between two consecutive pilot-plant runs. Some of the salient conclusions can be summarized as follows:

- Removal of organics and coliform bacteria exhibited the so-called pseudo-first order decay kinetics.
- The effective reaction time in the wetland bed, depth of saturated zone in the bed, recirculation of wastewater from downstream to upstream position showed desirable effects and the overall performance of HSSF-CW improved. More experimental runs are planned to investigate some of the field-scale issues.
- Dry periods in-between the consecutive pilot-plant runs did not seem to influence the removal of coliform bacterial. More experimental work is planned to investigate the kinetics of degradation and operational issues in this context.

2.3 WP4 Post Treatment

WP4 tasks and activities focused on post-treatment aspects, analyzing options for upgrading the "treated water" produced by different NTSs namely BF, MAR and CW and other natural systems for wastewater treatment for different intended applications.

2.3.1 Assessment of raw water and product water quality

The baseline data on water quality and existing pre- and post-treatment systems for BF, MAR as well as...
The baseline data on water quality and existing pre- and post-treatment systems for BF, MAR as well as CWs and other NTSs for wastewater treatment and reuse were gathered through literature review and field data collection and sampling. Pre- and post-treatment applied to different NTSs in India can be summarized as follows:

- for BF pathogens, hardness, NH4+, NO3-, organic micropollutants are the main water quality concerns in abstracted water and the post treatment methods applied are disinfection, lime softening, aeration, coagulation, sedimentation and rapid sand filtration.
- for MAR sedimentation and sand filtration are used as pre-treatment. Fe, Mn, F, and As (of geogenic origin) are the main quality concerns in the abstracted water and the post treatment methods applied are disinfection, aeration + sand filtration and adsorption/coagulation based processes for As and F removal.
- for CW and other NTSs for wastewater treatment sedimentation (septic tanks, settling basins, grit chamber), UASB, (if any) are used as pre-treatment. Pathogens, organic matter, nutrients and organic micropollutants are the main water quality concerns in abstracted water and the post treatment method applied (if any) is chlorination.

Removal of pathogens, hardness, ammonium and nitrate are the key element of post-treatment systems for bank filtrates in India. Limited information is available on the concentrations of organic micropollutants (OMPs) in the raw water and filtrates at the BF sites in India. At a majority of the BF sites in India with good surface water quality (e.g. Uttarakhand), chlorination is the only treatment applied.

MAR is practiced at different scales in India using rainwater or surface water mainly to replenish the groundwater. MAR technologies used in India include among others, percolation tanks, infiltration wells, infiltration channels, ponds and check dams. Sedimentation tanks, sand filters, wrapped PVC pipes and metallic filters are commonly used pre-treatment system before MAR. Based on the groundwater quality data and water analyses from the Saph Pani case studies, post-treatment of groundwater may be required at different sites for the removal of Fe, Mn, As, NO3 and F.

CWs and other NTSs are used in India for treatment of different types of wastewater. The national survey identified 108 sites across India utilizing NTSs for wastewater treatment. Out of these 108 publicly operated sites, only 2 have a post-treatment, namely chlorination. Typically 1-2 mg/L of chlorine is added at the outlet before the effluent from NTSs is reused or discharged into the water body.

2.3.2 Tailoring of post-treatment options
Field and laboratory-scale studies were carried out to analyze water quality and assess options for removal of different contaminants during NTSs and subsequent post-treatment.

- At the BF site Delhi OMPs present in river water are partially or fully removed during soil passage. The main water quality concerns are elevated concentrations of ammonium, fluoride, iron, manganese and arsenic in BF well water. These are solved in that the water is mixed with water from other sources and treated extensively at full-scale treatment plants before supply. Water from hand pumps/ tube wells in this area should be treated at household level to remove ammonium, nitrate, arsenic and fluoride.
- At the BF sites Haridwar, Srinagar and Nainital the water quality problems are minor including nitrate and hardness in Srinagar and Nainital. Disinfection of the bank filtrate is required to ensure complete removal of pathogens and to maintain and disinfectant residual in the distribution system.
- At the check dam for MAR in Periapalayam site (Chennai) pathogens are the main water quality concern. Post-treatment is needed for the removal of pathogens and turbidity. Household water treatment for well-water is recommended.
A summary of the findings of laboratory-scale studies on the removal of different contaminants from treated water from NTSs are presented below:

• The removal of phosphate and nitrogen from CW effluent by magnetic biochar (prepared from different plants used in CW systems) was analyzed. The highest phosphate removal (from a standard solution of concentration 50 mg/L PO4 3- ) were observed in magnetic Canna indica (60% removal after stabilization) followed by magnetic biochar samples of water hyacinth stem and water hyacinth leaf, Typha latifolia, Colocasia (stem) with removal in the range of 50–55%. All biochar samples showed ammonium removal efficiency of 20–50% from the standard solution of 20 mg/L concentration. Nitrate removals in all cases were <5%.

• Laboratory studies on post-treatment of bank filtrates for ammonium removal showed that at filtration rate of 5 m/h NH4+-N removal by rapid sand filtration (RSF) could be as high as 99% (for initial concentration of 15 mg/L NH4+-N) while that by dry filtration (no supernatant) was around 94%. The maximum ammonium removal efficiency with ozonation was around 50% at the pH range of 6 - 8. Furthermore, a high amount of chlorine (9.2 mg Cl2 per mg of NH4+-N) is required to remove ammonium by breakpoint chlorination. Therefore, RSF in one or two steps (depending upon ammonium concentration) with intermediate aeration is the best and cost effective option for ammonium removal from bank filtrate. Breakpoint chlorination could be useful to remove the traces of ammonium in the filtrate of RSF and to provide final disinfection.

2.3.3 Performance assessment of post treatment under different scenarios

Key future scenarios or global change drivers which are likely to influence the performance of NTSs were identified and their effect on quantity and quality of water obtained from NTSs as well as coping strategies were outlined. Summaries of the future post-treatment requirements for different NTSs in India are presented below:

BF systems: BF systems along relatively polluted stretches of river will require extensive post-treatment to remove bulk organic matter, ammonium, as well as OMPs in order to meet water quality standards. The post-treatment requirements for BF systems are likely to increase in the future unless comprehensive programmes are implemented to control indiscriminate wastewater disposal to water bodies. Appropriate locations for siting wells, construction of wells at proper distance from the river, increasing the number of wells as well as flood proofing of the wells are some of the coping strategies for the design of BF systems to meet future challenges with respect to quantity and quality of water.

MAR systems: Pre-treatment requirements for MAR systems will be more critical in the future if the quality of the rain or storm water changes significantly and if wastewater treatment plant effluents are used for MAR. The impacts of population growth on MAR could be due to increased sewage production, combined with probable groundwater overexploitation, increased use of fertilizers and pesticides etc. Post-treatment methods like aeration followed by rapid sand filtration, coagulation or adsorption-based processes would be relevant for removal of geogenic contaminants (Fe, Mn, As and F) now and in future due to several potential water quality impacts of global change pressures. Additional advanced post-treatment options would be required in future to deal with organics, nutrients and OMPs in groundwater, originating from sewage pollution, fertilizers and pesticides.

CW and other NTSs: The field survey of NTSs in India showed that several NTSs are not functioning properly or not meeting the water quality requirements due to poor O&M. Furthermore, some of the NTSs do not have proper pre-treatment systems. Therefore, proper design, implementation and O&M of pre-treatment systems require serious attention to improve overall performance of NTSs in India. The field
Treatment systems require serious attention to improve overall performance of NTSs in India. The field survey also clearly showed that the concentration of microbial organisms is relatively high in the effluents of NTSs even for agricultural reuse. This can be addressed either by proper design of pre-treatment and NTSs or with the introduction of a range of post-treatment systems (e.g. disinfection) depending upon water quality requirements.

2.3.4 Option assessment of post treatment
Analysis of and recommendations on improvement of the post-treatment systems applied at different case study sites
Summaries of the existing post-treatment at BF case study sites and recommendations for improvement are presented below.

Haridwar: The only post-treatment applied to the water abstracted from the production wells in BF site Haridwar is disinfection by using sodium hypochlorite (NaClO). The following is recommended to improve the post-treatment practice:
- A system should be in place to check the quality of the disinfectant stock solution and the amount of disinfectant dosed and doses should be adjusted accordingly, as required.
- The present practice of shock-dosing NaClO solution at certain intervals directly into the caisson wells should be improved to prevent corrosion of production and pumping/pipe systems and to ensure a regular and steady concentration of disinfectant in the supply-water.

Srinagar: Disinfection using NaClO is the only post-treatment applied to water abstracted from RBF wells in Srinagar. Nitrate concentration is above the permissible limits in bank filtrate. The following options are recommended to improve the quality of bank filtrate:
- Changing operational design and pumping conditions: Nitrate concentration can be reduced to a permissible level by increasing the pumping rate. This modification will increase the portion of young bank filtrate and decrease the proportion of groundwater and old bank filtrate originating from upstream part of the town.
- Mixing with other water: Mixing RBF well water with the treated water from the existing conventional treatment plant (directly treating the river water) in Srinagar can lower the nitrate concentration in the water supply.
- Installation of nitrate treatment system: Post-treatment methods such as ion exchange, reverse osmosis, biological or chemical denitrification and can be used for nitrate removal. However these are less attractive than option 1 and 2, especially in Uttarakhand (India) because of high costs, their need of an uninterrupted power supply and of significant amount of maintenance and operational know-how.

Nainital: Disinfection using bleaching powder is the main post-treatment step in Nainital. There is an ion-exchange system for water softening at one of the pumping stations. The following is recommended for this BF site:
- A system should be in place to check the quality of the bleaching powder and the dosage. Disinfectant dosage should be adjusted accordingly, if required.
- A proper hardness removal system should be provided for post-treatment which is currently only limited to disinfection and occasional operation of ion-exchange units.
- Use of alternative water sources with lower hardness together with the management of the pumping regime of the wells could be an alternative to ion-exchange systems in order to reduce costs and the overall hardness in the water supplied.
Development of a decision matrix to select appropriate post-treatment options

Based on the literature review, some basic criteria for preliminary selection of sites for soil/aquifer-based NTSs (BF, ARR and SAT) were compiled. Additionally, key pollutants to be removed before or after NTSs, removal efficiencies of different NTSs and conventional water treatment processes (used as pre- and post-treatments for NTSs) were gathered. Furthermore, data on costs of different NTSs as well as above-the-ground-conventional water treatment systems were collected. Based on these data, matrices and a step-wise procedure were developed for the selection of pre- and post-treatment systems for different soil/aquifer-based NTSs depending upon the source water quality. Each matrix includes a list of pollutants to be removed, lists of pre-treatment/and post-treatment systems that can be selected together with a NTS with their removal efficiencies, and respective guideline values for drinking water quality. The matrices and the procedure developed can be used by the designers and planners to make a preliminary selection of NTSs and associated pre- and post-treatment systems.

2.4 WP5 Modeling and System design

The specificity of natural treatment systems is that they rely on natural processes depending on complex interactions of surface water, wastewater and groundwater and the contaminants they may contain with the aquifer matrix, with microorganisms and with plants. The functioning of NTS needs to be understood to be able to predict their performance. Main scopes of WP5 were (1) to establish, on the basis of a variety of measurements, conceptual models of the relevant processes for different NT systems in a representative variety of geological and hydroclimatic settings in India, (2) to develop integrated numerical models that simulate the behaviour of the NTS as closely as possible and (3) to demonstrate the usefulness of modelling for planning, implementing and optimising NTS in the specific Indian context.

2.4.1 Modelling and optimising BF systems (Haridwar, Srinagar, New Delhi sites)

Crucial aspects of RBF were determined through numerical flow, transport and reactive transport models. Those included the determination of key parameters for purification capacity as the mixing proportion of river bank filtrated in the pumped alluvial groundwater and the travel time from the river to the pumping wells (Haridwar and Srinagar case studies) as well as the simulation of transport of nitrogen species within the aquifer material, both on lab scale and field scale (Delhi case study).

The Haridwar case study highlights the importance of riverbank filtration (RBF) as a sustainable natural treatment technology for the provision of drinking water with bacteriologically acceptable quality capable to meet the highly dynamic drinking water demand in the context of an important place of pilgrimage. Thus, the objectives of the numerical groundwater flow modelling study for Haridwar were (1) to identify the flow paths of the bank filtrate to the RBF wells and the travel times as key parameter for bacterial removal and (2) to achieve overall understanding of the hydrogeological system in response to dynamic hydrological regime of the Ganga River. A three dimensional finite element two layered numerical groundwater flow model was set up in Visual MODFLOW. Subsequently the particle tracking tool was used in MODPATH to visualize the flow paths and travel times of water to the RBF wells. The zone budget method in MODFLOW was used to determine the portion of bank filtrate abstracted by the RBF wells.

Modelling allowed identifying the flow paths of bank filtrate and the groundwater catchment areas of the RBF wells and helped to identify potential sources of contamination to the wells. The study showed that the wells which abstract the highest portion of bank filtrate, have overall lower or at the most an equal magnitude (only in some cases) of thermotolerant coliform counts compared to RBF wells that abstract an
magnitude (only in some cases) of thermotolerant coliform counts compared to RBF wells that abstract an equal or greater portion of ambient groundwater. Thus, flow modelling helped illustrate the effectiveness of the natural RBF system to remove pathogens and the risk of contamination to unconfined aquifers from inhabited areas without appropriate collection, treatment and discharge of domestic sewage and wastewater.

For the Srinagar RBF case study site, the 3D groundwater flow model developed under MODFLOW provided a prognosis of the flow path and travel time of the bank filtrate (steady state conditions). In order to optimise the proportion of bank filtrate abstracted directly from the river and to enable a prediction of the effect of the monsoon on the proportion and travel time of the bank filtrate, transient simulations were conducted on the basis of the WP1 monitoring program. Coupled with the water quality measurements on pathogen removal, the transient model can be used as a tool for prognosis of the risk (based on travel-time and field measurements of coliforms) of the monsoon upon pathogen removal at this RBF site. For Delhi, the floodplain aquifer is the resource with the highest fresh water potential. However, strongly elevated ammonium concentrations were found in the river water and in the aquifer close to the river during the Saph Pani sampling campaigns.

Laboratory column experiments gave indications as to the ammonium degradation/sorption processes occurring at the field site and were successfully modelled through 1D inverse thermo-kinetic modelling. Inverse modelling was conducted with PHREEQC v3 to identify reactions which can explain the evolution of the water composition from infiltration to the wells. A 2D flow and non-reactive transport model was developed with MODFLOW to determine the effective porosities and the dispersivities of the different sediments. Using the transport parameters determined with the non-reactive tracer modelling, 2D and 1D flow and reactive transport models were developed with MODFLOW and PHT3D. At aquifer scale, 1D modelling of flow paths was applied to determine how long it would take to flush out the ammonium from the 500 m wide strip near the river (19 to 61 years in the two layers of the aquifer, provided that the assumed linear flow velocity is accurate). This provides valuable information to water managers on the reaction time of the system to any remediation measures.

2.4.2 Modelling approach of Musi River wetland treatment/SAT site

The Musi River downstream of Hyderabad with a significant proportion of waste water has a cascade of overflowing weirs/pond at which water is diverted into irrigation channels on both sides of the river. Year round irrigated agriculture, water in the irrigation canal, overflowing diversion structures (weirs), storage ponds etc. has resulted in a rise in the water table and converted the riparian zone along the river into a wetland, intermediate between natural and engineered (constructed) wetlands.

Modelling with the widely used MIKE SHE/MIKE 11 software helped to understand the hydrodynamic behaviour of the groundwater-surface water systems under the influence of the outlined anthropogenic activities. The distributed hydrologic modelling of the Musi wetland demonstrated MIKE SHE’s ability to represent complex hydrological systems found within many wetland environments where groundwater, surface water interactions are common processes. The detailed water balance analysis helped understanding the movement and quantity of water from one level to other. The integrated modelling tool, upscaled to watershed scale, will enable basin management to optimise the share of groundwater and (wastewater containing) surface water use for irrigation so to maximize the benefit and minimize the negative impact of wastewater irrigation practices.

2.4.3 Modelling, monitoring and optimising MAR in the context of seawater intrusion (Chennai site)

Excessive and heavy pumping of groundwater from the Arani and Koratalaiyar (A-K), 40 km north of
Excessive and heavy pumping of groundwater from the Arani and Koratalaiyar (A-K), 40 km north of Chennai, is the main reason for seawater intrusion endangering Chennai city water supply. Several check dams were constructed to mitigate this problem by increasing groundwater recharge. WP5 modelling analysed the causes of seawater intrusion and possible remediation strategies by simulating different pumping and managed recharge scenarios.

The methods and tools used to generate the coupled model are: (1) A rainfall-runoff model (NAM), integrated in the 1D surface water model; (2) A 1D surface water model (MIKE 11) for the two rivers Arani and Koratalaiyar; (3) A 3D groundwater model (FEFLOW) for the alluvial aquifers of AK basin which is coupled to the MIKE 11 model, to describe the interaction between the ground- and surface water in detail, (4) a density dependent model to report fresh water-seawater interactions.

Groundwater head variations were simulated under two scenarios, with and without check dams. Results show a maximum (during monsoon) of 3 m increase in groundwater heads with the implementation of check dams in the model at this location. With the coupled groundwater surface water model, three scenarios were simulated: one without check dams, scenario 1 considering most of the existing check dams until date and scenario 2 with three additional check dams as well as an increase of dam height by 1 m. The results indicate that additional check dams have a positive (local) effect on the groundwater heads, just as the raising of the dams' height, though the effect of the latter is considerably smaller than that of additional dams. The results also show that additional check dams can retain water further upstream, possibly leading to a delay or even a lack of groundwater recharge in the downstream part of the catchment. With the integrated model it was possible to display salt water intrusion processes. The model is now ready as a management tool to assess the long-term benefits of MAR structures on the saltwater intrusion process.

2.4.4 Modelling, monitoring and optimising MAR in hard-rock-saprolite settings (Maheshwaram site)

Modelling infiltration from percolation tanks of variable geometry via a partially saturated weathering zone:

To assess the performance of percolation tanks, a very widespread MAR feature in India, the three-dimensional finite difference transient state numerical groundwater code MARTHE was optimized by implementing three-dimensional non-perennial surface water bodies in continuity with groundwater via an unsaturated zone. Development included the spatio-temporal evolution of the natural percolation tanks (i.e. volume and geometry) linked to topography, rainfall, evapotranspiration, infiltration, runoff, and groundwater dynamics. Simulations show that this module “LAC” is able to simulate the relation between surface water and groundwater while respecting the water balance and to assess the highly variable geometry of infiltration tanks over the dry and wet season. The 3D MARTHE software, already integrating coupled surface-groundwater flow under varying saturation states, including density driven flow, is now ready, with the implementation of a specific module for percolation tanks, to be applied to MAR systems on weathered crystalline basement rocks in India and elsewhere. Such massively integrated models are still the exception and will be increasingly used as decision-making tool for assessing the quantitative effects of MAR on groundwater resources at the watershed scale.

Maheshwaram watershed-scale transient state finite differences modelling used Visual MODFLOW software with a regular square/rectangular grid. The watershed was assumed to be a two layer system, the top layer being the porous weathered layer on top of the fractured layer represented as equivalent porous medium. The preliminary zone budget calculations in the Tummulur tank area allowed estimating the water fluxes from and onto the tank area.

The reactive transport modelling for the Maheshwaram site assessed the influence of percolation tanks on crystalline basement rocks on water quality, in particular on fluoride concentrations, triggered by water...
Crystalline basement rocks on water quality, in particular on fluoride concentrations, triggered by water-rock interactions with F-containing minerals and evaporation together with agricultural backflow on paddy fields. The geochemical model of solute recycling, using a 1D PHREEQC reactive-transport column, was adapted to the percolation tank problem. Reactive transport column modelling was performed over a period of 110 days.

Scenario simulations show that the beneficial effect of MAR may be variable over the year, being strongest during monsoon with significant dilution, whereas, during the dry period, F accumulation occurs. In sum, the beneficial effects observed during monsoon are countered by adverse effects during the dry period so that no overall water quality improvement related to the MAR system can be expected at local, and, most likely, also at regional scale.

2.4.5 Synthesis of the modelling approaches in form a modelling toolbox, specifically adapted to the Indian context

Different types of NTS (BF, MAR and CW) were modelled by WP5 partners in a large variety of geological and hydro-climatic settings, representative of the Indian subcontinent, thus demonstrating the utility of state-of-the art integrated surface-groundwater flow and transport models as planning and management tools.

The modelling approaches were synthesised in form of two chapters, intended as a guide for practitioners, in the Saph Pani Handbook, providing an overview of model types applied to generic cases of NTS (MAR and RBF) as well as a synopsis of the Saph Pani case studies. The modelling tools used are widespread and accessible. The work conducted in WP5 revealed that model integration is the biggest challenge for modelling NTS. Especially in the case of constructed wetlands or for SAT we need to take into account surface runoff, the unsaturated soil zone, complex but crucial for water purification, the saturated groundwater flow and, in the case of MAR, even the density driven saltwater flow in coastal aquifers. Integrated modelling of complex systems like NTS on different scales up to basin scale needs specialists trained in the application of those tools and the knowledge and knowhow created in the project needs to be transmitted widely to young scientists and engineers through training programmes organised by the Indian institutions who were involved in the development of those methods within Saph Pani.

The principal lesson learnt from Saph Pani WP5 is that analytical or numerical models can be used at all stages of NTS implementation, starting with initial planning of individual systems, over upscaling at watershed scale, up to system optimisation to reach defined water quantity and quality targets. Such models enable water managers to test diverse scenarios so that they can be used to optimise implementation of NTSs within a watershed (which type? where? how big?). At local scale, models also may be useful for improving any individual NTS by fine-tuning technical options. Overall, they are management tools that help avoiding costly real-size trial and error testing of NTSs and also may avoid surprises with respect to the expected impact of NTSs on water quantity and quality.

2.5 WP6 Integrated Sustainability Assessment

WP 6 aimed at complementing the technical components of work packages 1, 2 and 3 through investigations on environmental, health and safety, economic, social and institutional aspects of the Saph Pani technologies. The ultimate goal of this work was to develop specific policy recommendations based on an integrated assessment.

The work started with a rapid assessment of those aspects in several existing case studies across India. Building on this work, detailed assessments and subsequent integration of the assessment results was carried out in three case studies: In Haridwar for RBF, in Chennai for MAR and in Hyderabad for CW.
Carried out in three case studies: in Haridwar for RBF, in Chennai for MAR and in Hyderabad for CW. The outcomes of the detailed assessments were presented to and discussed with various stakeholders in one stakeholder and one policy workshop in the case studies Chennai and Hyderabad. A summary of the resulting policy recommendations is provided below.

2.5.1 Summary of policy recommendations for the case study Chennai
Groundwater is an important source of domestic water supply in Chennai during the regular droughts and the peri-urban villages depend completely on groundwater. As agriculture and industry overexploit groundwater, which is evident from the lowering of the water table and the intrusion of sea water, more effective instruments would be needed to control the extraction of groundwater and the use of water. Amongst options to secure future water supply, two MAR approaches were considered, namely building large check dams or building many small infiltration ponds. However, check dams for groundwater recharge are costly and conflicts about land acquisition have caused substantial delays in the past. For the same reason, infiltration ponds could meet resistance, as thousands of ponds would be needed, but there is no legislation that would make them mandatory. Amongst other feasible options is rainwater harvesting (RWH) on roofs: It is already mandatory, but it can be made more effective by continuous enforcement (monitoring). Desalination plants and reverse osmosis of brackish water are too costly solutions to cover the basic demand, and consumers may not accept them. Building new reservoirs as additional water sources is costly and was not considered, as Tamil Nadu state already operates reservoirs outside the state. Instead the enlargement of existing reservoirs was considered; it was the most cost effective of the considered options.
Thus, in the short term the most economical and least conflict-ridden solution appears to be the enlargement of existing reservoirs. In the long term, infiltration ponds, which are the second most economic solution, are an alternative that most stakeholder representatives would accept. However, there is a coordination problem, as it would have not much effect, if only a few hundred farmers would build infiltration ponds: They would face costs, but the groundwater table would barely rise. To solve this problem, stakeholder representatives would support the legal amendments needed to implement MAR structures, such as the establishment of a state authority responsible for MAR. It was foreseen by the Tamil Nadu Groundwater Development & Management Act of 2003, which was repealed in 2013. Only certain aspects were preserved in the form of Government Orders. Most stakeholder representatives would favor regulations similar to this law.

2.5.2 Summary of policy recommendations for case study Hyderabad
Assuming that the natural habitat shall be preserved, treating river water prior to its use for irrigation would be beneficial for the health of farmers and possibly also of consumers, and it would have positive impacts for the environment.
With respect to implementation, there may be a decentralized treatment, where farmers build small constructed wetlands on their own plots. However, many farmers only lease the land, and their landlord might not accept if they build a constructed wetland. Another option is to build a centralized system, where farmers feed irrigation channels with treated river water. For such a system also monitoring of water quality would be easier. However, such a centralized constructed wetland requires a huge land space, which is only feasible if there is a suitable natural wetland system, as in the study area.

For decentralized treatment, costs were estimated. Consumers alone could finance it with moderately higher prices (at most 10% increases), if farmers were setting up constructed wetlands on their own plots.
higher prices (at most 10% increases), if farmers were setting up constructed wetlands on their own plots. However, even in an upscale market (Rythu bazaar/Uppal market) in the vicinity of government research institutions and software companies, where 63% of the interviewed consumers held an academic degree, only a minority of consumers was genuinely willing to pay more for vegetables grown with clean water. Hence, unless there are government initiatives to support healthier food, farmers raising prices for cleaner production might not find enough customers. Notable in this context would be the government of India sponsored ‘national vegetables initiative for urban clusters’, which aims at the provision of vegetables at sustainable prices, considering that in cities vegetable consumption in average is way below the recommendations for a healthy life.

Thus, in view of the generally low willingness of consumers to pay more for cleaner food production, the costs and efforts for the construction and maintenance of the system should be shared amongst consumers, farmers and the taxpayer: The construction of the infrastructure should be financed by the public and either operated by the farmers, if it is a decentralized system, or by the municipality, if it is a centralized system, as then farmers and their organizations would be overtasked by the construction and operation of a centralized system. For a decentralized system, the farmers’ costs for untreated water (mainly pumping) would remain the same as now, but they would input labor to take care of the constructed wetland. For a centralized system, farmers should pay a moderate sum for treated water, comparable to the volumetric cost estimate for decentralized systems. Instead, as farmers are amongst the poorest segment of the population, the city could subsidize cleaner irrigation water. Consumers should accept moderate price increases. Here, support by the above mentioned ‘national vegetables initiative for urban clusters’ may ensure, that vegetables remain affordable for all.

Legal regulations are needed that oblige farmers to use clean water, when it is made available. Otherwise there would be free-riders, namely farmers not using treated water. They would produce at lower costs. They could either sell at the higher prices of the other farmers using treated water (gaining a higher profit for worse products). Or they could sell their vegetables at dumping prices, compared to cleaner produced food, making consumers unwilling to accept the higher prices – they would opt out from cost sharing. Therefore, even considering that fines for farmers are not well received by any stakeholder group, farmers using untreated river water (instead of the treated one supplied at low costs) should be fined.

2.5.3 Policy recommendations for bank filtration in India

The results of the various investigations conducted on bank filtration (BF) within Saph Pani show that BF can potentially improve the drinking water supply in India. In conclusion to the “International Conference on Natural Treatment Systems for Safe and Sustainable Water Supply in India”, certain aspects were highlighted that are relevant for policy recommendations, as follows:

• Bank filtration should be further developed and applied in India wherever technically feasible, e.g. where suitable hydrogeological conditions exist and in combination with appropriate post-treatment systems.
• For the effective nation-wide propagation of BF in areas where suitable hydrogeological conditions exist, it is essential to develop a master plan based upon the integration of scientific results of Saph Pani and DST-WTI funded projects on BF and the Indo-German Science & Technology Centre funded workshop in 2014 on “Science-based Master Planning for Bank Filtration Water Supply in India”.
• For the effective implementation of BF in the various states in India, the Central Government should issue a directive to state governments. The directive should emphasize the consideration of BF as an alternative and/or supplement to existing or planned direct surface water abstraction systems. As an example, the Department of Drinking Water of the Government of Uttarakhand, issued a government order on 25.03.2006 wherein specific technologies for drinking water supply such as BF and the use of indigenous
specific technologies for drinking water supply such as BF and the use of indigenous
"Koop" wells should be encouraged by water supply companies working in Uttarakhand.

- As many rural and urban areas in India are facing drinking water problems in terms of quantity and quality, the implementation of BF projects can be financed through specific programmes of the Government of India like the National Rural Drinking Water Programme and the Urban Development Programme.

- For the faster implementation of BF projects, a database of industrial firms, including small and medium enterprises having the required skills, should be made and published via internet.

- For greater visibility of BF and improved technology transfer, at least one BF demonstration site should be developed in each state where it can be applied.

- The investigations on the construction and operation of BF systems should also include economic comparison with existing drinking water production plants using surface water directly as source water.

- Safety issues should be highlighted by preparing a fact-sheet on main advantages of BF, such as a high buffering capacity to cope with extreme events, accidental spills and terrorism.

- A guideline for implementation of BF in India should be prepared and distributed to the various states.

- Assistance to determine the feasibility of BF and subsequent hydrogeological investigations to select an appropriate BF site, design the BF system and manage and operate it, can be secured through the Indo-German Competence Centre for Riverbank Filtration of which the National Institute of Hydrology Roorkee is the coordinator in India supported for scientific and technical aspects by the Indian Institute of Technology Roorkee and for aspects related to implementation by the Uttarakhand State Drinking Water Supply and Sanitation Organisation - Uttarakhand Jal Sansthan (UJS).

Potential Impact:

3 Potential impact

3.1 Scientific and technical impact

The research area addressed in Saph Pani and the scientific potential assembled in the project enabled the achievement of a significant scientific impact which was characterized by a wide range of new findings on the hydraulics, hydro-geochemistry and the resulting removal capacity of ions, nutrients, organic pollutants and pathogens of different natural treatment systems.

The findings are based on case study investigations on-site and complementary lab-studies. They will help to foresee and simulate the effects of management options so as to improve design, implementation and operation of the schemes. The many on-the ground experiences of the project were combined with the development of models and tools. In this category a matrix to select appropriate treatment trains must be highlighted. Compiling the newest data on cost and elimination capacity, a step-wise procedure was developed to choose a suitable treatment train depending upon the source water quality and desired water quality. The tool can be used by the designers and planners to make a preliminary selection of NTSs and associated pre- and post-treatment systems. Numerous mathematical models ranging in scale from structure up to catchment were developed. They often coupled surface and groundwater flow and in some cases also the hydro-geochemical processes. These models included also new programming modules, i.e. a percolation pond with variable geometry for monsoon/non-monsoon season, extending the range of possible applications to this structure, abundant in India. This kind of models will impact further work, for example the integration of groundwater and surface water management currently going on in India with the scientific support of Saph Pani project partner NIH.

In all, Saph Pani has delivered over 30 articles in scientific journals, mostly peer reviewed and the Saph
In all, Saph Pani has delivered over 30 articles in scientific journals, mostly peer reviewed and the Saph Pani Handbook presenting in-depth an overview of the most important findings and striking success stories of the project. Saph Pani has contributed to and benefited from the scientific education: A total of 9 PhD theses and 13 master theses contributed to the project.

The knowledge and experience gathered in Saph Pani has led to capacity building in the participating institutions and beyond. The many techniques and concepts developed will be of great value in further research, advisory and commercial activities of the project partners. Spin-off projects concerning all the three technologies studied (BF, MAR and NTS for WW) are starting in India, in Europe and also in collaboration between the continents. For example, the Saph Pani activities in bank filtration together with the Water Technology Initiative of the Department of Science and Technology (DST) of the Government of India in the state of Uttarakhand has led to the DST expressing keen interest to spread the concept of BF to other parts of India.

3.2 Policy relevance and impact

Saph Pani supports the implementation of both Indian and European Policy in place such as the Indian National Water Policy and the National Urban Sanitation Policy with important relations to State Sanitation Policy as well as the EU Water for Life Initiative and the achievement of the Millennium Development Goals. The Technology Mission Plan Document “Winning, Augmentation and Renovation” – WAR for Water, highlights the needs for action in the fields of wastewater recycling and MAR/rainwater harvesting and proposes demonstrating technical solutions through research and installation of demonstration sites, both foreseen by the Saph Pani project.

There is an ongoing interest in MAR in India as shown in the recent programs (e.g. Integrated Watershed Management Program; Repair, Renovation and Restoration scheme; Bharat Nirman; Artificial Recharge of Groundwater through Dugwells). Thus, the results of WP2 are strongly relevant to the national policies being implemented by the Government of India. The work provides an important scientific basis for further MAR development, for example with its case-study in Chennai, state capital of Tamil Nadu comparing different techniques. On the other hand, in the semi-arid Deccan Plateau having hardrock aquifers which correspond to the setting of Raipur and Maheshwaram case studies, MAR schemes already play an important role in rural areas. In these settings the project could also draw attention to limitations and drawbacks of the technique.

Several of the scientific papers published are related to policy. For example, a peer-reviewed article prepared and published as a result of Saph Pani recommends investigation of the technical and socio-economic feasibility of using RBF for urban and de-centralised water supply schemes in India having suitable hydrogeological conditions. This would also serve as a first step towards meeting the goals of the Government of India’s ‘National Action Plan on Climate Change’.

The recommendations Saph Pani were requested by the Minister of Water Resources at the final conference of the project. These were formulated and handed over to the Ministry of Water Resources. They are part of the policy brief of the project and were also provided to the:

- Ministry of Drinking Water & Sanitation
- Ministry of Environment & Forest
- Department of Science & Technology

3.3 Socio-economic impact

The provision of safe drinking water and reclaimed water for non-potable uses is of fundamental importance for the development of India as a whole. While sanitation coverage is low and the pollution of...
importance for the development of India as a whole. While sanitation coverage is low and the pollution of surface water significant, access to safe drinking water is severely constrained particularly for the poorer part of the population. Only natural treatment processes offer the perspective of relatively quick improvement of the situation with manageable investments and without an excessive increase of energy demand in the water sector. The concepts developed in WP3 of Saph Pani are very promising in this respect. In one of the models, NTS for wastewater treatment can be managed by the local communities and for example provide both drinking water and fodder for cattle, allowing an increased income.

3.4 Dissemination and exploitation
The activities and results of the projects results were presented at over 50 occasions. The audience was in most cases the scientific community, but also included policy makers, authorities, industry and the general public.
The final conference of Saph Pani was attended by around 100 participants in addition to the Saph Pani consortium. The two day event was filled with presentations on the outcomes and recommendations could be given to senior level policy and decision makers and networking was done extensively during the breaks. Three ongoing EU-India projects with a focus on natural treatment systems where presented to promote exchange, namely SWINGS, Saraswati and NaWaTech.
The website was continually updated and had steadily increasing number of visitors approaching 400 per month. Biannual newsletters in English and Hindi regularly informed over 200 persons from the project, relevant institutions and the partner network about project activities. A total of 7 leaflets were distributed to over 150 relevant water utilities, public authorities and agencies for distribution to the general public. As mentioned, the project has generated considerable foreground which is already being exploited, mainly scientifically, by the project consortium and their network.

3.5 Ensuring long-term impacts
Saph Pani’s structure was such that impacts of the project can be realized beyond the actual lifetime of the project itself. The investigations were case study oriented and the locally involved stakeholders and communities can take the project results along and integrate them in the daily operation of natural treatment systems. The results will enable research institutions and companies to go further with new knowledge and tools, addressing open questions and offer new services and products in the field. Further dissemination and training activities will help to spread the project results and tools beyond the partnership and particularly address water authorities, water utilities, technology planners and providers, local communities as well as research institutions, universities and schools. For example, training programmes on Natural Water Treatment Systems, based on the training modules developed as part Saph Pani, are recommended to be conducted at multiple locations on a regular basis, project partner NIH has agreed to take on a lead role in this. Saph Pani has identified a large potential for integration in existing education for the academic project partners to pursue. Also existing networks, such as the River Bank Filtration Network and Indo-German Competence Centre for Riverbank Filtration will be enlarged and further used for dissemination and training activities beyond the Saph Pani project.

Glossary
BF Bank Filtration
BOD Biochemical Oxygen Demand
CPCB Central Pollution Control Board
CW Constructed Wetland
List of Websites:

5 Website and contact details
http://www.saphpani.eu/

5.1 Contact details of project partners
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