# Saph Pani

Enhancement of natural water systems and treatment methods for safe and sustainable water supply in India

Project supported by the European Commission within the Seventh Framework Programme Grant agreement No. 282911

Deliverable D 6.1

Report on initial sustainability assessment

| | |
|---|---|
| Work package | WP6 Integrated sustainability assessment |
| Deliverable number | D 6.1 |
| Deliverable title | Report on initial sustainability assessment |
| Due date | Month 12 |
| Actual submission date | Month 17 |
| Start date of project | 01.10.2011 |
| Participants (Partner short names) | CEMDS (Editor)<br>HTWD (RBF)<br>IITB (NWWTS)<br>IWMI (NWWTS)<br>UJS (RBF) |
| Authors in alphabetic order (main contribution) | P. Amerasinghe (NWWTS), S. R. Asolekar (NWWTS), L. Essl (all sections), T. Grischek (RBF), P. K. Gupta (RBF), K. Heinze (RBF), M. Jampani (NWWTS), C. Kimothi (RBF), D. Kumar (NWWTS), M. Lesch (RBF), C. Sandhu (RBF), M. Semwal (RBF), P. D. K. Singh (RBF), M. Starkl (all sections) |
| Contact for queries | Markus Starkl<br>CEMDS<br>Gregor – Mendel – Strasse 33<br>A-1180 Wien<br>+43-1-47654-5057<br>markus.starkl@boku.ac.at |
| Dissemination level:<br>(**PU**blic, Restricted to other **P**rogrammes **P**articipants, **RE**stricted to a group specified by the consortium, **CO**nfidential- only for members of the consortium) | PU |
| Deliverable Status: | Draft 1.0 |

# Content

# List of tables

# List of figures

# 1 Introduction

WP6 is aimed at complementing the technical components of work packages (WP) 1, 2 and 3 through investigations on environmental, health and safety, economic, social and institutional aspects of the Saph Pani technologies. This will enable the Saph Pani project to develop policy recommendations based on an integrated assessment of selected case studies, incorporating social, health, environmental, institutional and economic aspects which are as important as technical factors to achieve sustainable provision and access of water for communities in India.

Thus, in task 1 of WP6, an initial sustainability appraisal of currently existing natural treatment systems will be conducted, in cooperation with the technical WPs. It is envisaged that around 10-15 natural treatment systems will be selected for the rapid assessment, and subjected to a SWOT (Strength, Weaknesses, Opportunities, and Threats) analysis of which will help carry out more detailed sustainability assessments where relevant.

# 2 Methodology

The main intended benefit of all Sap Pain case studies is the provision of and access to safe water for human consumption or agriculture use. Thus, the sustainability assessment evaluated 14 selected case studies, to see if intended benefits of the natural treatment systems (technologies) were achieved. Further, other relevant expected and unexpected benefits were also studied, for example, income generation and employment for those communities that are associated with the systems, and risks that could jeopardize the successful functioning of the systems. Based on the intended and unintended benefits, current risks and future risks, the case studies were classified as a “success” or “failure” cases. During the rapid assessment we also studied the underlying reasons for success or failure of the cases and carried out a SWOT (Strength, Weaknesses, Opportunities, and Threats) analysis for a robust assessment. We have assessed the performance failure under two categories, namely, failure to provide water with the intended quality (malfunction, technical failure) and/or a failure of the intended use of the provided water (mal-use, social failure).

The methodology for the rapid assessment is based on previous studies conducted in India (Starkl et al., 2010) and is comprised of the following four steps (see Figure 1):

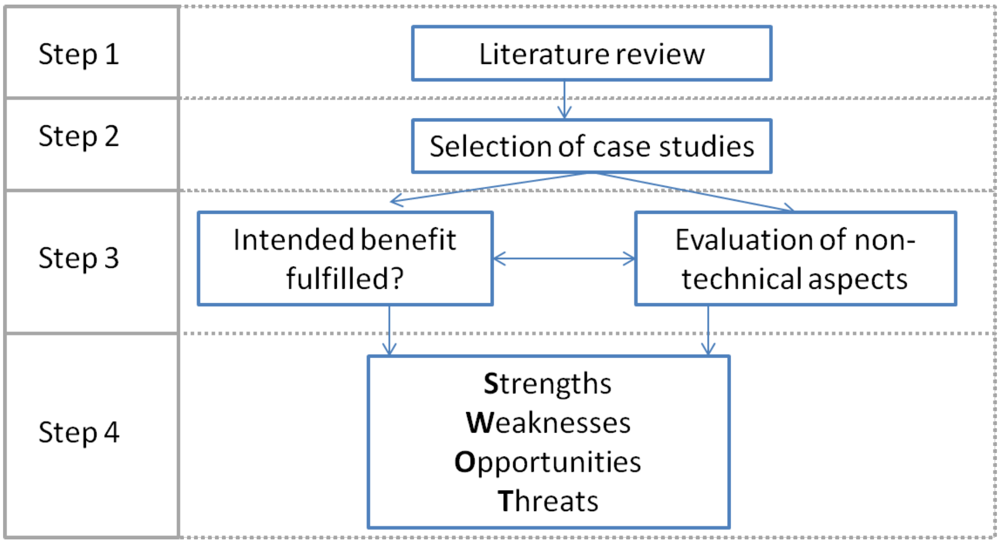


**Figure 1: Methodology for assessment**

Step 1: Survey and review of existing information on Indian case studies

First, a survey and a review of natural treatment technologies that exist in India were carried out based on a literature search. Existing information on non-technical (environmental, health and safety, economic, social and institutional) aspects was summarised and relevant issues and knowledge gaps were highlighted.

Step 2: Identification of suitable case studies for the rapid assessment

After the survey and review of existing case studies, suitable case studies were selected for the rapid assessment. They were selected based on certain criteria such as existing knowledge gaps, its current use, accessibility or application under real life conditions.

Step 3: Rapid assessment

The rapid assessment was primarily based on questionnaires: a general questionnaire for all case studies (Annex A1) and tailor made additional specific questionnaires (Annex A2 and A3) were used for the different technology groups, considering the already available information and technology specifications. The general questionnaire was targeted at collecting basic background information, especially non-technical information. The specific questionnaires focused on aspects important for each of the technology groups (e.g. certain risks that are only relevant for a certain technology, such as e.g. health risks and safety of wastewater reuse in food production). Expert visits and initial interviews with targeted stakeholders and users were conducted to fill the questionnaires and get an overall impression of the functioning of the NTS.

Step 4: SWOT analysis

To assess the potential of the technologies in India, a SWOT-analysis was conducted. SWOT analysis was initially developed for business management, but has also been used in natural resource management (e.g. Srivastava 2005, Terrados 2007, Mainali 2011).

The SWOT analysis provides a framework for analyzing a situation by identifying strengths and weaknesses, but also recognises challenges and develops strategies for the future (Srivastava 2005). Thus, in this analysis, the strengths are viewed as advantages that support the decision to implement a system; weaknesses show what can be improved or what needs to be investigated before implementation. Opportunities refer to possible chances and positive improvements, whereas threats show risks and obstacles for the future.

# 3 Natural wastewater treatment systems (NWWTS)

## 3.1 Overview

NWWTSs utilise natural processes such as attenuation and buffering capacity of natural soil-aquifer and plant-root systems, and as such, the process of contaminant removal is not aided by the input of significant amounts of energy and/or chemicals (Sharma and Amy 2010). NWWTSs can be classified as soil-based and aquatic treatment systems. Examples for soil-based systems are, subsurface flow constructed wetlands (SFCW), soil aquifer treatment (SAT) systems or planted filters (PF). Aquatic systems are duckweed or waste stabilization ponds (WSP). They can be used as secondary or tertiary treatment systems and in combination with conventional and other NWWTSs (hybrids) or solely based on the influent water quality and intended reuse of the treated water. It has also been reported that a combination of different treatment technologies allows for improved water quality of the effluent (Alvarez et al., 2008, Mbuligwe, 2004, Kaseva, 2004).

## 3.2 Existing evaluation results

The survey of existing natural treatment systems across India showed that the prevailing natural treatment systems for wastewater treatment are waste stabilization ponds and duckweed ponds; other technologies such as modified constructed wetlands and floating wetlands have been implemented only at pilot scale so far.

The literature search resulted in locating around 70 NWWTS case studies[1] in India. An overview of the documented information is given in Table 27 (Annex 8.1). Although for some systems evaluation results were available the information was sparse or did only cover technical aspects. Table 1 shows a summary of the results.

[1] Only those WSP with existing evaluation results are listed in Table 27; for a list of all existing WSPs see Deliverable D3.1

**Table 1: Total number of identified NWWTSs**

| Type of technology | Number of systems[2] | Evaluated aspects |
|---|---|---|
| Waste stabilisation ponds (WSP) | 26[3] | technical (quality of effluent), health aspect (faecal coliforms in effluent) |
| Polishing pond (post-treatment) | 1 | none |
| Constructed wetlands (CW) | 5 | none |
| Duckweed ponds (DP) | 19 | none |
| Soil Biotechnology (SBT) | 13 | technical, health, social, economic, institutional |
| Combination of DW and WSP | 1 | technical and health |
| Planted filters (PF) | 3 | technical (one case study) |

The following section summarises the existing results.

### 3.2.1 Environmental aspects

The environmental risk is related to impact of the effluent on surface or groundwater and therefore directly related to the effluent quality and the technical performance of the treatment systems. For details on the technical performance see Deliverable D3.1.

### 3.2.2 Health aspects

In general, emphasis on health safety aspects in the evaluated NWWTS systems was poor and comprised only testing of faecal coliforms in the effluent, but not the destiny of the treated water.

Waste Stabilization Ponds (WSP) and soil biotechnology systems (SBT) have been tested on their ability to remove coliforms from the wastewater. SBT are able to reduce coliforms in orders of 2–3 logs, the performance of WSP varies and the effluent usually still contains a high number of coliforms. As the Indian norm prescribes no standard for coliforms, there is only little emphasis on this aspect. The SBT systems in Maharashtra have been assessed on hygienic aspects with special emphasis on the handling and the reuse of treated water. The evaluation showed that there is potential risk for children that play on the lawns where treated water is sprinkled (Starkl et al., 2010)

### 3.2.3 Social aspects

In few identified evaluation reports social aspects were included. Only one study (Starkl et al., 2010) investigated acceptance of SBT systems implemented in schools in

[2] Number of identified systems based on literature review conducted in December 2011

[3] Only those WSP with existing evaluation results are listed in Table 27; for a list of all existing WSPs see Deliverable D3.1

Maharashtra. The study has shown that the users accept the treated water well for reuse for gardening and toilet flushing, because they are aware of their contribution to water conservation.

#### 3.2.4 Institutional aspects

No evaluation of institutional arrangements was found in any of the cases described in the literature. In case of the waste stabilisation ponds, the non-compliance with the norms is often traced back to weak operation and maintenance (O&M) of the plant (CPCB 2005), but no detailed assessment has been conducted.

#### 3.2.5 Economic aspects

Only for SBT systems, an economic evaluation has been conducted; for all other NWWTS construction and operation and maintenance (O&M costs) were not documented.

Land requirement of SBT for a typical 100 MLD plant is estimated to be 1.1 $m^2/m^3$ wastewater per day with capital cost of 93.8 US$/$m^3$ wastewater per day and annual O&M costs of 0.1 US$/$m^3$wastewater per day. Energy requirement of SBT systems is estimated to be 0.03–0.05 kWh/$m^3$ (Nemade 2009). For the other technologies no detailed economic assessment has been conducted so far.

### 3.3 Selection of case studies for rapid assessment

#### 3.3.1 Relevant non-technical aspects

The natural wastewater treatment systems comprise a variety of technologies; as such no general conclusions could be made from the information that was documented in the literature. As shown in section 3.2, the technical performance of natural treatment systems were documented for 50% of case studies, however, only a few studies included social, institutional and economic aspects.

We identified 5 aspects that could be important for the long-time sustainability of natural treatment systems, and these are:

1. Health aspects: there may be imminent risk to the persons that get into contact with the wastewater, effluent or products irrigated with the treated wastewater. The main groups that can be affected by the treatment system are:
    a. Operators: operators handle side products and get into direct contact with wastewater
    b. Communities living close to the treatment plant: depending on the location of the treatment plant, residents can be affected by mosquitoes, smell or other nuisances
    c. Farmers: farmers who use the treated wastewater for irrigation and get into direct contact with the effluent
    d. Consumers: consumers of wastewater irrigated crops can be exposed to risk if cultivated vegetables are contaminated and eaten raw

2. Social aspects: the attitude of farmers and consumers and other users towards the reuse of treated wastewater from natural treatment systems has not been assessed in a systematic way so far. Other aspects concerning the social acceptance are related to problems of residents living near the treatment plant, who experience problems with mosquitoes, rats, odour or other nuisances.
3. Institutional aspects: institutional aspects, in particular the organization of operation and maintenance activities as well as monitoring and control of the treatment plants are crucial for the successful functioning of any treatment system and these aspects shall be documented
4. Economic aspects: there is only sparse information on construction costs and operation and maintenance costs of the existing systems. It is important to document the O&M costs (personnel, material, energy) and the economic value of side products (e.g. sludge, duckweed, fish, etc.).

### 3.3.2 Case studies

The selection of the case studies was done in consultation with the local partners and accessibility and existing contacts. The natural treatment systems that were selected for in-depth studies are presented in Table 2 and the locations can be seen in Figure 2.

**Table 2: Selected case studies**

| Case studies | Reasons for selection |
|---|---|
| WSP Mathura I, Uttar Pradesh (UP) | The waste stabilization ponds have already been visited by IITB and contacts with local operators have been established.<br>The treatment plants were easily accessible by car within a few hours drive from Delhi. |
| WSP Mathura II, UP | |
| WSP Mathura III, UP | |
| WSP, Agra I, UP[1] | |
| WSP, Agra II, UP[1] | |
| Polishing pond, Hyderabad, Andhra Pradesh | IWMI has established contacts with the treatment plant and obtained the required permission to visit the plant. |
| Planted gravel filter, Agra, UP | This treatment plant has been implemented in a slum community to demonstrate the feasibility of natural treatment systems in a peri-urban context. Representatives from the implementing NGO could be met and the contact had been established before by IITB. |
| DP and WHP, Punjab | The duckweed/water hyacinth ponds in Punjab are the only project of this type that could be identified in India. As it was not possible to get information from literature about the accessibility of these systems in advance, a field visit was conducted and based on the accessibility of the systems and local persons that were in charge for operation and maintenance of the systems, the treatment plants to be evaluated were selected. |
| CW, Bhopal: | The constructed wetlands in Bhopal have been selected because the Indian Institute of Technology Mumbai (IITB) has already established contacts to the operators. |
| SBT systems | SBT systems were not selected for further evaluations as an assessment covering all relevant aspects was already conducted by Starkl et al. (2011) and Kadam et al. (2007). |

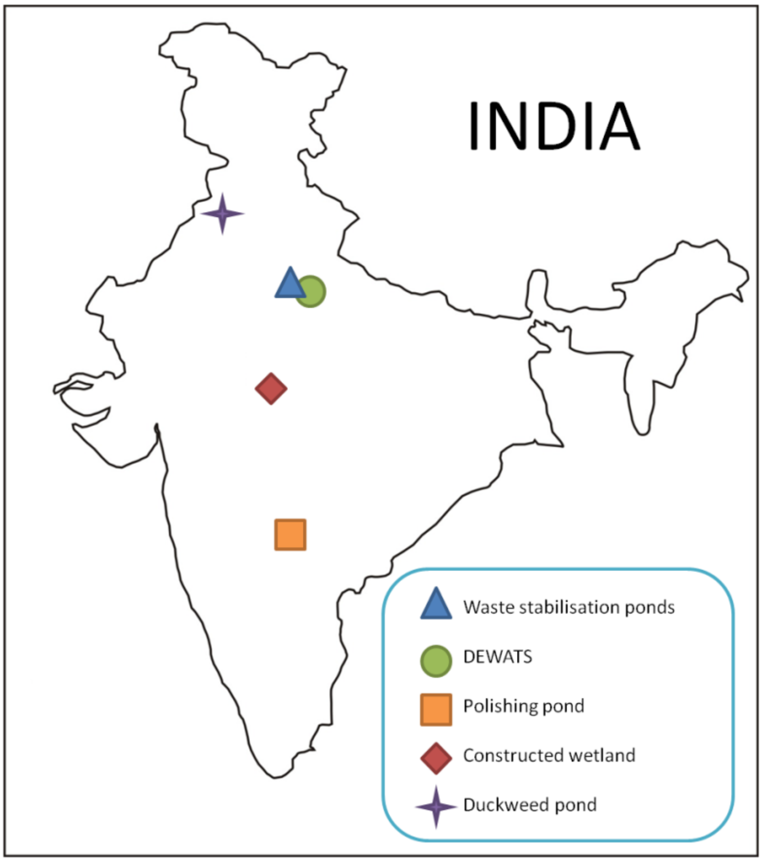


**Figure 2: Location of case studies**

## 3.4 Results of the rapid assessment

### 3.4.1 Waste stabilisation ponds (WSP)

The intended benefit of waste stabilisation ponds is treatment of wastewater according to Indian standards and reuse of the effluent if possibilities for reuse exist within the near surrounding of the treatment plant. Waste stabilisation ponds work without energy input and operation and maintenance is limited to the removal of solids from the pre-treatment unit.

**Mathura I**

The WSP in Mathura consists of a pre-treatment unit with rack and grit chamber and two treatment chains consisting of four ponds (see Figure3 and Figure 4). The first pond is an anaerobic pond, followed by two facultative anaerobic ponds (FAP) and a maturation pond (MP). However, at present only one set of chambers is functioning and the other is being dried out for repairs. Currently water is not reused, but it was tried to cultivate fish in the FAP and MP. Due to problems (see below) this practice was stopped.

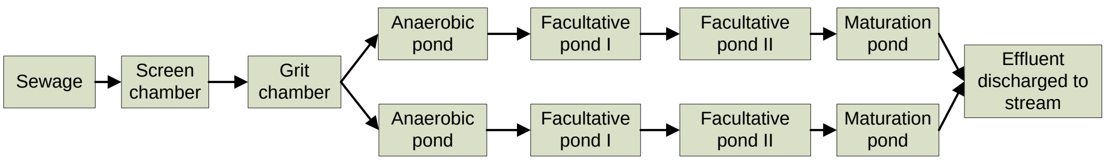

**Figure3: Schematic flow chart of waste stabilization pond Mathura I**

Domestic wastewater (13.59 MLD) from the city of Mathura is conveyed to this treatment plant, but the community living close to it is not connected to the sewer network. The waste stabilisation pond in Mathura was constructed and commissioned by the National River Conservation Directorate (NRCD) operated and maintained by Mathura Jal Board (Water Board).

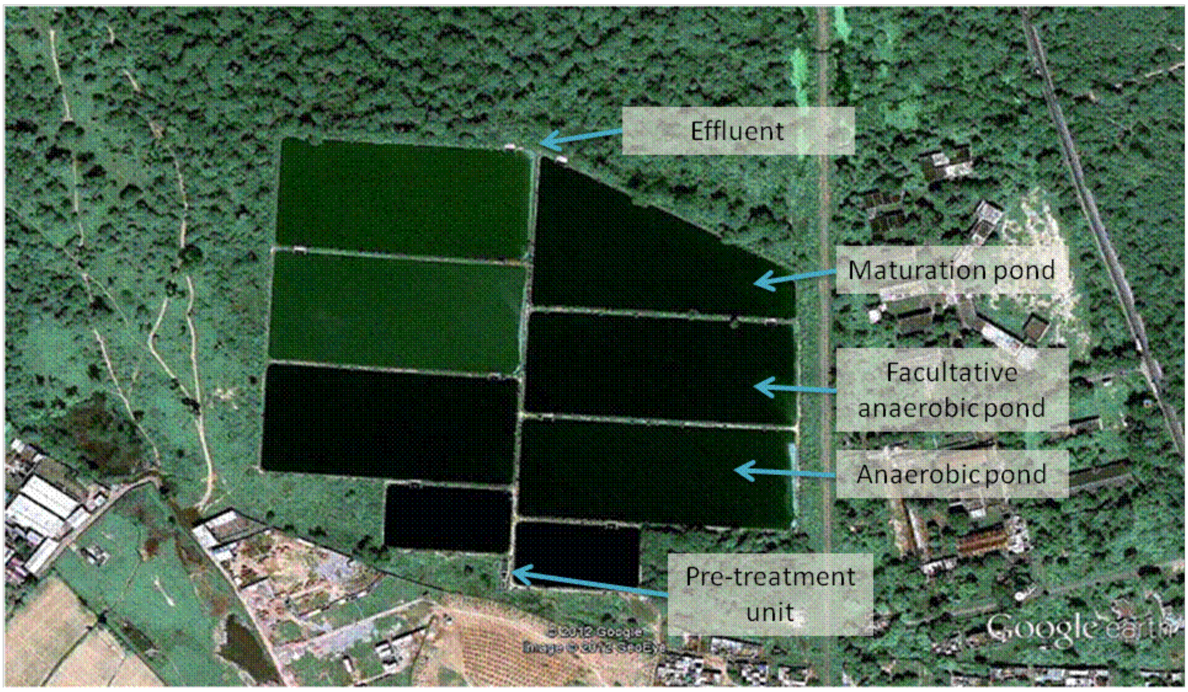


**Figure 4: WSP in Mathura I, picture from 2009 (Source: Google Earth)**

*Health aspects*

There could be risks related to faecal-oral transmission of pathogenic agents to operators as they have no special equipment for the handling of primary and secondary sludge; they use a shovel and have no gloves. However, the degree of risk could not be assessed as the quality of the incoming wastewater was not available for study.

Communities living close to the treatment system appeared to have been affected by the WSP as commented by some members. According them some members became sick due to the nearby drinking water pumps becoming contaminated. While there is no water quality data available to support this, a possible contamination of the ground water could have occurred due to a hole in the cement lining in the facultative anaerobic ponds (FAP) (see Figure 5). At present, the WSPs are undergoing repairs, and therefore, not functioning.

Treated wastewater is not reused in agriculture; therefore there are no risks to farmers and consumers. .

*Social aspects*

The field visit has revealed a problem of acceptance: according to three local people, who were interviewed during the site visit, the last of the four ponds was used for cultivation of fish. One local user has informed that after a community member fell sick, the practice of rearing fish was stopped. Local people believed that the reason for the illness of the community member was due to eating contaminated fish from the pond.

As mentioned under 3.4.1.1.1, due to the problem related to contamination of groundwater, communities are unhappy with the placement of the WSP as the system is not even serving their community by collecting the sewage. These tensions could become a problem in the future.

*Institutional aspects*

The main institutions involved are the Mathura Jal Board, the Central Pollution Control Board (CPCB) and a private company that is contracted for one year by the Mathura Jal Board.

One technical supervisor of the Mathura Jal Board was responsible for supervising all wastewater treatment plants in Mathura.

The treatment performance is monitored every month by the Mathura Jal Board and the CPCB, but the information on the performance is not available to the public.

The actual operation and maintenance is handled by the private company. Two operators have been selected from the local community. The operators are responsible for cleaning the rack and guiding the plant. They did not receive a specific training.

The site visit showed that the institutional arrangements worked well as technical problems such as infiltrating wastewater were being tackled immediately.

*Economic aspects*

The construction costs of the WSP are not known.

The operation and maintenance of the WSP has been outsourced to a private company at a cost of 400000 INR per year according to the operators. The salary of the operators was reported as 32000 INR per year and free housing was provided by the company close to the plant.

According to the operators, there is no revenue from selling any by-products. The treated water is discharged to the nearby stream and sludge is stacked around the premises of the treatment plant. The maturation pond was successfully used for rearing, but this practice was stopped due to acceptance problems (see 3.4.1.1.2)

*Summary of evaluation results*

The intended benefits of the treatment plant are mainly fulfilled (see Table 3). Effluent quality could not be assessed as the monitoring results are not available public, but it seems that the system is working well based on the visual impression during the field visit. Reuse of the treated water for irrigation is not possible within the near surroundings as there is no farmland adjacent to the treatment plant (see Figure 4). No energy is required to operate the treatment plant, but nevertheless power cuts appear to affect the system as the wastewater is pumped to the pond system. The operators, who were selected from the local community, have no special skills. Their main task is removing solids from the pre-treatment unit.

**Table 3: WSP Mathura I – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - monitoring results not available<br>- based on the impression during the field visit, the system seems to be working well, even though only 50% of the treatment plant were operational, the effluent was clear (visual impression) |
| Reuse of treated wastewater | not applicable | - reuse within the surrounding not possible as no agriculture is practiced |
| No energy requirements | yes | - the treatment plant itself requires no energy to be functional<br>- pumping is required to transport wastewater to the treatment plant |
| No skills for O&M required | yes | - the operators are from the local community and need no special training, their main task is removal of solids from pre-treatment unit |

**Figure 5: Hole in lining of FAP**

**Figure 6: Maturation ponds: left side operational, right side not functional**

**Matura II**

This WSP was built around10 years ago in Mathura by the local water board. It has a capacity of 14.5 MLD and treats domestic wastewater. The structure is the same as for Mathura I, but the intended benefit is not only treatment according to norms, but reuse of treated wastewater in agriculture. Treated water is currently used for agriculture in the adjacent fields. Figure and Figure 8 show the layout of the treatment plant.

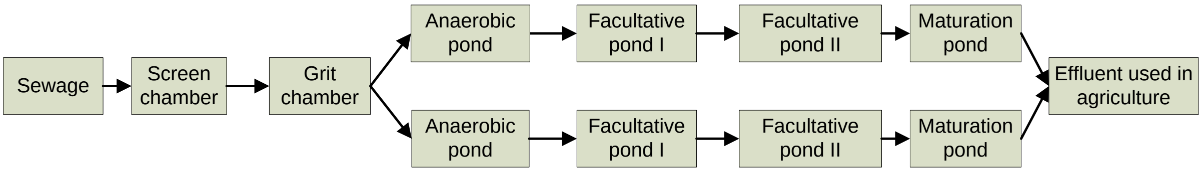


**Figure 7: Schematic flow chart of waste stabilization pond Mathura II**

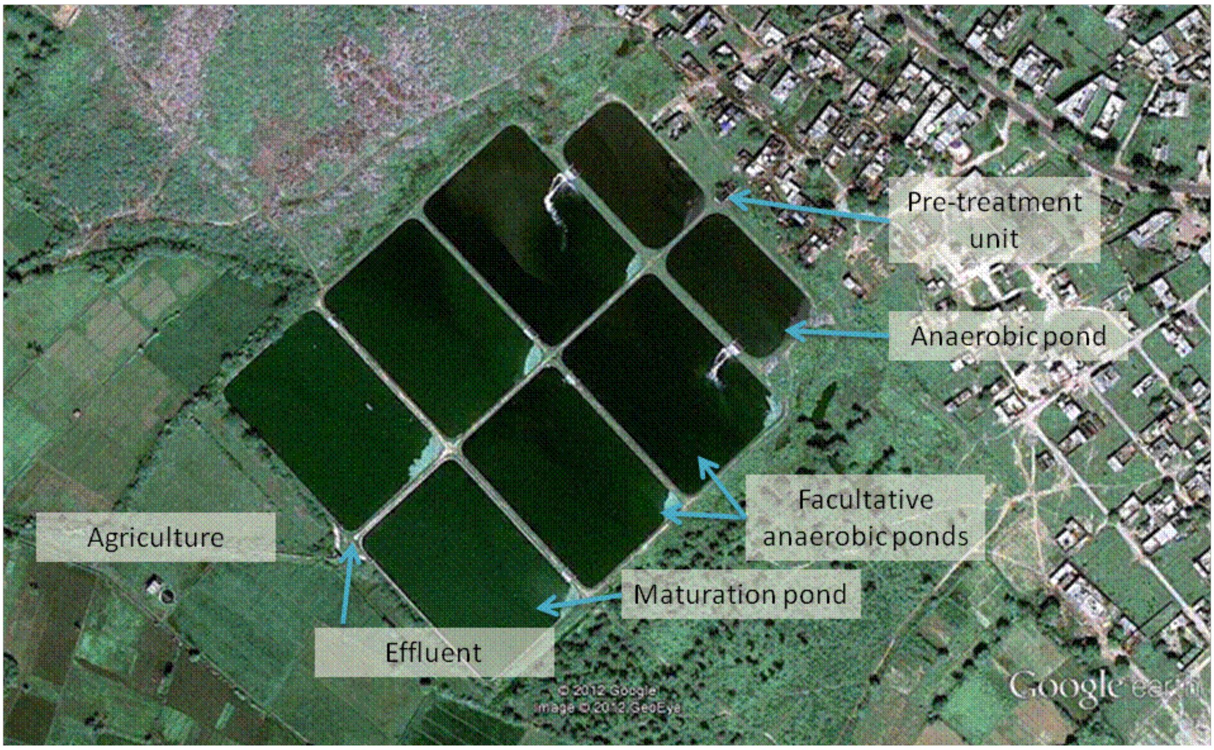


**Figure 8: WSP II in Mathura, picture from 2009 (Source: Google Earth)**

*Health aspects*

The risk to operators is similar to Mathura I.

There are some houses located near the inlet of the treatment plant that are using water from tube wells. Monitoring wells located around the treatment plant are checked regularly to assure that wastewater is not infiltrating.

The reuse of treated wastewater in agriculture involves a risk for farmers who get into contact with the treated wastewater and consumers of the irrigated vegetables. The main agricultural crops irrigated are eggplants, cucumber, pumpkin and cereals. As some of the irrigated vegetables are eaten raw, there is a possible risk to consumers. However, the risk for farmers and consumers cannot be quantified as the quality of the treated wastewater was not available for the assessment.

*Social aspects*

The acceptance of the treated water for irrigation purposes was investigated in group discussions with local farmers. Three such group interviews were held (group 1: seven male farmers, group 2: family of six persons, mainly women, group 3: three farmers, who used groundwater and wastewater for irrigation). Their opinion on the quality of the water they are using for irrigation was investigated.

The treated wastewater was used the whole year round. In total 100 acres are planted with the water of this wastewater treatment plant and the farmers would like to use more water, but the distribution pipes are a limiting factor.

If they had the choice between groundwater and treated wastewater for irrigation they would choose the treated wastewater. The groundwater quality was good, but the groundwater has two disadvantages: it is expensive and it contains no nutrients. Chemical fertilizer was not used because the nutrients in the wastewater were adequate to have three crop cycles per year. Before they used the treated wastewater they applied chemical fertilizer and used groundwater irrigation.

Local communities had no acceptance issues as reported by the operators.

*Institutional aspects*

The main institutions involved were the Mathura Jal Board, the Central Pollution Control Board (CPCB) and a private company that is contracted for one year by the Mathura Jal Board.

The roles of the Mathura Jal Board and the CPCS are the same as for Mathura I.

Three persons are employed by the private company: two non-technical operators and one technical operator. Their main task is cleaning of the pre-treatment unit.

*Economic aspects*

The construction costs are not known.

According to the operator, the municipality pays 700000 INR per year to the private company for operation and maintenance.

The land next to the WSP is leased to local farmers who can also use the treated water. The farmers reported that the price of leasing the plots included the use of wastewater and vary according to soil fertility between 16000-48000 INR/year per acre.

The treated wastewater is reused in agriculture by the nearby farmers. In two group interviews and one individual interview, the perception of the farmers was captured (see social aspects). The results show that the annual benefit of using wastewater is 8500 INR per year per acre (see Table 4).

**Table 4: Economic benefits of wastewater use in agriculture, Mathura I WSP**

| Component | INR |
|---|---|
| 1 bag of urea (50 kg)<br>1 bag of diammonium phosphate DAP (50 kg)<br>Irrigation with groundwater, 1 cycle | 500<br>1200<br><br>600-800/per acre (average 700) |
| **Annual financial input** | |
| Fertiliser (2 bags urea, 1 bag DAP) | 2200 |
| Groundwater, 9 cycles | 6300 |
| Total | 8500 |

*Summary of evaluation results*

The intended benefits of the treatment plant were fulfilled (see Table 5). However, effluent quality could not be assessed as the monitoring results were not available. Farmers are using the effluent for irrigation. Although the system appeared to be running normally, the ponds were contaminated with plastic materials. Plastic wastes were floating in the anaerobic pond and the surrounding of the pre-treatment unit was dirty (see Figure 9 and Figure 10).

**Table 5: WSP II Mathura – Fulfilment of intended benefit**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | monitoring is conducted, but results are not made public<br>- plastic waste floating in anaerobic ponds, (based on visual impression), dirty conditions around treatment plant |
| Reuse of treated wastewater | yes | the treated wastewater is used for irrigating vegetables and cereals (see Figure 11 and Figure 12) and the water is even preferred over groundwater as it is cheaper and no additional chemical fertilizer is required |
| No energy requirements | yes | - the treatment plant itself requires no energy to be functional<br>- pumping is required to transport wastewater to the treatment plant |
| No skills for O&M required | yes | - the operators are from the local community and need no special training, their main task is removal of solids from pre-treatment unit |

**Figure 9: Plastic waste in anaerobic pond**

**Figure 10: Pre-treatment unit**

**Figure 11: Agriculture around the treatment plant**

**Figure 12: Crops cultivated with treated wastewater**

**Mathura III**

This treatment plant was constructed more than 10 years ago. The system consists of two treatment chains with four ponds on each side (see Figure 13 and Figure 14). The water is reused for irrigation of cereals and vegetables that are not eaten raw.

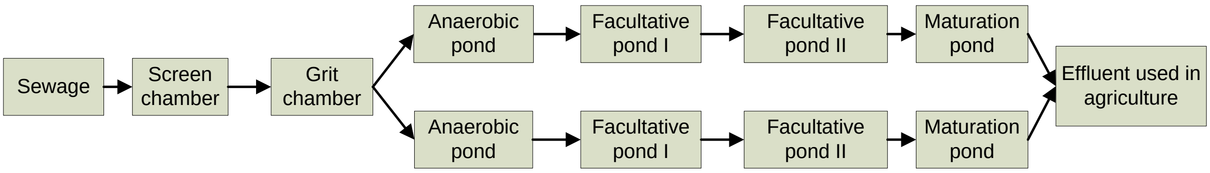


**Figure 13: Schematic flow chart of waste stabilization pond Mathura III**

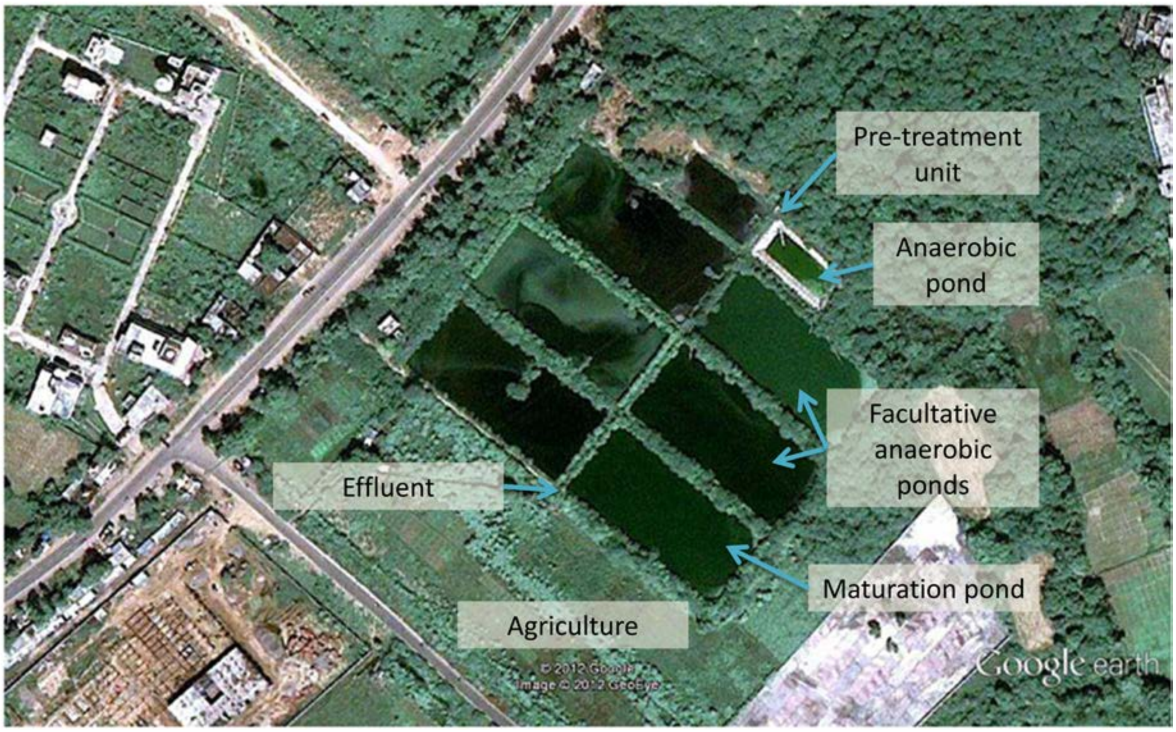


**Figure 14: WSP III in Mathura, picture from 2009 (Source: Google Earth)**

*Health aspects*

This treatment plant is not maintained by an assigned operator.

There is a possible risk of flooding during monsoon season for the surrounding houses in case the racks get blocked. Another possible risk is related to leaking treatment ponds that will not be detected soon as there are no monitoring wells and no operator.

There is a risk to farmers who are using the effluent for irrigation purposes as they are handling the water.

The water is used to irrigate cereals and vegetables that are not eaten raw; therefore the health risks for consumers are low.

However, the risk for farmers and consumers cannot be quantified as the quality of the treated wastewater is not known.

*Social aspects*

One farmer was interviewed about his satisfaction with the treated water: he was satisfied with the water quality. The water contains nutrients and he does not have to use chemical fertilizer. He is aware that the water cannot be used for domestic purposes.

*Institutional aspects*

There is no arrangement for operation and maintenance of the treatment plant and the system is currently working without any supervision and monitoring. There is a risk for the future.

*Economic aspects*

The construction costs are not known.

In contrast to the other WSPs in Mathura, no private company is contracted and the system is not maintained. Therefore, no costs occur.

Treated wastewater is reused by farmers who are paying 15000 INR per year for renting the farmland according to one local farmer who was interviewed. The costs for water are included in the rent of the field.

*Summary of evaluation results*

The intended benefits are partly fulfilled. However, this system seems to be in a bad condition: there is no operator, the racks are partly blocked and a lot of solids (mainly plastics) are floating in the ponds. The rack could become completely blocked and cause flooding. There are no groundwater monitoring wells and leaks in the pond can hardly be detected. Even though the skills for operators are low, no operator has been assigned for the operation and maintenance of the treatment plant. Future risks are indicated.

**Table 6: WSP III Mathura – Fulfilment of intended benefit**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - no monitoring conducted<br>- the system is not maintained at all, the pre-treatment system is partly blocked (see Figure 15), waste is floating in the ponds (Figure 16), plants are covering the surrounding and make access difficult (see Figure 17) |
| Reuse of treated wastewater | yes | the treated wastewater is used for irrigating vegetables and cereals (see Figure 18) and the interviewed farmer was satisfied with the quality |
| No energy requirements | yes | - the treatment plant itself requires no energy to be functional<br>- pumping is required to transport wastewater to the treatment plant |
| No skills for O&M required | **no** | - even though the operational requirements are low, no operator is assigned |

Figure 15: Partly blocked pre-treatment unit

Figure 16: Plastics in the anaerobic pond

Figure 17: Maturation pond

Figure 18: Farmers using the treated wastewater for irrigation

**Agra I**

This WSP was built 18 years ago in Agra by the local water board. It has a capacity of 10 MLD and treats mixed domestic and industrial wastewater. The water is passing two treatment chains with an anaerobic pond; two facultative ponds and one maturation pond on each side (see Figure 19). Water is discharged to a stream.

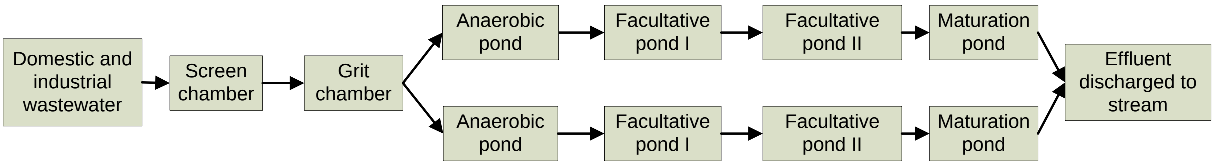

**Figure 19: Schematic flow chart of waste stabilization pond Agra I**

*Health aspects*

The risk to operators is similar to Mathura I.

The operator reported that when the system was built 18 years ago, the ponds were not lined and water could infiltrate which caused groundwater pollution. Then the system was lined with concrete. Now there is a monitoring well to ensure that groundwater is not contaminated.

Treated wastewater is not reused in agriculture, therefore no risks to farmers and consumers occur.

*Social aspects*

According to the operator, farmers do not want to use the water for irrigation due to the high salinity levels caused by the wastewater coming from the textile industry. He reported that farmers also do not want to use the sludge because they believe that it is harmful to the plants due to an overdose of nutrients.

According to the operator, there is no problem of acceptance of the treatment plant by the nearby residing local community.

*Institutional aspects*

The main institutions involved are the local water board, the CPCB and a private company contracted for operation and maintenance.

The local water board is responsible for monitoring of effluent quality and groundwater wells. The CPCB is conducting additional monitoring. Both institutions are not publishing the monitoring results.

The private company is responsible for operation and maintenance of the treatment plant. There are three operators and one supervisor working in the treatment plant. Their main tasks are cleaning of the rack and the surrounding of the ponds. Once a year each side of the treatment chain is cleaned.

*Economic aspects*

The construction costs are not known.

According to the operator, the contracted company receives annually 700000 INR for the operation and maintenance of the treatment plant. The staffs receive a salary of 2500 INR/month (operator) and 5000 INR/month (supervisor).

There are no benefits from the reuse of side products.

*Summary of evaluation results*

The intended benefits are partly fulfilled (see Table 7): based on the visual impression during the site visit, the wastewater treatment plant seems to be working well. Effluent is not reused, even though it was initially intended. No monitoring results are available in public. No energy is required for the treatment process and operation and maintenance works well. No further risk was identified.

**Table 7: WSP I Agra – Fulfilment of intended benefit**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - no monitoring results available<br>- system seems to be working well |
| Reuse of treated wastewater | no | the treated wastewater is used not used for irrigation as farmers have reservations against the water quality |
| No energy requirements | yes | - the treatment plant itself requires no energy to be functional<br>- pumping is required to transport wastewater to the treatment plant |
| No skills for O&M required | yes | - the operators are from the local community and need no special training, their main task is removal of solids from pre-treatment unit |

Figure 20 shows the pre-treatment unit and Figure 21 shows one of the maturation ponds.

**Figure 20: Pre-treatment unit**

**Figure 21: Maturation pond**

**Agra II**

The 2.25 MLD treatment plant was constructed around 10 years ago under the Yamuna Action Plan. The capacity is not enough and currently a new wastewater treatment plant is constructed nearby. Untreated wastewater is bypassed.Water is not reused as no agriculture is practiced in the surrounding area. The layout is similar to the other visited WSPs (see Figure 22).

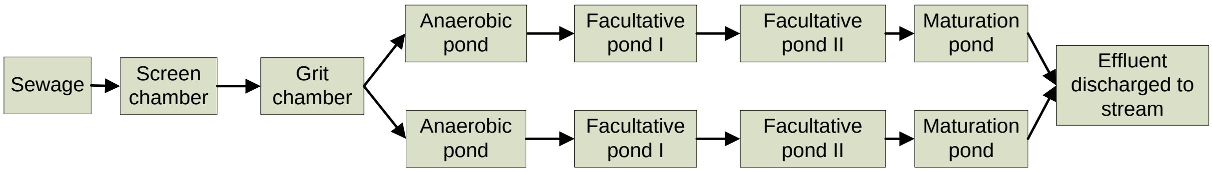


**Figure 22: Schematic flow chart of waste stabilization pond Agra II**

*Health aspects*

The risk to operators is similar to Mathura I.

The residents are using water from nearby tube wells and one monitoring well was installed to control the groundwater quality.

Treated wastewater is not reused in agriculture, therefore no risks to farmers and consumers occur.

*Social aspects*

Treated wastewater is not reused; therefore acceptance is not an issue.

According to the operator, there were no problems of acceptance of the treatment plant with people from the local community.

*Institutional aspects*

The main institutions involved are the local water board, the CPCB and a private company contracted for operation and maintenance.

The local water board and the CPCB are responsible for monitoring of the effluent quality and the monitoring well. The monitoring results are not public.

The private company employs four non-technical and two technical operators for operating the treatment plant and a pumping station. Their main task is cleaning of the rack and cleaning of system. Once a year each side of the treatment chain is cleaned.

*Economic aspects*

The construction costs are not known.

According to the operators, the contracted company receives 300.000 INR per year. The six operators receive a salary of 3200 INR / month and can live within the premises of the treatment plant.

*Summary of evaluation results*

The intended benefits are fulfilled (see Table 8). The treatment plant seems to work well based on the visual impression during the site visit. It will soon be expanded with an up flow anaerobic sludge blanket (UASB). No further risks could be identified.

**Table 8: WSP II Agra – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - no monitoring results available<br>- the system seemed to work well, clean surrounding (see Figure 23) |
| Reuse of treated wastewater | not applicable | no agriculture is practiced (see Figure 24) |
| No energy requirements | yes | - the treatment plant itself requires no energy to be functional<br>- pumping is required to transport wastewater to the treatment plant |
| No skills for O&M required | yes | - the operators are from the local community and need no special training, their main task is removal of solids from pre-treatment unit |

**Figure 23: Treatment unit**

**Figure 24: Effluent to drain and then to Yamuna river**

### 3.4.2 Polishing pond

Polishing ponds are usually a single component of conventional or natural treatment systems. They serve as a post-treatment unit to improve the quality of the effluent, before it is discharged. The assessment was made for the whole treatment plant as it is not possible to evaluate the functioning of the pond without considering the entire treatment plant.

The intended benefit is the treatment of wastewater according to the Indian norms for stream disposal. An additional benefit of the visited treatment plant is the improvement of the environmental conditions in the surrounding area.

**Hyderabad**

The wastewater treatment plant was constructed in 2009 at Nallacheravu in Hyderabad. Its design capacity is for treatment of 30 MLD. Currently it receives around 15 MLD and should receive the full volume, once the network coverage is completed. After passing the pre-treatment unit consisting of screens and grit chambers, wastewater enters four up flow anaerobic sludge blankets (UASB) reactors, then an aerated pond and finally a polishing pond (see Figure 25). The effluent is chlorinated.

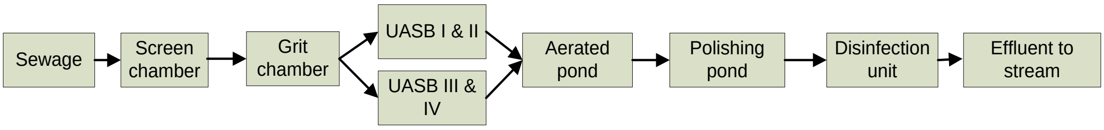


**Figure 25: Flow chart of treatment plant in Hyderabad**

Treated water is released to a nearby stream (mainly consisting of untreated wastewater and storm water) which is used as source for irrigation, but the water is not used directly. Farmland is adjacent (see Figure 26 and Figure 31) to the treatment plant and the farmers are now using water from a stream which is of worse quality than the effluent.

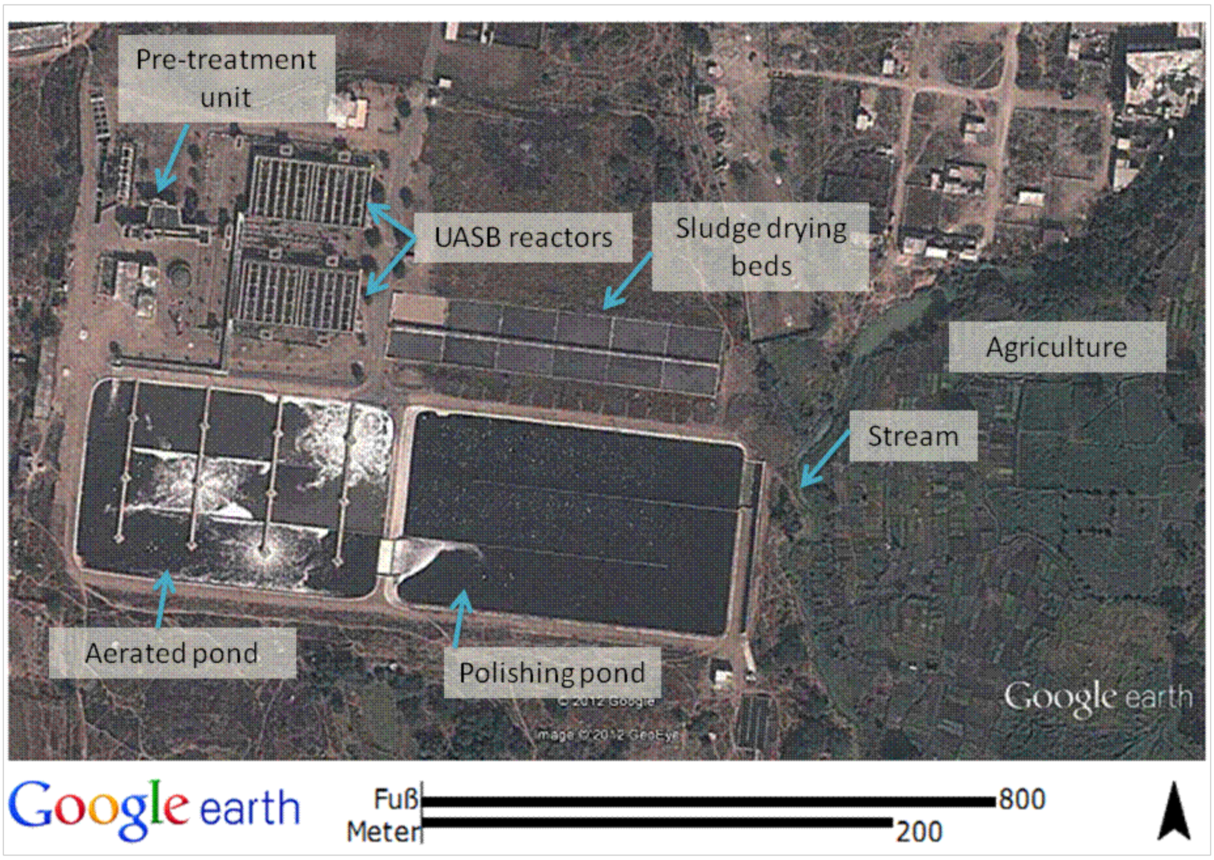


**Figure 26: WSP in Mathura, picture from 2009 (Source: Google Earth)**

*Health aspects*

There is a risk to operators who are working without special equipment and get into contact with wastewater and sludge. However, health problems have not been reported so far.

There is an informal settlement located next to the treatment plant. In case of flooding, the houses could become flooded.

Treated water from the system is discharged to a storm water stream nearby and not reused. Therefore, no risks to farmers or consumers occur. According to the management, the water quality matches the norms stipulated for disposal.

*Social aspects*

The effluent is not directly used for irrigation: it is discharged to a small stream from where farmers extract water for irrigation. One farmer cultivating downstream of the STP vegetables (e.g. spinach, amaranth, tomatoes) was satisfied with the quality of water she received even though the quality of the water was worse than the quality of effluent (see Figure 27 and Figure 28) .

There have been no problems of acceptance with the local population so far. According the operators, there were no problems concerning acceptance of the treatment plant so far.

*Institutional aspects*

The main institutions involved are the Hyderabad Municipal Water Supply and Sewerage Board (HMWSSB), the CPCB and a private company that is contracted to operate the treatment plant.

The HMWSSB and the CPCB are responsible for monitoring of the treatment plant. Two people from the HMWSSB are working in the treatment plant to oversee the functioning.

The private company is contracted for three years, the contract is now expiring and a new contract is tendered. Attempts will be made to retain current operators as they are already well trained and know how to operate the treatment plant. The operators are trained at the ITI (industrial training institute) after their secondary education (10$^{th}$ grade).

At present, 19 people of the company are working in the treatment plant. Total man-power is not sufficient to cover all the activities, especially, for sludge drying, which requires emptying and drying under natural conditions. It is envisaged to employ additional staff for the handling of sludge.

The standards (and even more parameters) are checked daily in a lab located within the premises of the treatment plants for inlet, UASB effluent, facultative lagoon effluent and final outlet effluent for pH, temperature, BOD, COD, TSS, Faecal coliforms (FC) in a laboratory within the treatment plant. Also the volume entering the treatment plant is monitored. The institutional arrangements are well coordinated at this plant and the discharge standards meet the criteria set by the CPCB. Table 9 shows the performance of the treatment plant in 2011.

**Table 9: Performance of the treatment plant in Hyderabad (annual average of 2011)**

| Unit name | | Unit 1 UASB influent and effluent | Unit 2 FAL influent and effluent | Unit 3 PP influent and effluent |
|---|---|---|---|---|
| $BOD_5$ | $BOD_{inlet}$ | 177.56 ± 42.77 | - | - |
| | $BOD_{outlet}$ | - | - | 17.72± 4.5 |
| COD (mg/L) | $COD_{inlet}$ | 452.93 ± 75.31 | 234.84±58.06 | 126.93±25.74 |
| | $COD_{outlet}$ | 234.84± 58.06 | 126.93± 25.74 | 86.44±11.05 |
| *p*H | $pH_{inlet}$ | 7.7 ± 1.05 | 7.5 ± 0.15 | 7.9 ± 0.16 |
| | $pH_{outlet}$ | 7.5 ± 0.15 | 7.9 ± 0.16 | 7.9 ± 0.16 |
| TSS (mg/L) | $TSS_{inlet}$ | 452.06 ± 55.96 | 107.74 ± 43.15 | 65.00 ± 21.23 |
| | $TSS_{outlet}$ | 107.74 ± 43.15 | 65.00 ± 21.23 | 47.73 ± 21.25 |
| Faecal Coliform (MPN/100ml) | Inlet | $6.41x10^5$± $0.76x10^5$ | | |
| | Outlet | | | 6317.64 ±796.41 |

*Economic aspects*

The cost for installation of the STP system was 150 million INR and annual operation and maintenance costs of 675000 INR per year incur, of which 225000 INR are personnel and maintenance costs, and 450000 INR are for electricity. The costs for post-treatment activities are not known; the amount of chlorine used is at 2 mg/l. The costs are covered by the Hyderabad Municipal Water Supply and Sewerage Board (HMWSSB). A fee is levied for sewage treatment which amounts to 30% of the water bill (at present a flat rate of INR 212 per household per month).

While there are opportunities for revenue generation from by-products (sludge, treated water, biogas), no gainful economic benefits are reported. The amount of wastewater received at present is not sufficient for economical production of biogas; further, the generator that has been installed is a duel fuel generator, which according to the operating company costs more to operate than the energy that can be harnessed from the plant.

At present, there is no market for sludge. The downstream farmers feel that the water carries adequate nutrients, and therefore additional supplements are not required (according to the staff at STP). The sludge is dried in the premises (see Figure 29), and used for gardening within the site.

*Summary of evaluation results*

The system is working well and fulfils its intended benefit. There are no problems with the load and there is still capacity to connect more people. Clogging is happening from time to time, because of rough debris, especially plastics. Since the law against use of plastics (APPCB, 1998) was implemented the less low density plastics reach the STP. A potential threat is the use of the bypass (see Figure 30) to release the untreated wastewater during power cuts. This will contribute to an increase in the pollution loads in the adjacent waterways. The rapid turnover of technical staff can have an impact on the future functioning.

**Table 10: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | yes | the system is working well (see Table 9) and has still more capacity |
| Improvement of environment | yes | the lake, in which wastewater was discharged before construction of the wastewater treatment plant, is now cleaner and biodiversity has increased (based on visual judgement of local partners during field visit, see Figure 31) |

**Figure 27: Interview with a farmer**

**Figure 28: Agriculture near WWTP**

**Figure 29: Sludge drying beds**

**Figure 30: Bypass (in this case some solids were blocking the valve)**

**Figure 31: Lake that received wastewater before plant was constructed (now overgrown)**

### 3.4.3 Planted gravel filter

The planted gravel filter is the last part of a treatment system consisting of a baffled septic tank, anaerobic baffled reactor and/or anaerobic filter. The intended benefit is treatment of wastewater according to Indian norms and reuse of treated wastewater. The system is easy to operate and maintain and requires low energy.

**Agra**

The system consists of a pre-treatment unit, a baffled septic tank, a baffled filter reactor and planted reed beds (see Figure 32). The assessment was made for the whole treatment plant, which receives 50 cubic meter domestic wastewater per day, as it is not possible to evaluate the functioning of the planted gravel filter (see Figure 35) without considering the entire treatment plant.

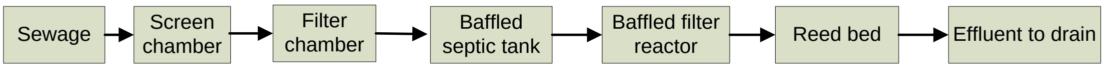


**Figure 32: Schematic flow chart of decentralised wastewater treatment system**

The treated wastewater is not reused. It enters an open channel, where the remaining wastewater and storm water that do not enter the treatment plant (as the system is very small) are conveyed to Yamuna River.

An additional intended benefit of the system is the improvement of the environmental situation in the area

It is planned to upscale the system in the near future. For the larger system, reuse of water for irrigation purposes is intended. The location of the treatment system within the slum area can be seen in Figure 33.

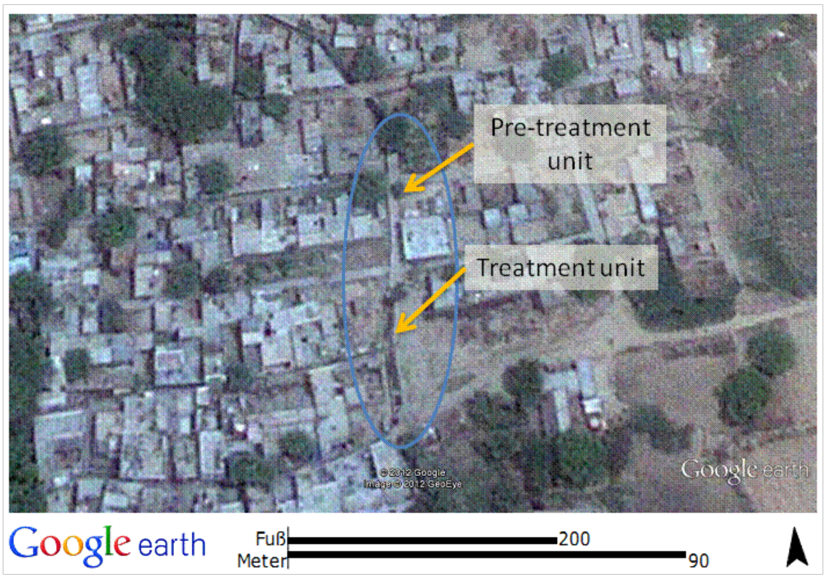


**Figure 33: Planted gravel filter in Agra (Source: Google Earth)**

*Health aspects*

Operators are exposed to a possible risk of faecal-oral transmission when emptying the grit chamber. It is located under the pavement (see Figure 34) and even more difficult to empty than conventional pre-treatment units. However, the risk cannot be quantified as the quality of the incoming wastewater is not known.

The system is located in a residential area. According to the operator there were no complaints about mosquitoes or other nuisances affecting the health so far.

There is no health risk emanating from the treatment system for farmers or consumers as treated water is not reused.

*Social aspects*

Treated wastewater is not further used, therefore no issues concerning acceptance of treated wastewater occur.

There were no problems related to acceptance of the treatment plant so far. With the implementation of the system, employment opportunities during construction and for operation and maintenance were created and the environmental situation is improving. The community was involved in construction and the newly created pavement on the top of the pre-treatment unit is a meeting place for the villagers. Community participation was an integral part of implementation and the community is also involved in the operation of the treatment plants (NIUA 2011).

*Institutional aspects*

The main institutions involved in operation and maintenance of the treatment system is the Centre for Urban and Regional Excellence (CURE) which already assisted in construction, where also support from the Agra Nagar Nigam (ANN), USAID FIRE (D), Cities Alliance and financial assistance from Water Trust, United Kingdom and London Metropolitan University was provided.

Two operators from the community are operating the treatment plant. They were trained and in case of problems the implementing NGO (CURE) can be contacted. Their main task is cleaning of the rack, all other task e.g. cleaning of filter material, removing of solids from grit chamber are done when necessary. Every three months, the effluent quality is monitored by the local NGO, but the results are not public.

The current institutional arrangement works well as in case of problems the local NGO provides support to the operators. Until now, only one problem occurred which could be solved by the operators in cooperation with the NGO: the system was blocked in March 2012 and the operators had to remove the filter material, wash it manually and put it back to the system.

*Economic aspects*

The investment costs were 1.1 million INR.

Annual operation and maintenance costs are around 300.000 INR. Cost recovery is done in an unconventional way: the revenues from the “Mughal Heritage Trail”, which was initiated by the same NGO that implemented the WWTP (see institutional aspects), are used to pay the salary of the operators. The revenues from the trail are sufficient to pay five guides on the trail and two operators in the treatment plant (see Table 11). The operators receive a salary of 3500 INR /month each.

**Table 11: Costs and revenue for operation and maintenance of treatment plant in Agra**

| Components | Value |
|---|---|
| Number of visitors per year<br>Revenues per visitor (INR) | 450<br>700 |
| **Total revenues: 700IR/person * 450 visitors per year (INR/year)** | **315000** |
| Costs per operator/tour guide: 12 x 3500 INR/year | 42000 |
| 5 guides (INR/year) | 210000 |
| 2 operators (INR/year) | 84000 |
| **Total costs (INR/year)** | **294000** |

*Summary of evaluation results*

The intended benefits are mainly fulfilled (see Table 12). The monitoring results were not available, but based on the visual impression; the treatment system seemed to work well. Water is not reused, but it is planned to reuse the water after up scaling of the treatment plant.

Plans for an upgrade of the system have already started. Apart from the treatment of domestic wastewater, another intended benefit was to improve the quality of the environment of the poor families in Kuchhpura. As reported by the National Institute of Urban Affairs (NIUA 2011) the environmental situation has improved. The open channel that conveyed the wastewater to the Yamuna River is now covered and can be crossed easily even during monsoon.

The treatment process requires no energy and only basic skills are required. However, continuous support from the NGO proved to be a reason for success.

No additional risks could be detected.

**Table 12: Planted gravel filter Agra - fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - monitoring is conducted, but information about performance is not available in public |
| Reuse of treated wastewater | no | - the treated wastewater is not reused, but it is planned to reuse the effluent after up scaling of the treatment plant |
| No energy requirements | yes | - no energy is required for the treatment process<br>- wastewater is collected by a gravity sewer |
| No skills for O&M required | partly | - the operators have no special skills, but they received a short training from the supporting NGO |
| Improvement of environmental situation | yes | compared to the situation before, the environmental situation has improved, this was confirmed during the site visit by local people |

**Figure 34: Pre-treatment unit below pavement**

**Figure 35: Treatment unit planted with canna indica**

### 3.4.4 Constructed wetland

The intended benefit of constructed wetlands is treatment of wastewater according to Indian norms and low energy requirements. Additional expected benefits may depend on local circumstances.

**Bhopal I (park)**

Figure 36 shows the components of the treatment system: around 25% of the total wastewater is entering the horizontal flow constructed wetland (see Figure 37) , the remaining 75% are directly entering the natural treatment system (see Figure 38) planted with *canna indica* as the capacity of the constructed wetland is not enough to treat the entire wastewater stream


**Figure 36: Flow chart of the treatment plant in Bhopal**

Treated water from the natural wetland is released to a small pond from where it is pumped for irrigation.

Nearby an open stream of untreated wastewater is crossing the park. It is crossing the park without being treated or used for any purpose.

Additional intended benefits are the avoidance of problems with mosquitoes and reuse of water.

*Health aspects*

There are no formally assigned operators. The park operators employed for the maintenance of the park have no special equipment and come directly into contact with the treated wastewater. The results of the monitoring in 2003 showed E.Coli of $8x10^{3}$ MPN/100 ml in the effluent which is lower than the recommended standard of the CPCB (2008) of $10^4$ MPN/100 ml, but lower than the desirable $10^3$ MPN/100 ml. As no recent monitoring results are available, the risk cannot be quantified.

Visitors of the park are the main stakeholder group that is impacted by the constructed wetlands. As the systems are not well maintained accumulating wastewater can become breeding grounds for mosquitoes. In the park area raw wastewater is conveyed to the treatment plant in an open unlined channel. Visitors, especially children who are not aware of the water quality, can easily come into contact with the untreated wastewater. Besides, a large stream of untreated wastewater is crossing the park.

The treated wastewater is used for gardening within the park. As mentioned above, there is a risk for the park staff that is getting into contact with the water.

As water is not produced for agricultural purposes, there are no consumers that could get into contact with products irrigated with treated wastewater.

*Social aspects*

Park staff is handling the treated wastewater for gardening. Three operators were interviewed. They think that the use of treated water contributes to water conservation.

There are no communities around the treatment plant; however visitors to the park can be affected due to the quality of the water used for irrigating the lawns. Eleven visitors were interviewed and those who come regularly to the park were aware of the treatment plant located within the park area. There is also stream of untreated wastewater crossing the park and 50% of the respondents reported odour emanating from this stream. Also the appearance of mosquitoes was mentioned as problem, but the respondents think that the mosquitoes are not originating from the treatment plant, but from the untreated wastewater. One respondent reported that he had seen children playing at the outlet of the treatment plant where water accumulates to be later used for irrigation. All respondents think that wastewater is a safe water source for the irrigation of the park. Table 13 shows the sample characteristics and the results of the small survey.

**Table 13: Sample characteristics and results, CW Bhopal**

| Descriptive statistics | Sample Description | n=11 respondents |
|---|---|---|
| Gender | Male<br>Female | 64%<br>36% |
| Age | 20 – 30<br>31 – 40<br>41- 50<br>51 - 60 | 27%<br>18%<br>18%<br>37% |
| **Question** | **Answers** | **Percentage** |
| How often are you visiting the park? | first time<br>two times per week<br>every day | 18%<br>27%<br>55% |
| Do you know which water is used in this park for irrigation? | treated wastewater<br>no | 45%<br>55% |
| Did you experience any problems/risks (related to the (treated) wastewater)? (multiple answers possible) | mosquitoes<br>children playing with the treated water<br>bad smell of untreated wastewater (note: not related to treatment plant)<br>no | 45%<br>9%<br>45%<br>6% |
| Do you think that treated wastewater is safe to be used for irrigation? | yes<br>no | 100%<br>0% |

*Institutional aspects*

The main stakeholder involved in operation and maintenance of the treatment plant is the Bhopal Municipal Corporation (BMC) that is not continously operating the treatment plant, but reduces the activities to annual cleaning of the pre-treatment unit. Plants are growing wild (see Figure 37) in the treatment unit, but the initially planted *Phragmites karka* still prevails.

The Madhya Pradesh Pollution Control Board controls the effluent every month, but the results are not available for the case study. Table 14 shows monitoring results from the year 2003.

**Table 14: Chemical and microbial parameters tested –CW Bhopal (Source: Vipat et al. 2008 , monitoring period: September 2003)**

| | | Average Values September 2003 | | | | | |
|---|---|---|---|---|---|---|---|
| S.No | Parameters (Conc. in mg/l) | Inlet/ Waste-water | After Pretreatment | Outlet treated water | Treatment Performance (% Reduction ) | | |
| | | | | | PT | CW | Whole CW |
| 1 | pH | 7.9 | 7.5 | 7.00 | 4.80 | 6.80 | 11.3 |
| 2 | Turbidity (NTU) | 72 | 41.8 | 8.30 | 42.0 | 80.0 | 88.4 |
| 3 | Total Solids | 103 | 78.9 | 30.2 | 23.4 | 61.7 | 70.7 |
| 4 | Total Suspended Solids | 75 | 58.2 | 15.7 | 22.4 | 73.0 | 79.0 |
| 5 | Total Dissolved Solids | 28 | 20.7 | 14.5 | 26.2 | 30.0 | 48.3 |
| 6 | Chemical Oxygen Demand | 142.0 | 98.7 | 31.6 | 30.5 | 68.0 | 77.8 |
| 7 | Dissolved Oxygen | 1.30 | 1.30 | 3.10 | 0.00 | 139* | 139* |
| 8 | Total Kjeldahl Nitrogen | 13.5 | 12.0 | 4.20 | 11.0 | 65.0 | 68.8 |
| 9 | Ammonium Nitrogen | 6.80 | 5.78 | 3.20 | 15.0 | 45.0 | 53.3 |
| 10 | Nitrate Nitrogen | 2.50 | 2.21 | 0.95 | 11.5 | 57.0 | 62.0 |
| 11 | Organic Nitrogen | 4.20 | 4.00 | 0.00 | 5.00 | 100.0 | 100.0 |
| 12 | Biological Oxygen Demand | 57.0 | 46.7 | 19.5 | 18.0 | 58.2 | 65.7 |
| 13 | (*E.Coli*) Most Probable Number / 100ml | $6x10^5$ | --- | $8x10^3$ | --- | 98.7 | 98.7 |

*Economic aspects*

The system was constructed 20 years ago and the costs were 1.4 million INR according to a sign in the park.

No operation and maintenance costs occur as there are no operators assigned and no electricity and spare material are required.

The pre-treatment unit is cleaned when necessary by the park staff. Water is used for irrigating the whole park with a size of 65 acres.

*Summary of evaluation results*

The intended benefits are mainly fulfilled (see Table 15), but odour and mosquitoes were evident in the stream of untreated wastewater crossing the park. Evaluation results from the year 2003 showed good performance of the treatment plant, no energy is required for the treatment process and water is completely reused. At present the system appears to have degraded, and there could be health risks to the staff who come into contact with the treated water and children who play with the treated water that is collected for irrigation.

**Table 15: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | yes | published evaluation results are 15 years old, data from central and local pollution control board not available |
| Reuse of treated wastewater | yes | the treated wastewater is used for gardening within the park (see Figure 39) |
| No energy requirements | yes | the treatment unit requires no energy |
| No odour and mosquito problem | partly | odour and mosquitoes are a problem, but emanate not from the treatment unit, but from the stream of untreated wastewater crossing the park (see Figure 40) |

**Figure 37: Constructed wetland**

**Figure 38: Natural wetland**

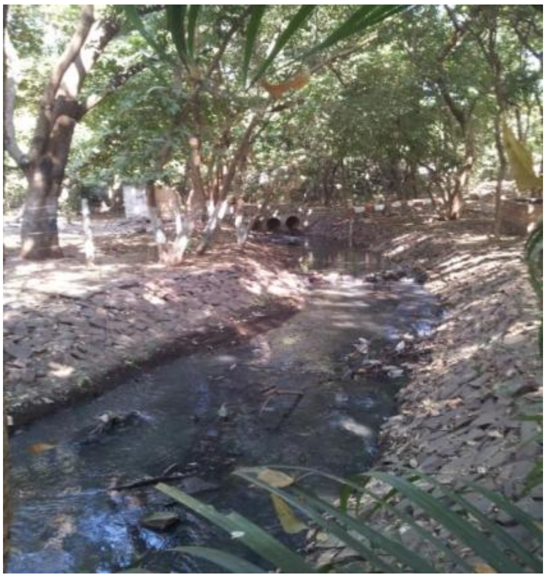

**Figure 39: Treated water used for irrigation (without using gloves)**

**Figure 40: Wastewater stream crossing park**

**Bhopal II (slum area)**

The intended benefit is treatment of wastewater which is the discharged to an underground sewer.

The constructed wetland is located in a slum area in Bhopal in Madhya Pradesh. It treats 0.5 MLD wastewater of the adjacent community. The wastewater passes a settling unit and a septic before entering a horizontal subsurface flow constructed wetland (see Figure 41)

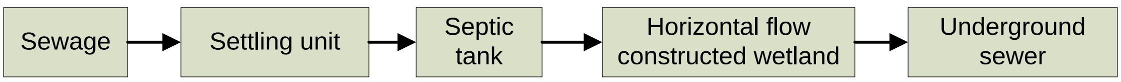


**Figure 41: Flow chart of treatment plant in Bhopal**

Treated water is released to an underground sewer. Both inlet and outlet cannot be accessed.

*Health aspects*

There is no officially assigned operator; therefore no risks to operating staff occur.

Communities living close to the treatment plant in the slum community are directly affected by the treatment plant and reported some issues that could impact health: as the system is not well maintained, accumulating wastewater are breeding grounds for mosquitoes and rats.

The outlet of the constructed wetland is underground and effluent discharges to a sewer and is not reused. Therefore, no risks to farmers or consumers occur.

*Social aspects*

Effluent is not reused; therefore acceptance of treated water is not an issue.

The constructed wetland is located within a residential area. Houses and treatment plant are only separated by a fence and a narrow alley. Seven direct neighbours were interviewed and all respondents reported problems related to the treatment plant (see sample characteristics in Table 16). All of them knew about the purpose of the constructed wetlands. The main problem mentioned by 60% of the respondents is the high number of mosquitoes which find a humid habitat within the constructed wetland. Other problems mentioned by the neighbours are clogging of the sewer which transports the wastewater from to the treatment plant and resulting flooding, smell and risks for children: the constructed wetland is located one meter below pavement level and is easily accessible which poses a potential risk to children who can fall into the treatment unit. The surrounding is not well protected and one respondent reported an accident one year ago when a nearby power pole collapsed and fell into the treatment plant. The neighbours trace the problems back to lack of operation and maintenance.

**Table 16: Sample characteristics and results, CW Bhopal**

| Descriptive statistics | Sample Description | n=7 respondents (out of 10 direct neighbours) |
|---|---|---|
| Gender | Male<br>Female | 71%<br>29% |
| Age | 20 – 30<br>31 – 40<br>41- 50<br>51 - 60 | 43%<br>14%<br>29%<br>14% |
| **Question** | **Answers** | **Percentage** |
| Do you know how the treatment system works? | septic tank and vegetation to treat wastewater<br>no | 86%<br>14% |
| Did you experience any problems? | mosquitoes<br>bad smell<br>clogging of sewer and flooding<br>rats<br>fire<br>risk for children | 57%<br>29%<br>29%<br>14%<br>14%<br>14% |

*Institutional aspects*

The main institution involved is the Bhopal Municipal Corporation (BMP), who also constructed the treatment plant.

There is no formal operation and maintenance arrangement, but in emergency cases like clogging or fire (see social aspects below), the BMC takes over responsibility.

Monitoring is not conducted, but the treatment plant will be investigated in detail in WP3.

*Economic aspects*

The constructed wetland was constructed ten years ago and the costs were 1.1 million INR not including land costs (personal communication, IITB).

No operation and maintenance costs occur as there is no formal arrangement for operation and maintenance.

*Summary of evaluation results*

The intended benefits are mainly fulfilled: wastewater is treated, but no results of the analysis of the effluent are available. The system requires no energy for treatment and wastewater is conveyed to the treatment plant in a gravity sewer. Residents in the adjacent community complained about mosquitoes and possible risks for children. Possible risks for the residents living next to the treatment plant exist as illustrated above.

**Table 17: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - influent and effluent are underground and no monitoring results are available. In WP 3 the detailed assessment will investigate the effluent quality |
| No energy requirements | yes | - no energy is required for the treatment process<br>- wastewater is collected by a gravity sewer |

**Figure 42: Constructed wetland**

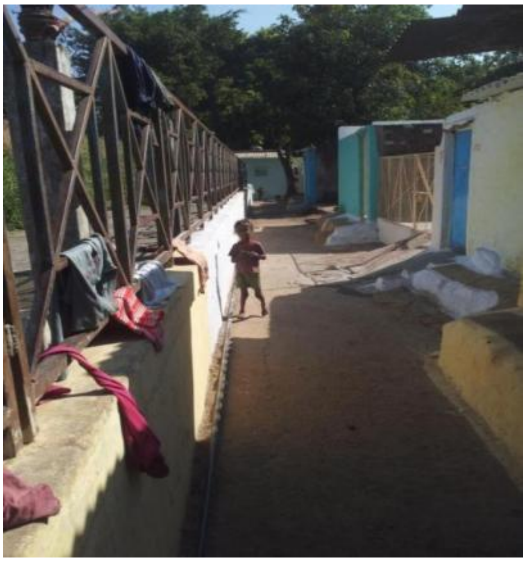

**Figure 43: Residential area next to treatment plant**

### 3.4.5 Duckweed and water hyacinth ponds

The intended benefits of duckweed ponds (DP) and water hyacinth ponds (WHP) is treatment of wastewater according to Indian norms, reuse of treated wastewater, use of by-products (duckweed, fish) and low energy use.

**Naruana**

The water hyacinth pond is located in the rural community Naruana near Bathinda in Punjab. It receives 0.25 MLD domestic wastewater from the local community. Water is conveyed in an open drain to the treatment system, which is common in rural India. The wastewater reaches a pond system which consists of a water hyacinth pond, an oxidation pond and a fish pond (see Figure 44). The sewer (see Figure 45) was constructed 30 years ago and the hyacinth pond was implemented in 2007 by the local government (see Figure 46). Before the system was built, wastewater directly discharged to the village pond, which is now used for rearing fish (see Figure 47).

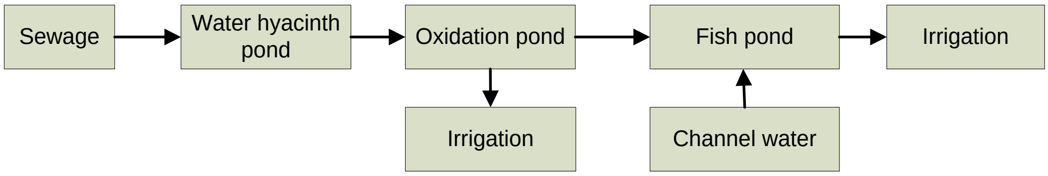


**Figure 44: Flow chart of treatment plant in Naruana**

There is no effluent; all water is used for irrigation (see Figure 48). Water for irrigation is extracted by pumps from the oxidation pond and the fish pond which receives additional water from the nearby irrigation channel if necessary.

*Health aspects*

There is no formal arrangement for operation of the ponds, therefore no risks occurs to operating staff. However, during the annual cleaning of the pond, people from the village come into contact with sludge, wastewater and water hyacinths. As the quality of the wastewater is not known, the risk cannot be quantified.

The treatment plant is located near a residential area. The main risk for people residing near the ponds is flooding during heavy monsoon rain. According to three local people who were interviewed there have been no problems so far.

The treated wastewater is used to irrigate wheat, sorghum and cotton. There is a possible health risk to farmers who come into contact with the treated wastewater, but as the quality of the effluent is not known, it cannot be clearly determined.

The risk to consumers is low as the cultivated crops (wheat, sorghum and cotton) are not eaten raw.

*Social aspects*

Two farmers that use the water for irrigation purposes and one member of the local sports club, which organises the annual cleaning campaign, were interviewed. All interviewed persons know that this is a wastewater treatment plant and the plants help to clean the water. They perceive that the water is better than the water from the irrigation channel as yields increase by 5-10% without additional use of fertilizers. Further, they are aware that the water can only be used for irrigation. The main restrictions concerning availability of treated water are related to the distance of the fields, In future it is expected that a common pumping station will be built which will allow more farmers to be supplied with the treated wastewater.

According to the three local people that were interviewed there have been no problems with acceptance of the pond system so far. The ponds have existed since a long time and are perceived as part of the village.

*Institutional aspects*

The main institution involved in the operation of the pond system is the local sports club that organises annual cleaning of the ponds within a general cleaning campaign for the whole village in which the community participates. After the removal of accumulated sludge, the sports club organisers the planting of new hyacinth plants in the pond.

There is no arrangement for permanent operation of the treatment system. There are no permanent operators assigned and the quality of the treated wastewater is not monitored.

*Economic aspects*

The construction costs are not known. Labour for construction was provided within the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) which is a guarantee scheme for hundred days of work at minimum wage for every adult living in rural households.

According to local people, the water hyacinths are removed annually during the communal village cleaning campaign initiated by the local sports club, but not used for any purpose. The fish which is cultivated in the village pond is auctioned once a year. The revenues of 100000 INR are added to the communal village fund.

Excess water is used for irrigation purposes. One farmer reported that the crop yield increases 5-10% if he uses the treated wastewater instead of channel water which corresponds to an economic benefit of 13500 – 27000 INR per acre if fields are planted with wheat and cotton.

*Summary of evaluation results*

The intended benefits are partly fulfilled (see Table 18). It is not known whether Indian standard of water quality is fulfilled as no monitoring is conducted, but the water undergoes treatment and the local community is satisfied with the solution as additional income is generated by the fish. Treated water is used for irrigation. Water hyacinths are not further used for any purpose after harvesting and dumped next to the treatment plant. The treatment requires no energy and wastewater is collected in a gravity sewer.

There is a potential risk of flooding during monsoon season.

**Table 18: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - no monitoring results available |
| Reuse of treated wastewater | yes | - treated wastewater used for irrigation |
| Use of side products | partly | - cultivation of fish<br>- water hyacinth not used for any purpose |
| No energy requirements | yes | - no energy is required for the treatment process<br>- wastewater is collected by a gravity sewer |

**Figure 45: Open sewer**

**Figure 46: Water hyacinth pond**

**Figure 47: Fish pond**

**Figure 48: Cotton fields**

**Saidpur**

The DP was constructed in 2004 and receives 0.35 MLD domestic wastewater from the local community. Wastewater enters the duckweed pond via an open sewer (see Figure 50 and Figure) and then flows into the fish pond from (see Figure 52), after which it is extracted for irrigation (see Figure 53). There is no outlet and only excess water is used for irrigation to keep the level in the fish pond high.

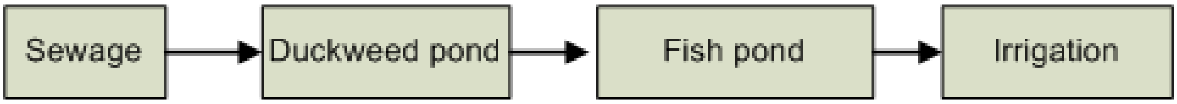


**Figure 49: Flow chart of treatment plant in Saidpur**

*Health aspects*

There is a possible risk to the operators who removes the duckweed from the water surface. Currently, removal is carried out without any special equipment, and the cleaners are exposed to the contaminants.

The treatment plant is not located in a residential area; therefore, no risks to any communities. .

There is a possible risk to farmers who come into contact with treated wastewater, which is used to irrigate wheat, sorghum and cotton. However, the risk cannot be quantified as the quality of the treated wastewater is not known.

The quality of the fish was tested twice by the Food Corporation of India for heavy metals and pathogens and showed that fish were suitable for eating. The risk for the consumer of irrigated plants is low as the types of crops grown are not eaten raw.

*Social aspects*

The treated water is accepted for irrigation and the two interviewed farmers even prefer it over groundwater as it contains more nutrients.

According to the two farmers, there are no problems with the community as this treatment system is located outside the residential area.

*Institutional aspects*

The main institutions involved are the local government and the Ludhiana Pollution Control Board.

One person was assigned by the local government to remove the duckweed from the pond every week.

The quality of the effluent is monitored twice a year by the Ludhiana Pollution Control Board, but the information about the performance is not public.

*Economic aspects*

The construction costs are not known. Labour for construction was provided within the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) which is a guarantee scheme for hundred days of work at minimum wage for every adult living in rural households.

According to two local people who were interviewed, operation and maintenance costs are recovered with the revenues from auctioning the fish. The annual earnings of 50.000 INR are used to 25% to pay the operator; the remaining money goes to the village fund. As additional benefit, orange trees are planted around the treatment unit and villagers can pick oranges whenever they want.

*Summary of evaluation results*

The intended benefits are mainly fulfilled (see Table 19) and no further risks were detected. As no monitoring results are available, no statement about the performance can be made, but the treatment plant seemed to work well based on the visual impression during the field visit. Treated water is used for irrigation. Operation costs can be recovered by the earnings from selling the fish.

**Table 19: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - monitoring is conducted, but results are not public<br>- treatment plant seemed to work well |
| Reuse of treated wastewater | yes | - treated wastewater is used for irrigation |
| Use of side products | yes | - duckweed is used as fish fodder<br>- fish are cultivated in fish pond<br>- orange trees around ponds generate additional benefit |
| No energy requirements | yes | - no energy is required for the treatment process<br>- wastewater is collected by a gravity sewer |

**Figure 50: Inlet of duckweed pond**

**Figure 51: Duckweed pond**

**Figure 52: Fish pond with orange trees planted around**

**Figure 53: Agriculture around treatment plant**

**Bathinda district**

The intended benefit is treatment of wastewater of the local community and reuse of water for irrigation. This is not a constructed, but a natural treatment system. It receives 0.25 MLD wastewater which is conveyed in an open sewer (see Figure 55) to the village pond, where water hyacinths (see Figure 56) were planted around five years ago. There is no outlet.

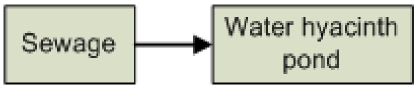


**Figure 54: Flow chart of treatment plant in Bathinda district**

*Health aspects*

There is no formal arrangement for O&M; therefore operating staff is not exposed to any risk. During the attempt to remove the plants from the pond (see below), people can come into contact with the wastewater and can be exposed to possible health risks.

Wastewater in the water hyacinth pond is hardly accessible as it is covered by a thick layer of water hyacinths. There is no smell and no problems with mosquitoes, as reported by the users.

Water from the pond is not used for any purpose, therefore no health risk emanate from treated water.

*Social aspects*

Ten persons from the village expressed their opinion about the pond system. Treated water cannot be used as a thick layer of plants is covering the surface. Before the plants grew in the pond, villagers used to irrigate their fields with the water from the pond, but now it is not possible anymore as the water is not accessible, which is considered as problem by local people.

According to villagers, bad odour from the wastewater disappeared, but the excessive grow of water hyacinths in the pond makes the use for cattle watering and irrigation impossible as the water disappears under a thick layer of plants.

Local people are not aware of the beneficial effect of water hyacinths on wastewater but think that this plant is deterring them from the use of pond water.

*Institutional aspects*

The local government is the only institution involved in O&M of the natural treatment system.

There is no arrangement for operation. It was tried to remove the water hyacinths with the help of 30 workers employed under the MGNREGA scheme, but after one month the water hyacinths again covered the surface of the village pond and villagers did not try again to remove them.

*Economic aspects*

This system was not constructed; it is the village pond that existed already for a long time before.

There is no formal arrangement for operation and maintenance.

Water hyacinths are not used for any purpose even though examples for their use in India are reported in literature (Malik 2007).

*Summary of evaluation results*

The intended benefit is not fulfilled as the water in the pond is now not available for irrigation or cattle rearing. This is due to the uncontrolled growth of water hyacinths. The people have thus lost a source of irrigation water.  The performance is not known as it is not monitored. Local people are not satisfied with the treatment plant as they perceive the plants as an obstacle. However, according to local people, the bad smell disappeared. Table summarises the fulfilment of intended benefits.

**Table 20: Results of evaluation – Fulfilment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Treatment of wastewater according to Indian standard | not available | - no monitoring results |
| Reuse of treated wastewater | no | - not possible due to thick layer of plants |
| Use of side products | no | - no use of water hyacinths, no cultivation of fish |
| No energy requirements | yes | - no energy is required for the treatment process<br>- wastewater is collected by a gravity sewer |

**Figure 55: Inlet of water hyacinth pond**

**Figure 56: Village pond covered with water hyacinths**

## 3.5 Overall discussion and conclusions - NWWTS

This study showed that there is a wide variety of natural wastewater treatment systems present in India used for different purposes and with highly varying design capacities. The SWOT analysis brought out the following results:

### 3.5.1 SWOT Analysis

**Strengths**

An important aspect in all of the cases studied was that the system required low or even no energy input.

The study showed that economic benefits from by-products of wastewater treatment are numerous and not only limited to the use of treated wastewater for irrigation, but also for rearing of fish. The planting of fruit trees in the area of the treatment plant as done in Punjab appear to have good acceptance.

In all case studies, where the treated wastewater was reused, users were satisfied with the quality. If used for irrigation, farmers appreciated the content of nutrients in the water, which replaced chemical fertilizer. In the park in Bhopal, operating staff agreed that the reuse of the treated wastewater contributed to water conservation.

**Weaknesses**

Land requirements of natural treatment systems are higher than for mechanised treatment systems and vary between 1,5 m² per person for constructed wetlands and 6 m² per person for a pond system (Arceivala and Asolekar 2007, Maldonado 2007). Lower space requirements can be achieved by combining mechanised and natural treatment systems. For systems located near communities, problems with odour and mosquitoes were reported.

**Opportunities**

Due to high land prices in peri-urban and urban areas natural treatment systems are mainly suitable in rural areas, however, natural treatment systems may be used for green areas in urban areas and be integrated in urban landscaping as the example of the constructed wetland in Bhopal shows. In rural areas, space can be saved if the existing village ponds are integrated with the wastewater treatment systems as seen from the examples from Punjab.

An even higher use of by-products as shown in the case studies is possible, if e.g. sludge treatment becomes more popular.

**Threats**

Institutional and organisational issues are considered to be of high importance, similar to studies reported from constructed wetlands in Mexico (Starkl, 2010b) and Thailand (Brix, 2010). It has been clearly demonstrated that this aspect is relevant for the long-term sustainability as those systems, where no formal arrangement for operation and maintenance exists are prone to clogging and flooding and problems cannot be tackled immediately.

As mentioned above, the natural treatment systems required low or even no energy input. However, as water is usually pumped from pumping stations to the treatment plants, power cuts can affect the functioning.

Potential risks for affected stakeholder groups (operators, neighbours, farmers, consumers) need to be further investigated. Municipalities should take particular care if the NWWTSs are close to human habitations and ground water aquifers, to anticipate health related issues, and be ready to address them. For the users, health risk assessments should be mandatory, and for the produce, food safety measures and testing should be part of the agriculture production process. For consumers, it is advisable to follow the multi barrier approach of the WHO (2006) and take measures to reduce contamination even at household level, by washing and disinfecting vegetables before consumption.

### 3.5.2 Conclusions

The assessment provided insights into challenges and the potential of natural treatment systems. A summary of the main SWOTS can be seen in Figure 3.

| STRENGTHS | WEAKNESSES |
|---|---|
| • low energy requirements<br>• benefit of side products<br>• high acceptance for reuse of treated wastewater | • high land requirements<br>• odour and mosquitoes (if located near human settlements) |
| **OPPORTUNITIES** | **THREATS** |
| • potential for rural areas<br>• increased use of side products possible | • improper O&M arrangement can endanger functioning<br>• power cuts of pumping system affect treatment system<br>• possible health risks to operators, neighbours, farmers and consumers |

**Figure 57: SWOT analysis based on existing evaluation results and rapid assessment**

One of the main problems was that monitoring results, even where they existed, were not accessible. An environmental information system providing information on monitoring results and updated information about wastewater treatment plants would be a desirable tool to ensure accessibility and increase transparency.

# 4 Riverbank filtration (RBF)

## 4.1 Brief description of technology

The process of bank filtration (Figure 57) is initiated by the lowering of the groundwater table below that of an adjoining surface water table which causes surface water to flow through the permeable river bed and bank or lake bed into the aquifer as a result of the difference in water levels, provided that no artificial or natural barriers to this subterranean flow exist (viz. brick or concrete lined river, canal or lake bed, or a low hydraulic conductivity layer like clay). This flow may be the direct result of an influent river under natural conditions or be induced by abstraction wells (production wells). These wells extracting bank filtrate can be vertical or horizontal. Ground- and surface water levels, geologic data pertaining to the aquifer and river bed and hydrogeological modelling help in describing flow conditions during bank filtration.

The porous media serves as a natural filter and also biochemically attenuates potential contaminants present in the surface water. The process of bank filtration is illustrated in Figure 57.

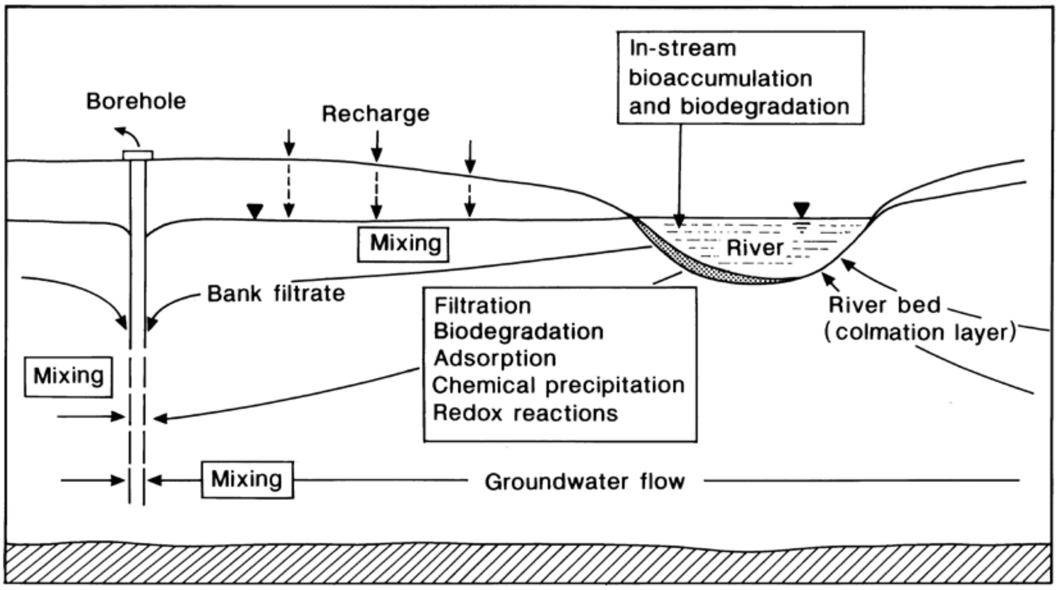


**Figure 58: Schematic diagram of processes affecting water quality during bank filtration (Hiscock and Grischek, 2002).**

Compared to direct abstraction of surface water for drinking water supply, RBF provides the following advantages:

- Protection against contamination by chemicals and pathogens.
- Sufficient water treatment to meet drinking water quality standards at some sites.
- Cost savings in water treatment if RBF is used as a pre-treatment step.

These advantages are a direct result of the natural purification properties of the aquifer, an integral part of the ecosystem, and combine to yield (pre)treated water for drinking purposes (Sandhu and Grischek, 2012).

## 4.2 Existing evaluation results

Around 14 existing RBF sites could be identified in India, out of which four sites in Uttarakhand were constructed in 2010 and are in development since then. The available evaluation reports and an overview of the aspects that have been evaluated can be seen in Table 6 in the Annex 8.2. The non-technical evaluation results can be summarised as follows:

### 4.2.1 Environmental and health aspects

The environmental impact refers to the impact of the RBF system on the river environment. No studies dealing with this aspect could be identified.

Providing hygienically safe water is a key goal of RBF. The systems were assessed for their efficiency and sustainability to provide pre-treated raw water of superior quality compared to directly abstracted surface water (for subsequent treatment to drinking water quality). The main benefit of RBF in India compared to the direct abstraction of surface water was a significant removal of total and fecal coliforms and turbidity (Sandhu et al. 2011a). Removal rates of fecal coliforms are usually 2.3 – 3.5 log during non-monsoon and up to 4.4 log in monsoon on account of the higher fecal coliform counts in surface water during monsoon as compared to non-monsoon (Sandhu and Grischek 2012). But some systems, e.g. Nainital performed even better with >4.2 and >4.4 log removal of fecal coliforms during the non-monsoon and monsoon respectively. In Haridwar, Ahmedabad and Patna the abstracted water from the production wells (mixture of bank filtrate and ambient groundwater) is disinfected before it is provided to the users and in Nainital water from the production wells is sufficiently free from coliform bacteria such that chlorination is not required (Dash et al. 2008). However, disinfection by chlorination is nevertheless carried out as a precaution. By using bank filtration as a pre-treatment technology, and followed by disinfection by chlorination, the water quality parameters are within the limits prescribed by the Indian Standard IS 10500 (1991). Lorenzen et al. (2010) state that the arsenic concentrations in the bank filtrate (at a shallow depth of 9–23 m) are much lower than those of the Yamuna River water because stable Fe-(hydr)oxides in the riverbed sediment could be a sorbent for arsenic. However, mixing of bank filtrate with deeper groundwater lowers the concentrations of arsenic and fluoride so that drinking water standards could be met in the abstracted raw water, and hence RBF should be developed further at the investigated site (Lorenzen et al. 2010). Only in Mathura, surface water quality is more polluted than in the other case studies on account of mainly extremely high microbiological pathogen loading and dissolved organic carbon concentration due to the high amount of untreated to partially treated domestic and industrial wastewater discharged into the Yamuna River. However, the studies conducted in Mathura (Singh et al. 2010, Kumar et al. 2012) have confirmed that RBF when compared to the direct pumping of river water followed by subsequent conventional treatment, appears to be an effective method of surface water abstraction to improve raw water quality. Accordingly, RBF can achieve significant reduction of turbidity, organic contaminants, colour, ultraviolet absorbing compounds, coliform bacteria etc. Since the need for pre-oxidation or chlorination is reduced or eliminated, adsorbable organic halogens, ammoniachlorine complexes, and disinfection by-products (DBPs) do not build-up (Kumar et al. 2012). However, in the case of polluted river waters, the need for an additional treatment step such as adsorption cannot be completely ruled out or eliminated. Nevertheless, the overall advantages of the natural bank filtration are significant. RBF can improve the water quality and reduce the treatment cost to a drinking-water utility using river/lake/reservoir water. Ultimately it can benefit the consumer in terms of both quality and cost. At Mathura, there is however a need to quantitatively assess the role DBPs like halonitromethanes and N-nitrosamines play in RBF (Kumar et al. 2012).

### 4.2.2 Social aspects

RBF structures provide an alternative water natural (pre-) treatment technology to humans and therefore the social acceptance and satisfaction of users has to be considered.

Social aspects have not been included in most evaluation reports because the focus has been on technical, geohydraulic and water quality parameters that describe the quantitative and qualitative efficiency of a RBF system. Only in Dandeli, by the Kali River in Karnataka a social evaluation was carried out in a pilot RBF system for rural drinking water supply. Sample household surveys were carried out to test the acceptance of the RBF system. The study concluded that the RBF system has gained widespread acceptance (Boving et al. 2012).

### 4.2.3 Institutional aspects

The institutional aspects encompass the organisational arrangements for operation and maintenance (O&M) and possible problems related to the management of the structures.

The satisfaction of users with the existing organisational framework was assessed in one case study in rural Karnataka (Boving et al. 2012). It showed that the community was well aware of the existence of the Water User Association which was operating the system and collected the user fees, but the trustworthiness of the Water User Association was questionned by some respondents.

### 4.2.4 Economic aspects

The economic aspects cover two issues: construction costs and operation and maintenance costs.

In the case study in Karnataka the costs of the RBF system for rural drinking water supply have been documented: the system serves 4000 people and the construction costs were INR 600000. Annual operation and maintenance costs sum up to INR 63500 (TERI 2010).

## 4.3 Selection of case studies for rapid assessment

#### 4.3.1 Relevant non-technical information

As shown above, whereas the technical and hygienic performance of RBF is well documented, only few studies have included social, institutional and economic aspects. Hence, almost no evaluation reports are available where an integrated assessment of RBF systems was conducted. Relevant non-technical aspects are:

1) Health aspects: the health risk refers to the risk for the consumer and is therefore related to the quality of the provided water. Compliance with the existing standards for water quality needs to be ensured. The health aspect is related but not exclusively linked to the technical performance of the RBF system, because other factors such as post-treatment of the abstracted filtrate, and subsequent supply to the consumer through the drinking water distribution network (pipes, storage tanks) are important. Nevertheless, it is included in the rapid assessment as one of the intended benefits is the provision of (pre-) treated water. Another benefit is the provision of raw water in sustainable quantity.

2) Social aspects: water from riverbank filtration is an alternative to other water sources (e.g. groundwater) and therefore the satisfaction of users with the provided water is relevant for the acceptance of the system.

3) Institutional aspects: the organisational arrangement of operation and maintenance (O&M) and the monitoring of water quality are the two main issues under this aspect. Depending on the size and the type of setting, urban or rural, O&M is done by municipal corporations or local water user committees.

4) Economic aspects: there are two cost components: construction costs and operation maintenance costs. The provision of financial resources for construction and the arrangement for recovery of operation costs are also covered under this aspect.

#### 4.3.2 Selected case studies

In consultation with the other partners, case studies for the detailed assessment were selected for the rapid assessment. The case studies are presented in Table 21 and the location can be seen in Figure 58.

**Table 21: Selected case studies**

| Case studies | Reasons for selection |
|---|---|
| BF 2, Haridwar | The urban RBF system comprising 22 production wells is easily accessible and staff from HTWD and UJS were able to conduct a survey about the satisfaction of the system among the consumers |
| BF 9, Dandeli | This is the only communally managed system implemented at a rural location in India. Information on non-technical aspects exists and will be further studied instead of conducting a field visit. |

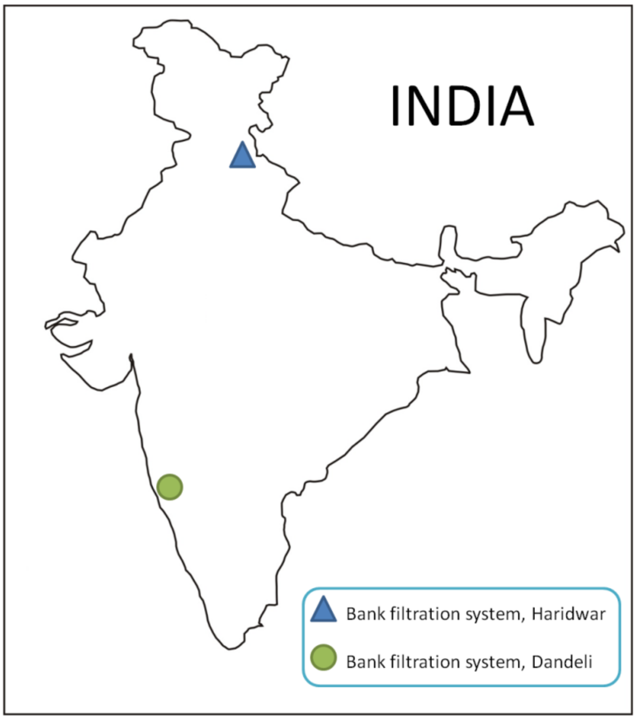


**Figure 59: Location of case studies**

## 4.4 Results of rapid assessment

### 4.4.1 Riverbank filtration

The intended benefit of riverbank filtration systems is the provision of water with a quality complying with the Indian drinking water norms (IS 10500 (1991)) throughout the year. Additional benefits depend on local circumstances.

**Haridwar, Uttarakhand**

The first RBF wells were constructed in the late 1970s or early 1980s (the exact date is not known). However, over the years, there has been a distinct change in technical terminology used to describe these wells. In pure scientific and technical terms, the RBF wells in Haridwar are large-diameter (~10 m) bottom-entry caisson wells. Colloquially, they are called infiltration wells by many of the local engineers. From a hydrogeological and water supply engineering perspective, this term is incorrect, because an infiltration well is a well into which water is pumped in and NOT a well out of which water is pumped out. The term infiltration well ( "I-well" or "IW" in short) basically denotes the principle of RBF in local terms, meaning that the water in the wells "infiltrates" from the nearby river into the subsurface and flows to the well. This discrepancy in terminology was clarified and corrected in 2005, and henceforth these wells are called RBF wells. However, the notation "IW" continues to be used by UJS to number the RBF wells e.g. IW18, IW 40 etc.

The proportion of pre-treated water for drinking originating from the 22 riverbank filtration (RBF) wells is around 68 %, with the remaining 32 % from groundwater abstraction wells (Sandhu and Grischek, 2012)) for the main part of the city of Haridwar (Uttarakhand), or the part of the city administered by the municipal corporation ("*Nagar Palika Parishad* – NPP"). The NPP does not include the suburban areas. If the entire urban agglomeration of Haridwar is taken into consideration, which includes all the suburban areas (including industrial areas), the contribution of bank filtrate is less. A schematical flow chart is provided in Figure 59.

The system in Haridwar faces high variations in water demand during religious occasions (such as during the major *Kumbh* and *Ardh Kumbh Melas* festivities) when up to around one million additional persons have to be supplied with drinking water. Even during monsoons, when the turbidity and coliform count of the Ganga river increases considerably, sufficiently pre-treated water is abstracted by the RBF wells such that the abstracted water is only disinfected by adding mainly sodium hypochlorite and sometimes bleaching powder.

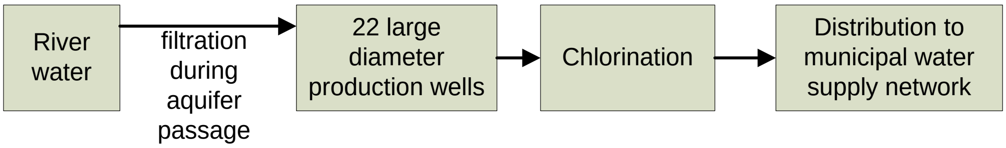


**Figure 60: Flow chart of RBF system in Haridwar**

*Health aspects*

Existing evaluation results show that the water conforms to the Indian standard for water quality after disinfection (IS 10500 (1991)). Evaluation of coliform counts showed a removal by 2.5 – 4.7 logs (Dash et al. 2010, Sandhu and Grischek 2012). The abstracted water from the RBF wells in Haridwar only requires disinfection by chlorination, and provides safe drinking water even when facing high variations in water demand and during monsoons (Sandhu et al. 2011).

*Social aspects*

Ten consumers of water from the riverbank filtration system, both from households and hotels in Haridwar, were interviewed about their perception on the water from the piped water supply system. The sample characteristics can be seen in Table 22.

**Table 22: Sample characteristics and results concerning expenditures on water, RBF Haridwar**

| Descriptive statistics | Sample Description | n=10 respondents (households) |
|---|---|---|
| Type of user | Household<br>Hotels<br>Export Business | 70% (Range 2-17 persons)<br>20% (Range 10-60 persons)<br>10% |
| Job Type | Hotel<br>Own business<br>Employment<br>Housewife<br>Student | 20%<br>40%<br>20%<br>10%<br>10% |
| **Expenditures on water** | **Unit** | **Value** |
| Household monthly expenditure on water | Average amount (in INR) | 103 (Range 75-183) |
| Hotels monthly expenditure on water | Average amount (in INR) | 394 (Range 388 – 400) |
| Commercial users monthly expenditure on water | Average amount (INR) | 1500 |

Only two interviewed consumers were aware that the water stems from a riverbank filtration system, but none of them knew how the system worked. In terms of water quality, 50 % of the respondents stated that the water they receive in the piped water supply system is a reliable and safe water source, whereas the others think that the water quality could be better; they complained about sand in the water and perceive the taste of the water sometimes to be salty. The second group prefers groundwater, spring water and rainwater or thinks that the water should be filtered.

Nevertheless, except two respondents, all are satisfied with the provided water as the tariff is low, the water is cold and the water comes from the holy river Ganga. Almost all experienced some problems so far: the most often mentioned problems concerned interrupted supply during power cuts and sand in the water. Few respondents said that the water was salty, that there is less water during summer or that the water quality during rainy season is bad. One user uses an additional filter at home before using the water. This is a common practice in many households in India and serves as an extra precaution. However, the use of such filters is not a direct indicator of the presence of pathogens in the water and is an inadequate indicator of the performance of the RBF system because contamination can occur between the point of disinfection and the consumer.

Asked for possible improvements, they proposed to improve water quality and increase water production.

*Institutional aspects*

The main institution involved is the Uttarakhand State Water Supply and Sewerage Organisation - *Uttarakhand Jal Sansthan* (UJS) which is operating the system. The main tasks encompass the collection of charges from the consumers, management of water supply, routine maintenance (e.g. lubrication of pump-motors, replacing worn parts; breakdown maintenance), studies for improvement (feedback from consumers, own operational experience) and to make improvement plans (e.g. improved design of well-filters).

Monitoring is also conducted by UJS: the quality of the provided water is tested and quality checks at household level are conducted.

*Economic aspects*

The construction costs per large-diameter caisson well were

- INR 5000000 (five million) for construction of well infrastructure (pump house, development, well, excavation of well)
- INR 500000 – 1000000 (five hundred thousand to one million)for electrical parts (pumping plant, automation panel, etc.)
- ~ INR 2500000 (two and a half million) for the distribution line (1 km)
- ~ INR 10000000 (ten million) for the overhead tanks (drinking water storage reservoirs) with a volume of 35 m³ per tank

In total there are three overhead tanks, 15 km pipe, 22 wells and pumping plants which sums up to around 200 million INR (depending on: topography, how far away people live, how many people, demand of water).

The operation and maintenance costs are summarised in Table 23.

**Table 23: Operation and maintenance costs (in million INR) of the RBF system in Haridwar**

| Year | Salary of staff | Annual repair and maintenance | Electricity (paid by Govt.) | TOTAL |
|---|---|---|---|---|
| 2008-2009 | 22.329 | 11.650 | 18.701 | 52.680 |
| 2009-2010 | 24.816 | 12.947 | 19.854 | 57.617 |
| 2010-2011 | 27.411 | 13.486 | 35.014 | 76.81 |
| 2011-2012 | 29.814 | 15.824 | 53.437 | 99.075 |

The tariff for households depends on the diameter of the connecting pipes:

- up to ½ inch diameter INR 120 per month
- up to ¾ inch diameter INR 324 per month
- up to 1 inch diameter INR 650 per month

Non-domestic (commercial) users pay between INR 422 (up to ½ inch diameter) and INR 1058 (up to ¾ inch diameter) per month.

The revenues are not sufficient to cover the O&M costs; the deficit is covered by subsidies from the government.

*Summary of evaluation results*

The intended benefits of the system are fulfilled (see Table 24). The reasons for the well functioning system are the selection of the right technology, regular maintenance and sustainable abstraction of water by the RBF wells throughout the year.

**Table 24: RBF Haridwar - fulfillment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Provision of drinking water complying to the Indian standard | yes | - all parameters lie within the limits of the Indian Drinking Water Standards (IS 10500,1991; Dash et al., 2010; Sandhu et al., 2011; Sandhu and Grischek, 2012) |
| Availability of water around the year | yes | - due to the natural gradient between the Upper Ganga Canal and the Ganga River (in between which most of the RBF wells are located), the recharge to the wells by water originating from the river is sustainable |

**Figure 61: Large-diameter caisson RBF well number 18 on Pant Dweep Island (Photo: L. Rossoff, HTWD, 2011)**

**Figure 62: The Upper Ganga Canal (UGC, lower and right foreground part of photo) starts at the Bhimgoda Barrage (upper right part of photo) on the Ganga River in Haridwar. The filtrate abstracted by the RBF wells originates from the Ganga River and UGC. (Photo: C. Sandhu, HTWD, 2010)**

**Figure 63: Example of a large-diameter RBF caisson well adjacent to the Ganga River in Haridwar (Photo: L. Rossoff, HTWD, 2011)**

**Dandeli, Karnataka**

A detailed examination of the existing documents showed that the non-technical aspects are already well assessed and documented. The information about this system is based on existing literature (Cady et al. 2010; TERI 2008, 2009, 2010; Boving et al. 2012).

An additional intended benefit of the system is that it shall be operated by the local community.

The system is a demonstration project in a rural area which was implemented along the Kali River in Karnataka. Two villages with 1500 inhabitants depend on river water which is polluted by local industry and untreated domestic wastewater. Baseline data was collected from October 2007 to January 2008. A GoogleEarth–based GIS coverage of the Kali River watershed was developed and five potential RBF sites could be identified. One of the potential sites identified has been selected as the RBF demonstration site. It is located approximately four kilometers downstream from Dandeli near the village of Kariyampalli.

The well design was based on the available hydrogeologic information. Four wells were drilled (see Figure 63).

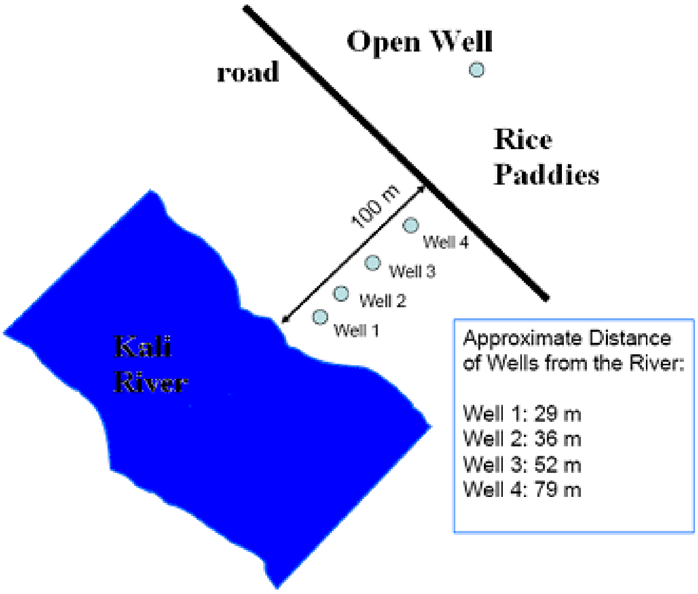


**Figure 64: Schematic picture of infiltration wells (Source: Cady et al. 2010)**

*Health aspects*

An independent laboratory analysis confirmed that RBF water quality meets all standards per IS: 10500-1991 (TERI 2010).

E. coli bacteria show an average removal of 99.2% and a maximum removal rate of 99.9% from the river to the production well in well 3. Water from the RBF system is safer to use than other drinking water sources in the area (e.g. surface water, open wells in the village) (Cady et al. 2010).

*Social aspects*

TERI conducted two household surveys to test the acceptance of the RBF system and assess possible changes in the health and economic status of the villagers served by it. The baseline survey with 110 households was conducted in January 2008 before the project was implemented and the second survey with ten households using the water from the RBF system in the village Kariyampalli was done in February 2010 after implementation. The water was used for all purposes except of irrigation and the untreated water from the river was used by less people than before. Accessibility of water sources has improved and people now spend less time for collecting water. All respondent used the water from the RBF directly without further treatment and were satisfied or very satisfied with the quality. Whereas more than 40% of respondents in the baseline survey reported health problems, not a single case household with bad health was identified in the post-implementation survey. The survey data shows that the overall health of the population increased considerably and that the RBF system has gained widespread acceptance when implementation activities were coordinated with community education (Boving et al. 2012).

*Institutional aspects*

The water user committee, which was formed by the local community is the main institution involved in operation of the RBF system.

Two operators are maintaining the system and analyze water samples. One business manager is being paid in-kind by access to free RBF water. One field technician is employed to ensure the smooth operation.

The RBF water quality is tested two times per week and the systems operating status is monitored daily (TERI 2008).

*Economic aspects*

The RBF system has the capacity to serve 4000 people with the possibility of up-scaling. It cost about INR 600000 to install and INR 63500 annually to operate. The cost of water to the household is about INR 70 per year (TERI 2010). The number of people living within the study area is lower than anticipated (less than 4000), which affects the amount of revenues. To compensate the lower revenues, support from a local paper mill which causes water pollution, is aspired (TERI 2009).

*Summary of evaluation results*

The information obtained from literature shows that the intended benefits are fulfilled. Water is provided throughout the year, but only four hours per day to save electricity costs. Users can fill their water storage tanks in this time. Water was tested by an external lab and fulfills Indian water quality standard. Operation is done by a Water User Committee that is responsible for daily operation tasks, monitoring and collection of water fees.

**Table 25: RBF Dandeli - fulfillment of intended benefits**

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments |
|---|---|---|
| Provision of water complying to the Indian standard | yes | - water was tested by an external lab and fulfills water quality standard IS: 10500-1991 |
| Availability of water around the year | yes | - only four hours per day<br>- users can fill their storage tanks in this time |
| Operation done by community | yes | - Water User Association was formed which is responsible for operating the system and collecting the water tariff. |

The long-term institutional sustainability of the created water committee can be a risk in the future, but as all respondents in the survey conducted by Boving et al. (2012) reported to be willing to join the committee, there seems to be no problem to find people willing to operate the system in the future.

## 4.5 Overall discussion and conclusions - RBF

The following text presents the SWOTs of RBF structures building up on the existing evaluation results and the rapid assessment.

### 4.5.1 SWOT Analysis

**Strengths**

At most existing urban bank filtration sites in India, RBF supplements surface water abstraction schemes for drinking (e.g. Ahmedabad, Delhi, Mathura, Nainital, Srinagar in Uttarakhand) and at some other sites (e.g. Haridwar, Satpuli in Uttarakhand, Medinipur and Kharagpur) it serves as an alternative to the direct abstraction of surface water (Sandhu et al. 2011a, 2012).

The main benefit of RBF compared to the direct abstraction of surface water is a significant removal of total and fecal coliforms and turbidity (Sandhu et al. 2011a, Sandhu and Grischek 2012). Detailed evaluation results can be further found in Dash et al (2008, 2010), Lorenzen et al. (2007, 2010), Sandhu et al. (2011b, 2012), Singh et al (2010), Sprenger et al. (2008, 2011, 2012), Kumar et al. (2012), Ronghang et al. (2012) and Cady et al. (2010). Except of one case study where raw water was highly polluted, the abstracted water complied mostly with the Indian standard for water quality even before chlorination was conducted (IS 10500 (1991). Where in use, RBF (along with much more limited post-treatment by disinfection using chlorination) is accepted as the sole treatment (Sandhu et al. 2012).

In both case studies sufficient water to cover the domestic demand was provided. In the rural case study in Karnataka (Boving et al. 2012) water is only provided four hours per day to save electricity costs. Users fill their private tanks in this time and use this water the rest of the day.

The rapid assessment of the two RBF systems showed that the water is well accepted by the majority of the users. Some problems concerning water quality and reliability were reported in Haridwar, whereas users in the communally managed systems were satisfied with their water supply.

**Weaknesses**

River and ambient groundwater quality can affect the quality of bank filtrate abstracted. Clogging of the river bed, dynamic discharge during the monsoon and changing river course (typical in topographically level terrain in India) can affect the quantity of the bank filtrate abstracted. These factors need to be taken into account when RBF systems are designed.

The example of Dandeli showed that the implementation of RBF systems in rural areas is possible, but only with external support. In the case of Dandeli, research institutions provided support for the determination of the location based on GIS analysis and a local NGO gave training on operation and maintenance and conducted awareness raising measures.

**Opportunities**

With more than 60% of irrigated agriculture and 85% of drinking water supplies dependent on it, groundwater is a vital resource for rural areas in India (World Bank 2010). Consequently, bank filtration has the potential to serve as a supplement to groundwater abstraction provided suitable hydrogeological, technical and institutional conditions exist. Even if currently only one communally managed rural case study could be identified (Boving et al. 2012), it nevertheless demonstrates that RBF systems have a potential for rural and peri-urban areas where a central drinking water supply management might not be possible.

Management of bank filtration schemes should be incorporated into wider catchment planning in order to limit potentially polluting activities in the groundwater recharge area and also to balance river infiltration losses with the ecological needs of the river, but due to site specific conditions, a general management strategy has yet to be defined (Grischek et al. 2011). The drinking water production of many cities and towns in India will be or is already in the process of being expanded and optimised to meet the growing water demand, such as through the City Development Plans or various schemes such as the 'Jawaharlal Nehru National Urban Renewal Mission', the Asian Development Bank's current 'North Eastern Region Capital Cities Development Investment Programme' and the planned 'Uttarakhand Urban Sector Development Investment Programme' and the World Bank's 'National Ganga River Basin Project' (Sandhu and Grischek 2012). According to Sandhu and Grischek (2012), the technical and socio-economic feasibility of using RBF for urban and decentralised water supply schemes should be investigated for locations (covered by these programmes) having suitable hydrogeological conditions, simultaneously also serving as a first step towards meeting the goals of the Government of India's 'National Action Plan on Climate Change' (NAPCC 2008).

For optimisation of existing RBF facilities and installation of new ones in India, the water companies will rely on further support from the state government and communities. Just local technical measures will not be sufficient. To achieve the goal of 24/7 water supply for the population, RBF has to be seen together as one element of IWRM only (Grischek et al. 2011). According to Grischek et al. (2011), other aspects, such as building consumer awareness on water wastage, leakage control and WHPAs are important and cannot be handled by the water companies alone, and hence by following the approach of IWRM, collaboration with governmental organisations and NGOs, local community authorities, agricultural and industrial sectors has to be intensified to make RBF in India a long-term success story.

**Threats**

RBF systems can be affected by floods as the example of Haridwar shows, where in 2010 the wells were flooded during monsoon season.

The absence of well head protection areas (WHPA) for drinking water production wells not only in Haridwar but also in most parts of India, is another factor which can result in contamination to source-water due to anthropogenic activities. Due to the episodic occurrence of pathogens in surface water and the risk of contamination of wells during floods it is very important to design WHPA for RBF sites. For the siting of new RBF schemes it is strongly suggested to involve the wellhead protection strategy in the planning stage.

Consequently, RBF sites in India should be evaluated for the risk of pathogen breakthrough and the possibilities to delineate wellhead protection zones and agree upon adequate protection measures (Grischek et al. 2011).

A factor that can endanger the quality and quantity of the abstracted water by RBF is a change of upstream surface water uses. Pollution or extraction of surface water by industries can affect the river water characteristics. Thus constant monitoring is required to ensure safe drinking water. Human impact on streams (e.g., for flood control, hydropower generation and channel construction for irrigation) changes the natural runoff regime; Dams dramatically alter the flow characteristics of rivers; in particular the transport and deposition of solids, the erosion of the river bed, and the interactions with the groundwater may be significantly affected by dams. Nevertheless, such activities could also have a positive effect for the use of RBF if the concepts of RBF are accepted and included already at the planning stage (Grischek et al. 2011).

Proper operation and maintenance is a key to the good functioning of RBF system. In all community managed schemed, the long-term sustainability of local user committees is an important challenge. Decreasing motivation or new job opportunities can cause changes in the composition of the water user committees. Continuous support from outside organisations is necessary to assure that the committee is active and to assist in case of problems.

### 4.5.2 Conclusions

A summary of the main SWOTS can be seen in Figure 65.

| STRENGTHS | WEAKNESSES |
|---|---|
| • alternative to direct abstraction of surface water<br>•provision of water with drinking water quality<br>• constant water source<br>• high acceptance | • water quality and quantity impacted by river water quality and changing river topography<br>• external support required (for rural schemes) |
| **OPPORTUNITIES** | **THREATS** |
| • alternative to groundwater based schemes<br>• potential for rural areas<br>• incorporation into catchment planning | • possible affection by floods<br>• impact of upstream use on water quality and quantity<br>• risks related to long-term sustainability of water user committees |

**Figure 65 SWOT analysis based on existing evaluation results and rapid assessment**

The rapid assessment of the one urban and one rural RBF system showed that the water is well accepted by the majority of the users. Some problems concerning water quality and reliability were reported in Haridwar which alone (independent of other factors i.e. distribution network) is however not an indicator of the efficiency of the natural treatment system in itself, whereas users in the communally managed rural system were satisfied with their water supply. In the rural case study in Karnataka water is only provided four hours per day to save electricity costs. Users fill their private tanks in this time and use this water the rest of the day.

The urban RBF system in Haridwar is operated by the state water supply organisation, the rural system in Karnataka is operated by the community. The tasks to be fulfilled are similar and both arrangements work well.

The study showed a high potential for RBF systems especially for rural areas where so far only one community-managed RBF system has been documented.

# 5 Managed Aquifer Recharge (MAR)

## 5.1 Brief description of the technology

Managed aquifer recharge (MAR) is the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers, resulting in a corresponding increase in the amount of groundwater available for abstraction (Oaksford 1985).

Artificial recharge of groundwater is one of the oldest activities undertaken in India, where methods to conserve rainwater both above ground and underground are widespread due to the high annual variation in rainfall (concentrating on only 2-3 months per year, the monsoon season). More than 500000 traditional tanks and ponds can be found in peninsular India. These ponds (called *khadin, talab, johad, ooranis* or *nadi*) were constructed thousands of years ago for catering to the multiple uses of irrigated agriculture, livestock and human uses – usually abstracting the ponded surface water directly. Within the area of influence of these pondsare numerous shallow dug wells that are recharged with pond water (Sakhtivadivel 2007), thus using the ponds as artificial recharge structures.

Since the 1970s numerous watershed development projects (WDP) have been implemented in India. WDPs include different technologies of MAR and other, non-technical measures which aim at improving water availability in a watershed. The most often implemented technologies in India are check dams and percolations tanks (SAPH-PANI D 2.1 2012). Percolation tank or pond is a term used in India to describe harvesting of water in storages built in ephemeral streams or off-stream where water is detained and infiltrates through the permeable base to enhance storage in unconfined aquifers.Check-dams (also called Nala bunds) are barriers built across the direction of water flow of rivers. These dams retain part of the water flow and reduce the soil erosion during monsoon rains in the area upstream of the structure. The increased hydraulic pressure in the reservoir area increases the infiltration rate.

## 5.2 Existing evaluation results

Many studies could be identified where MAR systems have been evaluated, including environmental, health, social, institutional and economic aspects. MAR was usually one of the several components of the WDP and only in few cases, the MAR systems have been evaluated separately. Table 28 in the annex gives an overview of existing case studies. The main results are summarised in the following section.

### 5.2.1 Environmental aspects

The environmental impact of MAR systems is related to a change of groundwater quantity and quality. Deliverable D2.1 provides more information on these aspects. Possible impacts on climate and biodiversity have not yet been documented in literature.

With respect to the specific impacts of MAR on the groundwater table, considering the high number of implemented systems, there are few studies available where the real impacts on the groundwater levels were quantified, as field investigations are difficult and expensive (Glendenning et al. 2012). The following studies could be found:

A recent study (Glendenning and Vervoort 2010) indicated recharge efficiencies of around 7% of total rainfall in a case study watershed in Rajasthan. A similar value was obtained by Sharda et al. (2006a) for a case study in Gujarat, where various recharge schemes were constructed. The recharged water in the years 2003 and 2004 corresponds to 7.3 and 9.7% of the total annual rainfall. The study of Perrin et al. (2010) in Rajasthan was also in the same range with 5% - 8% of total annual monsoon rainfall.

Raju et al. (2006) reported a rise of groundwater level of up to 1.8 meters in the Swarnamukhi River basin in Andhra Pradesh after the installation of subsurface dams.

A study of three WDP in Gujarat, Tamil Nadu and Maharashtra by Gale et al. (2006) used another approach and compared the recharged amounts with the natural recharge capacity. It shows that the recharged amount of water to aquifers increased by 3 - 23% compared to the natural recharge situation.

The different results show that there is a high variability of aquifer response to MAR system. The measurement of the recharged amounts is usually done by analysis of water-level fluctuations in observation wells, which can over-estimate the recharged amount if the measurement is done near the recharge structure (Glendenning 2012).

An important aspect to consider is the impact of the recharged water quality on groundwater quality. Depending on groundwater quality and quality of the recharged water, groundwater quality improves (Sivakumar, et al., 2006; Sayana, et al., 2010; Kaledhonkar, et al., 2003) or detoriates (UNESCO, 2006). For more information on this aspect, see Deliverable D2.1..

### 5.2.2 Health aspects

Impact on the health of water users is an important issure for all technologies providing water. In modern systems, rainwater undergoes filtration and recharges the groundwater. No problems related to water quality were identified in the existing studies.

In traditional systems, where water is not only recharging the aquifer, but is also directly used from the recharge structures, some risks were highlighted. Even though not really being MAR systems as the aquifer passage is one of the most important features, some studies dealing with water quality from traditional rainwater harvesting system will be summarised here.

For instance, Pangare (2003) analysed 16 samples from *ooranis* in Tamil Nadu and found that the water from the *ooranis* needs treatment to reduce turbidity and biological pollutants prior to its use. In another study, *khadins* were evaluated and came to similar results: analyzed samples of hand pump water near the *khadin* fulfill the standards for drinking water, but water taken directly from the *khadin* needs treatment before use

(Bishnoi and Starkl 2011). This shows the importance of the soil passage through which the water is filtered.

### 5.2.3 Social aspects

MAR structures provide an alternative water source to humans and therefore the social impact has to be considered. Three types of social impacts are relevant:

1) Acceptance of water from MAR systems: water from the system is an alternative to other water sources and possible social problems can occur. The main questions are: are users satisfied with the new water source? what is their opinion compared to other water sources?
2) Benefit sharing: the newly created MAR infrastructures improve access to water, but usually not all members of a community are benefitting in the same way. The main questions are: who receives the benefits? what are the benefits?how are benefits shared among the community?
3) Social impact on downstream users: MAR structures may affect the water source of downstream users which can cause important social impacts on the downstream users

With respect to user acceptance, the study of Pangare (2003) has shown that water from the revived *Ooranis* is highly accepted or preferred compared to hand pumps, bore wells and combined water supply. For modern MAR systems, their acceptance is related to increased water availability in the existing wells. No problem related to acceptance was reported.

Concerning benefit sharing, the study of Gale et al. (2006) of three WDP showed that in all case studies, recharge was assumed to provide community-wide benefits, and hence structures were generally viewed as community assets, to be financed and managed by the community. Nevertheless, land owners are the ones who are benefitting most from the interventions. The direct benefits are increased yields which are experienced by those who own land and have access to groundwater sources. Landless people can indirectly benefit form MAR interventions if the increased agricultural output is related to an increased demand of labour which cannot be covered by the own family. In this case employment opportunities are generated. However, MAR systems create hierarchies of beneficiaries with landless benefitting least (Shah 2001, Sen et al. 2006). Keeping this in mind, the mapping of benefits and possible cross-subsidisation should be considered already during the planning phase.

With respect to downstream uses no studies about the social impact have been conducted so far.

### 5.2.4 Institutional aspects

The institutional aspects encompass the organisational arrangements for operation and maintenance (O&M) and possible problems related to the management of MAR structures.

Water has been traditionally managed by local institutions in India. As the review of MAR project documentations has shown, most of the systems are implemented in rural areas and operated by designated committees which are also responsible for collecting user fees. Therefore, the local institutional arrangements are important for ensuring the long term sustainability of MAR structures.

The evaluation of six modern water development projects in Andhra Pradesh (LNMRI 2010) has shown that the programmes remained weak with regard to community organization for maintaining the assets created as well as continuing the programme through user groups and people's involvement.The study recommended that efforts should be made to strengthen the participation of user groups in the programme in terms of obtaining their consent before taking up works and involving them in executing these works. Building up proper awareness and constant persuasion and motivation to make them take active part would ensure further effective contribution and sustainability of the programme. Similar results have been obtained in another study by Gale et al. (2006) where three watershed development projects in Maharashtra, Gujarat and Tamil Nadu have been evaluated.

Similar experiences were reported by AFPRO (2010) which studied a WDPt in Rajasthan. It showed that the organisational structures of traditional recharge technologies are similar and therefore the same challenges concerning operation and maintenance have to be handled. Users were satisfied with the work of the committee, but there can be risks related to long-term sustainability if the members of the committee do not fully recognise their role during operation and maintenance of the systems when the initial motivation decreases.

The organisation in water user committees can even aggravate social inequalities in communities as they tend to express the existing social hierarchies in the community, which often excludes the poorest members. A study of 18 districts in Madhya Pradesh showed that women are also underrepresented in Village Watershed Commitees (Sen et al. 2006).

### 5.2.5 Economic aspects

The economic aspects cover three issues: construction costs, operation and maintenance costs of MAR systems and the economic benefit for the water users.

The construction costs of typical recharge structures were documented by GOI (2007) and are based on the information of 4 – 16 case studies per technology. Table 26 below shows the total investment cost and the capital investment costs per m³ of recharged water. The costs (per m³) vary between 0,04€ -6,44€ depending on the type of structure applied. What becomes evident is the big range between cheapest and most expensive structure, which make a general statement about costs impossible.

**Table 26: Costs of recharge structures (Source: GOI 2007)**

| Type of structure | Investment costs (INR / €*) | Capital investment costs per m³ recharged water (INR / €`*) |
|---|---|---|
| Percolation tank | 155000 – 7100000 / 2200 - 100500 | 20 – 193 / 0.28 – 2.73 |
| Check dam | 150000 – 105000000 / 2120 - 1500000 | 73 – 290 / 1.03 – 4.10 |
| Recharge well | 100000 – 1500000 / 1415 - 21230 | 2.5 – 80 / 0.04 – 1.13 |
| Sub-surface barrier /dyke | 730000 – 1770000 / 10330 - 25050 | 158 – 455 / 2.24 – 6.44 |

* Exchange rate of 30.12.2011

Raju et al. (2006) reported construction costs of subsurface dams in a range of US$ 18000 to 74000 US$.

The construction costs of the traditional *Johads* built in Rajasthan are in the range of US$ 1,000. The renovation of *ooranis* in Tamil Nadu was supported by DHAN Foundation and the construction costs for each of the 32 *ooranis* can be found at www.dhan.org.

Only little information is documented on operation and maintenance costs. Only in one study (Bhagwat et al 2011) operation and maintenance costs of a water conservation project basically encompassing check dams for 16 villages in Madhya Pradesh, could be identified. Users pay 70-100 INR per month for the operation and maintenance of the water supply systems, which are supplied with recharged groundwater (personal communication with A.M. Singh 2012).

Concerning the economic impact on users, many studies have shown that increased crop productivity has largely brought higher net returns to local farmers (Shah 2001, Gale et al. 2006, Sen et al. 2006).

Based on the experiences in three watersheds in Gujarat, a cost-benefit analysis considering investment costs and increased crop production has been conducted for small checkdams with around 8 benefitting farmers. It resulted in a benefit/cost ratio of 4.07 (Shah 2001). Whereas this study only included local benefits and costs, a study on downstream impacts by Bouma et al. (2011) showed these impacts are considerable and that the net benefits for the upstream users are insufficient to pay back investment costs, if downstream losses are also considered.

The study showed that the benefits gained in the upstream region can compensate downstream losses as long as investments are kept low. If the investments increase, the net benefit of the MAR systems can become negative as downstream users lose more than upstream users gain.

Table 28 summarizes the existing MAR case study locations that could be identified and shows which aspects have already been evaluated for each case study. Pilot plants which served only to assess the potential of MAR have not been included in the survey.

## 5.3 Rapid assessment

A lot of evaluation studies have been conducted already.No additional rapid assessments of non-technical aspects were performed as it is unlikely that they would provide further insights.

## 5.4 Overall discussion and conclusions - MAR

The following text presents the SWOTs of MAR structures building up on the existing evaluation results.

### 5.4.1 SWOT Analysis

**Strengths**

Various strenghts of MAR systems were identified: MAR systems provide communal assets, from which local communities are benefiting. Higher agricultural yields can be expected and the quality of life of farmers is increased. Water provided in the recharge structures is well accepted by the consumers and sometimes even preferred over water from other sources. The amount of recharged water increased significantly compared to the natural recharge situation: Gale et al (2006) reported increased recharge of 3 – 23% in three evaluated case studies.

**Weaknesses**

The existing evaluation results showed that uneven distribution of benefits is the main weakness of MAR system. Concerning benefit sharing it became evident in the existing studies that benefits are not distributed evenly among the whole community, but that those who own land benefit more than landless people.

Another problem is related to use of water of traditional rainwater harvesting schemes before soil passage. The soil passage, where the water is filtered before use, is important to ensure good quality. The practice of using water directly from recharge structures is common for traditional rainwater harvesting systems, but this water turns out to be contaminated as it collects surface runoff and people step into the water to collect it before subsurface passage. As the subsurface passage is a relevant component of MAR schemes, this weakness is assigned to traditional rainwater harvesting schemes and not to MAR systems.

**Opportunities**

MAR has a very long tradition in India, but many of the traditional systems have been replaced by centralised system relying on surface or groundwater. A study about the potential of traditional recharge sytems in Rajasthan showed that there have been successful attempts in reviving kunds in Churu district of Rajasthan and also khadins have a high potential to solve drinking water problems as there are 118.600 hectares of land that could be used for construction of these systems (Babu 2008). The combination with modern technologies (e.g. sand filters, disinfection) can improve the water quality of traditional systems without subsurface passage..

A possibility to minimise the adverse impacts for downstream users is the implementation of small scale systems at sub-basin level. Sharda (2006b) proposes decentralised systems instead of centralised schemes to meet the water demand of communities in water scarce areas. Considering the possible impacts of large MAR systems, this approach may be a possibility to mitigate the negative effects. The water conservation project presented by Bhagwat (2011) is based on this approach: within a sub-basin of a river, small check dams were implemented and 16 villages in the watershed benefit from the project.

**Threats**

Concerning the threats related to MAR systems, various issues have been raised. Higher availability of water motivates farmers to change to new crops which can lead to unsustainable farming systems as groundwater replenishment is not as big as expected (Gale et al. 2006).

Another problem often not considered is that the water which is locally recharged could have been a source of water for downstream users who can experience water shortage as a consequence (Kumar et al. 2008). There are few basin-wide studies on that consider the trade-offs between upstream and downstream use.

The general public opinion of MAR systems is positive as they are considered to result in economic benefits through increased crop production. Bouma et al. (2010) come to the conclusion that downstream impacts are considerable and that the net benefits are insufficient to pay back investment costs. Basin-wide investigations on the impacts on water availability shall be conducted to see whether the welfare at basin level increases.

### 5.4.2 Conclusions

The existing literature on managed aquifer recharge is very extensive and showed that MAR systems provide various benefits. A summary of the main SWOTS can be seen in Figure 66.

| STRENGTHS | WEAKNESSES |
|---|---|
| • benefits for local communities (social and economic)<br>• high acceptance<br>• increased recharge compared to natural recharge | • uneven distribution of benefits |
| **OPPORTUNITIES** | **THREATS** |
| • revival of traditional structures and combination with modern components<br>• (sub-) catchment based approach can ensure equality | • over-estimation of recharged water<br>• change to unsustainable cropping pattern<br>• lack of participation can endanger ownership of structure and willingness for O&M<br>• adverse impact on downstream users |

**Figure 66: SWOT analysis based on existing evaluation results**

The following recommendations resulting from the SWOT analysis can be made:

Detailed investigations at the beginning of MAR projects are necessary to predict the response of aquifers on the planned measures. As a general recommendation, the investigation of the basin-wide effects should be integral part of new MAR projects.

India has a large number of traditional systems which have been abandoned and their revival in combination with modern treatment systems has a huge potential to mitigate water scarcity (Bishnoi and Starkl 2011, Sharda 2006b).

Many different WDPs have been implemented all over India in the last decades and those including a participatory component proved to be more sucessful than their technocratic counterparts. Also organisational arrangements have been studied and a well organised operation and maintenance scheme proved to be an important pillar for succesful working systems. Therefore participatory components should be integral part of every watershed development project.

# 6 Abbreviations

DP Duckweed pond

FAP Facultative anaerobic pond

GOI Government of India

INR Indian Rupees

IWRM integrated water resources management

KL cubic meter

MAR managed aquifer recharge

MLD million litres per day

MP maturation pond

NTS natural treatment systems

NWWTS natural wastewater treatment systems

O&M operation and maintenance

PF planted filters

RBF / BF riverbank filtration / bank filtration

SAT soil aquifer treatment

SFCW subsurface flow constructed wetlands

STP sewage treatment plant

SWOT **s**trengths – **w**eaknesses – **o**pportunuties – **t**hreats

UJS Uttarakhand Jal Sansthan (Uttarakhand State Water Supply & Sewerage Organisation)

WDP watershed development projects

WHP water hyacinth pond

WHPA well head protection areas

WSP waste stabilization pond

# 7 References


AFPRO (Action for Food Production) (2010) Terminal Evaluation for the Project "Vulnerability Reduction through Community Empowerment and Control of Water in the Marwar, Rajasthan", On behalf of and forUnited Nations Development Programme, New Delhi

Alvarez JA, Armstrong E, Gómez M, Soto M (2008) Anaerobic treatment of low-strength municipal wastewater by a two-stage pilot plant under psychrophilic conditions, *Bioresource Technology* 99 (2008) 7051–7062

Bhagwat I, Umar A, Luckose M (2011) Towards drinking water security through participatory water resource management approach in Bharad river sub-basin, Nowgaon Block, Chhattarpur District, India, 6th Rural Water Supply Network Forum 2011 Uganda, Rural Water Supply in the 21st Century: Myths of the Past, Visions for the Future

Bhati TK (2007) Watershed Development in Arid Rajasthan "Experiences, Impact and Lessons and Present Status, Presentation inThe Workshop/Review Meeting of the Project "Comprehensive Assessment of Watershed Programmes in India" July 23 to 27, 2007 at International Crop Research Institute on Semi-Arid Tropics, Patancheru, Hyderabad (A.P.)

Bishnoi S, Gupta A, Phansalkar M, Srinivasan RK, Stenström TA, Starkl M (2010) Comparison of indigenous and modern rainwater harvesting systems: case studies from India

Bishnoi S and Starkl M (2011) Traditional rainwater harvesting structures in India: potential andlimitations, Proceedings of IWA ASPIRE conference

Bouma JA, Biggs TW and Bower L (2011) The downstream externalities of harvesting rainwater insemi-arid watersheds: An Indian case study, *Agricultural Water Management 98* (2011) 1162–1170

Boving T, Choudri BS, Cady P, Davis A, Patil K, Reddy V(2012) Acceptance of a Riverbank Filtration System in Rural India, Journal of the Indian Water Works Association, accepted for publication

Cady P, Boving T, Choudri BS, Patil K, Reddy V (~2010) Health and Economic Profits from Riverbank Filtration in India

Central Groundwater Board (CGWB) (2000) Guide on Artificial Recharge to Ground Water, Ministry of Water Resources, New Delhi, May 2000

Central Pollution Control Board (CPCB) (2005) Status of Sewage Treatment in India, Government of India, New Delhi

Central Groundwater Board (CGWB) (2000) Guide on Artificial Recharge to Ground Water, Ministry of Water Resources, New Delhi, May 2000

Centre for Science and Environment (CSE) (2011), Policy Paper on Septage Management in India

Chaturvedi MK and Asolekar S R (2009) Wastewater Treatment Using Natural Systems: The Indian Experience. eds. J. Nair and C. Furedy In: *Technologies and Management for Sustainable Biosystems* ISBN: 978-1-60876-104-3, Nova Science Publishers.

CSE ( http://www.cseindia.org/node/2052)

Dash RR, Mehrotra I, Kumar P and Grischek T (2008) Lake bank filtration at Nainital, India: water-quality evaluation. *Hydrogeology Journal*, 16(6), 1089-1099.

Dash RR, Bhanu Prakash EVP, Kumar P, Mehrotra I, Sandhu C and Grischek T (2010). River bank filtration in Haridwar, India: removal of turbidity, organics and bacteria. *Hydrogeology Journal*, 18(4), 973-983.

Dewandel B, Gandolfi JM, Zaidi FK, Ahmed S, Subrahmanyam K (2007) A decision support tool with variable agroclimatic scenarios for sustainable groundwater management in semi-arid hard-rock areas, *Current Sci. 92*(8), 1093–1102.

Dillon P, Gale I,Contreras S, Pavelic P, Evans R, Ward J (2009) Managing aquifer recharge and discharge to sustain irrigation livelihoods under water scarcity and climate change, Improving Integrated Surface and Groundwater Resources Management in a Vulnerable and Changing World (Proc. of JS.3 at the Joint IAHS & IAH Convention, Hyderabad, India, September 2009). IAHS Publ. 330, 2009.

Edmunds WM (2006) Water quality in the evaluation and effectiveness of RWH and MARschemes– an overview, UNESCO G-WADI meeting on water harvesting, Aleppo, Syria 20-22nd November 2006, Final report

Fardin F, Hollé A, Gautier E, da Lage A, Molle P, Haury J (2010) Tropical plants of constructed wetlands for wastewater treatment on looking at human and social sciences, in Proceedings of the 12th International IWA Conference on Wetland Systems for Water Pollution Control (Poster Session), volume 2, Venise (Italie), International Water Association, 1079-1080.

Fardin F, Hollé A, Gautier E, Haury J (2011) Spatial, technological and social aspects of wastewater treatment in Puducherry region, India, presentation download under http://www.smallwat.org/web/uploads/comunicaciones/opmdg25_17h40m_franz_fardin.pdf

Gale IN, Macdonald MJ., Calow R, Neumandd I, Moench M, Kulkarni H, Mudrakartha S, Palanisami K (2006) Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management, British Geological Survey, Commissioned Report, CR/06/107N. 80pp

Glendenning CJ, van Ogtrop FF, Mishra AK, Vervoort RW (2012) Balancing watershed and local scale impacts of rain water harvesting in India—Areview, Agricultural *Water Management* 107 (2012) 1–13

GOI (Government of India) (2007) 'Report of the Expert Group on 'Groundwater Management and Ownership', Planning Commission, Yojana Bhawan, New

Delhi. (available under http://planningcommission.nic.in/reports/genrep/rep_grndwat.pdf)

Headley TR, Tanner CC (2006) Application of Floating Wetlands for Enhanced Stormwater Treatment: A Review

Indian Standard IS 10500 (1991) Indian standard specifications for drinking water. Bureau ofIndian Standards, New Delhi, India.

Juwarkar AS, Oke B, Juwarkar A, Patnaik SM (1995) Domestic wastewater treatment through constructed wetland in India, *Water Science and Technology*, Volume 32, Issue 3, 19

Kadam AM, Oza GH, Nemade PD, Shankar HS (2007) Pathogen removal from municipal wastewater in Constructed Soil Filter, *Ecological Engineering* 33 (2008) 37–44

Kadam AM, Oza GH, Nemade P, Dutta S, Shankar H (2008) Municipal wastewater treatment using novel constructed soil filter system, *Chemosphere* 71 (2008) 975–981

Kadam AM, Pravin D, Nemade PD, Oza GH, Shankar HS (2009) Treatment of municipal wastewater using laterite-based constructed soil filter, *Ecological Engineering* 35 (2009) 1051–1061

Kaledhonkar, M. J., Singh, O. P., Ambast, S. K., Tyagi, N. K. & Tyagi, K. C. (2003) Artificial Groundwater Recharge through Recharge Tube Wells: A Case Study. International Journal of Agricultural Research, June, Volume 84, pp. 28-32.

Kaseva ME (2003) Performance of a sub-surface flow constructed wetland in polishing pre-treated wastewater—a tropical case study, *Water Research* 38 (2004) 681–687

Kerr JM (2002) Watershed Development Projects In India - An Evaluation, Research Report 127, International Food Policy Research Institute, Washington, 2002

Kumar D, Patel A, Ravindranath R, Singh OP (2008) Chasing a Mirage: Water Harvesting and Artificial Recharge in Naturally Water-Scarce Regions, *Economic & Political Weekly*, Vol 43 No. 35 August 30 - September 05, 2008

Kuraishi MA and Sharma S (2010) An experimental investigation of nutrient removal efficiency in duckweed covered wastewater system, *Indian Journal for Environmental Protection*, No.9, September 2010

LNMRI (2010), Systematic Evaluation of IWDP and DPAP Programmes: A Study of Kurnool District, AP, Livelihoods and Natural Resource Management Institute (LNMRI), Hyderabad 2010

Londhe A (~2004), Impact of Water based Interventions of Rajiv Gandhi Watershed Mission on Tribal Livelihood: Case Study of Dhar District in Madhya Pradesh

Lorenzen G, Sprenger C and Greskowiak J (2007) Results of background work and data integration of MAR systems for an Integrated Water Resources Management. TECHNEAU integrated project: deliverable D 5.2.1. http://www.techneau.org.

Lorenzen G, Sprenger C, Taute T, Pekdeger A, Mittal A and Massmann G (2010) Assessmentof the potential for bank filtration in a water-stressed megacity (Delhi, India), *Environmental Earth Sciences*, 61(7), 1419-1434.

Mainali B, Ngo HH, Guo W, Nga Pham TT, Johnston A (2011) Feasibility assessment of recycled water use for washing machines in Australia through SWOT analysis, Resources, Conservation and Recycling, Volume 56, Issue 1, November 2011, Pages 87-91

Malik A. (2007) Environmental challenge *vis a vis* opportunity: The case of water hyacinth, *Environment International*, Volume 33, Issue 1, January 2007, Pages 122–138

Mbuligwe SE (2004) Comparative effectiveness of engineered wetland systems in the treatment of anaerobically pre-treated domestic wastewater, *Ecological Engineering* 23 (2004) 269–284

Murphy J (1991) Application of ODEX / TUBEX drilling method in a variably fractured volcanic / igneous environment. *Ground Water Management* 5, 799-814 (5th NOAC)

Narain P, Khan M A, Singh G (2005) Potential for water conservation and harvesting against drought in Rajasthan, India. Working Paper 104 (Drought Series: Paper 7). Colombo, Sri Lanka: International Water Management Institute (IWMI)

Nema P, Ojha CS, Kumar A, Khanna P (2001) Techno-economic evaluation of soil-aquifer treatment using primary effluent at Ahmedabad, India, Water Res. 2001 Jun;35(9):2179-90

Nemade PD, Kadam AM, Shankar HS (2009) Wastewater renovation using constructed soil filter (CSF): A novel approach, Journal of Hazardous Materials 170 (2009) 657–665

NIUA (National Institute of Urban Affairs) (2011) Peer Experience And Reflective Learning (PEARL), Urban Initiatives, Volume 5, New Delhi, November 2011

Oaksford, E.T. 1985. Artificial Recharge: Methods, Hydraulics, and Monitoring, In: *Artificial Recharge of Groundwater, T. Asamo, editor. Butterworth Publishers*, Boston, pp. 69-127

Oekotec (http://www.oekotec-gmbh.com/download_en/pdf/72dpi/Water_Reuse_72dpi.pdf)

Pangare V (2003) Impact on Livelihoods: “Rejuvenating Ooranis”, Watershed Development Initiative, Ramnad District, Tamil Nadu, IWMI Research Project supported by DFID

Pekdeger A, Lorenzen G, Sprenger C (2008) Preliminary report ondata of all inorganic substances and physicochemical parameterslisted in the Indian and German Drinking Water Standards fromsurface water and groundwater at the 3 (+1) field sites.TECHNEAU integrated project deliverable D 5.2.2. http://www.techneau.org.

Perrin J, Massuel S, Ahmed S (2010) Contribution of percolation tanks to total aquifer recharge: the example of Gajwel watershed, southern India

PSCST (Punjab State Council for Science & Technology) (http://www.punenvis.nic.in/water/technologies10.htm)

Raju N, Reddy T, Munirathnam P (2006) Subsurface dams to harvest rainwater—a case study of the Swarnamukhi River basin, Southern India. *Hydrogeology Journal* 14, 526–531

Ray C, Melin G, Linsky RB (eds) (2002) Riverbank Filtration—Improving source-water quality. *Wat. Sc. Tech. Lib*. 43, Kluwer Academic Publ., Dordrecht, Boston, London

Reed R, Singh IB, Mani S, Kanjur R, Simon N and Mol S (2005) Making the most of a scarce resource: Solar disinfection ofdrinking water in the arid zone of western Rajasthan, AridLands Newsletter, Water efficiency II: Rural areas and agriculture, No. 57, May/June 2005

Ronghang M, Kumar P, Mehrotra I, Kimothi PC, Adlakha LK, Sandhu C., Grischek T (2012) Perspective of Riverbank Filtration at a Hilly Town, Satpuli, India. Proc. 5th IPWE, Marrakech, 05.-07.01.2012.

Sakhtivadivel R (2007) The Groundwater Recharge Movement in India, Chapter 10, The Agricultural Groundwater Revolution:Opportunities and Threats to Development, Editors: M. Giordano and K.G. Villholth, CAB International 2007

SANDEC (1999) Duckweed Aquaculture: Potentials, Possibilities and Limitations for Combined Wastewater Treatment and Animal Feed Production in Developing Countries

Sandhu C, Grischek T, Kumar P and Ray C (2011a) Potential for riverbank filtration in India, Clean *Technologies and Environmental Policy*. 13(2), 295-316

Sandhu C, Grischek T, Schoenheinz D, Prasad T and Thakur AK (2011b) Evaluation ofBankFiltration for Drinking Water Supply in Patna by the Ganga River, India. In: *Riverbank Filtration for Water Security in Desert Countries*, Ray C. and Shamrukh M. (eds.), NATO Science for Peaceand Security Series, Springer, pp. 203-222.

Sandhu C and Grischek T (2011) Riverbank filtration as an ecosystem service for human health in India, Presentation held in Int. Conf. on IWRM, “Management of Water in a Changing World: Lessons Learnt and Innovative Perspectives, 12-13.10.2011, Dresden

Sandhu C and Grischek T (2012) Riverbank filtration in India – using ecosystem services to safeguard human health. *Water Science & Technology: Water Supply* 12(6), 783–790.

Sayana V, Arunbabu E, Kumar L, Ravichandran S. and Karunakaran K (2010) Groundwater responses to artificial recharge of rainwater in Chennai, India: a case study in an educational institution campus. Indian Journal of Science and Technology, 3(2).

Sen S, Shah A and Kumar A (2006) Watershed Development Programmes in Madhya Pradesh, Gujarat Institute of Development ResearchForum for Watershed Research and Policy Dialogue

Shankar HS (2000), Soil Biotechnology of IIT, Mumbai, Presentation: www.che.iitb.ac.in/faculty/hss/soilbiotech.pdf

Shah A (2001) Who Benefits from Participatory Watershed Development? Lessons from Gujarat, India, *Gatekeeper Series* no. 97, IIED

Sharda VN, Kurothe RS, Sena DR, Pande VC, Tiwari SP (2006) Estimation of groundwater recharge from water storage structures in a semi-arid climate of India, *Journal of Hydrology*, Volume 329, Issues 1–2, 30 September 2006, Pages 224-243

Sharda VN (2006b) Watershed management and Water harvesting as strategic tool for groundwater augmentation. Proc. Ground water governance in AisaSeries-1-Ground water, Research and management: Integrating science into management decisions. pp 134-146.

Sharma A (2006) Water harvesting context in the Indian Subcontinent,UNESCO G-WADI meeting on water harvesting, Aleppo, Syria 20-22nd November 2006, Final report

Sharma SK and Amy G (2010) Natural Treatment ystems. In: Water Quality and Treatment: Handbook of Community Water Supply. J. Edzwald (ed.), Sixth Edition, Chapter 15. Publisher: American Water Works Association and McGraw Hill Inc.

Singh P, Kumar P, Mehrotra I and Grischek T (2010) Impact of riverbank filtration on treatmentof polluted river water. *Journal of Environmental Management*, 91(5), 1055-1062.

Sivakumar, C., Elango, L. & Gnanasundar, D.(2006) Numerical modelling of groundwater

flow in south Chennai coastal aquifer. In: MODFLOW and More 2006 Managing groundwater systems. Colorado, USA: Colorado School of Mines, pp. 506-510.

Sprenger C, Lorenzen G, Hülshoff I, Grützmacher G, Ronghang M, Pekdeger A (2011) Vulnerability of bank filtration systems to climate change. Science of the Total Environment,409(4), 655-663

Srivastava PK, Kulshreshtha K, Mohanty CS, Pushpangadan P, Singh A. (2005) Stakeholder-based SWOT analysis for successful municipal solid waste management in Lucknow, India. *Waste Manage* 2005; 25(5):531–7.

Starkl M, Phansalkar M, Srinivasan MR, Roma E, Stenström TA (2010) Evaluation of sanitation and wastewater treatment technologies: case studies from India. Proceedings of National Sanitation Conference India, New Dehli, 2010

TERI (2010) Safe Water by Riverbank Filtration, brochure published by TERI ((http://www.teriin.org/index.php?option=com_ongoing&task=about_project&sid=84)

TERI (2009), DM2007 Project Implementation PROGRESS REPORT 3, 06.12.2009

TERI (2008), DM2007 Project Implementation, Progress report 1, 30.04.2008

Terrados J, Almonacid G, Hontoria L. (2011) Regional energy planning through SWOT analysis and strategic planning tools. Impact on renewable development. Renew.Sustain Energy Rev 2007; 11(6):1275–87.

The Hindu (2011) 16th September 2011 (http://www.thehindu.com/news/cities/Chennai/article2458454.ece)

UNESCO (2006) National Seminar on Rainwater Harvesting and Water Management, Nagpur, United Nations Educational, Scientific and Cultural Organization.

Valipour A, Raman K, Ghole VS (2009) A new approach in wetland systems for domestic wastewater treatment using Phragmites sp., *Ecological Engineering* 35 (2009) 1797–1803

Wafler M and Heeb J (2006) Report on Case Studies of Ecosan Pilot Projects in India, report for GTZ-ecosan

# 8 Annex

## 8.1 Existing evaluation results - NWWTS

**Table 27: Documented NWWTS and overview of existing evaluation results**

| N / N (D3. 1)* | Technology | Case study | Evaluation conducted? | | | | | Year of evaluation (construction) | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | | | Technical | Health safety | Social | Institutional | Economic | | |
| **Waste Stabilization Ponds (WSP)** | | | | | | | | | |
| 1/46 | WSP* | Punjab, Phillore | yes | yes | no | no | no | 2005 | CPCB (2005) |
| 2/45 | WSP | Punjab, Sultanpur Lodhi | yes | yes | no | no | no | 2005 (2003) | CPCB (2005) |
| 3 | WSP | Uttar Pradesh, Fatehgarh | yes | yes | no | no | no | 2005 | CPCB (2005) |
| 4/7 | WSP | Chhattisgarh,Kutelbhata village, Bhilai | yes | yes | no | no | no | 2002 (1965) | CPCB (2005) |
| 5/8 | WSP | Chhattisgarh, Risali, Bhilai | yes | yes | no | no | no | 2002 (1965) | CPCB (2005) |
| 6/9 | WSP | Chhattisgarh,Bhillai House | yes | yes | no | no | no | 2002 (1965) | CPCB (2005) |
| 7/10 | WSP | Delhi, Timarpur | yes | yes | no | no | no | 2004 | CPCB (2005) |
| 8/14 | WSP | Karnal, Haryana | yes | yes | no | no | no | 2005 | CPCB (2005) |
| 9/70 | WSP | Uttar Pradesh, Muzzafarnagar | yes | yes | no | no | no | 2005 | CPCB (2005) |
| 10/80 | WSP | Uttar Pradesh, Etawah | yes | yes | no | no | no | 2005 (2001) | CPCB (2005) |
| 11/79 | WSP | Uttar Pradesh, Kali Deh, Vrindavan | yes | yes | no | no | no | 2005 (2000) | CPCB (2005) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12/77 | WSP | UttarPradesh, Pagal Baba Mandir, Vrindavan | yes | yes | no | no | no | 2005(2000) | CPCB (2005) |
| 13/78 | WSP | Uttar Pradesh, Masani, Mathura | yes | yes | no | no | no | 2005 (2001) | CPCB (2005) |
| 14 | WSP | Uttar Pradesh Mathura | no | no | no | no | no | (2001) | personal communication with IITB |
| 15 | WSP | Uttar Pradesh Mathura | no | no | no | no | no | (2001) | personal communication with IITB |
| 16/76 | WSP | Uttar Pradesh, BangaliGhat, Dairy Farm Zone, Mathura | yes | yes | no | no | no | 2005 (2001) | CPCB (2005) |
| 17/69 | WSP | Uttar Pradesh, Burhi Ka Nagla, Agra | yes | yes | no | no | no | 2005 (2001) | CPCB (2005) |
| 18/66 | WSP | Uttar Pradesh, Peela Khar, Agra | yes | yes | no | no | no | 2005 (2001) | CPCB (2005) |
| 19/81 | WSP | West Bengal, Bhatpara, Madrail, Kakinara, Bhatpar | yes | yes | no | no | no | 2004 (1987) | CPCB (2005) |
| 20/88 | WSP | West Bengal, Titagarh, Dumping Ground, Dangapara | yes | yes | no | no | no | 2004 | CPCB (2005) |
| 21/88 | WSP | West Bengal, Titagarh, | yes | yes | no | no | no | 2004 (1988) | CPCB (2005) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Bandipur Gram Panchayat | | | | | | | |
| 22/85 | WSP | West Bengal, Panihati, Natagarh Gram Panchayat | yes | yes | no | no | no | 2004 (1988) | CPCB (2005) |
| 23/82 | WSP | West Bengal, South Suburban (East) and Tollyganj-Jadavpur, South Suburban (East), Kolkata | yes | yes | no | no | no | 2004 | CPCB (2005) |
| 24 | WSP | West Bengal, Kalyani, Block B2 & B3 Kalyani | yes | yes | no | no | no | 2004 (1987) | CPCB (2005) |
| 25/89 | WSP | West Bengal, Nabadwip | yes | yes | no | no | no | 2004 (1988) | CPCB (2005) |
| 26/84 | WSP | West Bengal, Behrampore | yes | yes | no | no | no | 2004 (1987) | CPCB (2005) |
| *There are more WSP for which no evaluation at all has been conducted so far. For a complete list, see Deliverable D3.1.* | | | | | | | | | |
| **Polishing pond** | | | | | | | | | |
| 1 | Polishing pond | Hyderabad | no | no | no | no | no | (2009) | - |
| **Constructed wetland** | | | | | | | | | |
| 1/105 | Constructed wetland (CW) | Punjab, PeepalMajra (District Ropar) | no | no | no | no | no | - (2003) | Punjab State Council for Science & Technol |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ogy (PSCST) |
| 2/106 | CW | Punjab, Shekhupur (Distt. Patiala) | no | no | no | no | no | - (2003) | PSCST |
| 3 | CW | Madras, Anna University | no | no | no | no | no | ? | Oekotec |
| 4/102 | CW | Madhya, Pradesh, Bhopal | no | no | no | no | no | | personal communication with IITB |
| 5 | CW | Madhya Pradesh, Bhopal | no | no | no | no | no | | personal communication with IITB |
| **Duckweed pond** | | | | | | | | | |
| 1 | Duckweed pond (DP) | Punjab, Ajnoha | no | no | no | no | no | - (2003) | PSCST |
| 2 | DP | Punjab, Manak Dheri | no | no | no | no | no | - (2003) | PSCST |
| 3 | DP | Punjab, Sanghol | no | no | no | no | no | - (2001) | PSCST |
| 4 | DP | Punjab, Chanarthal Kalan | no | no | no | no | no | - (2001) | PSCST |
| 5 | DP | Punjab, Sandhua | no | no | no | no | no | - (2003) | PSCST |
| 6 | DP | Punjab, Villa Teja | no | no | no | no | no | - (2003) | PSCST |
| 7 | DP | Punjab, Sahowal | no | no | no | no | no | - (2003) | PSCST |
| 8 | DP | Punjab, Takhanwadh | no | no | no | no | no | - (2003) | PSCST |
| 9 | DP | Punjab, Kot-Ise-Khan | no | no | no | no | no | - (2003) | PSCST |
| 10 | DP | Punjab, | no | no | no | no | no | - | PSCST |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Multania | | | | | | (2003) | |
| 11 | DP | Punjab, Marhi | no | no | no | no | no | - (2003) | PSCST |
| 12 | DP | Punjab, Dhelwa | no | no | no | no | no | - (2003) | PSCST |
| 13 | DP | Punjab, Burj Gill | no | no | no | no | no | - (2003) | PSCST |
| 14 | DP | Punjab, Gill Khurd | no | no | no | no | no | - (2003) | PSCST |
| 15 | DP | Punjab, BhaiBhaktaur | no | no | no | no | no | - (2003) | PSCST |
| 16 | DP | Punjab, Lakha Singh Wala | no | no | no | no | no | - (2003) | PSCST |
| 17 | DP | Punjab, ChunniKalan | no | no | no | no | no | - (2003) | PSCST |
| 18 | DP | Punjab, ChunniKhurd | no | no | no | no | no | - (2003) | PSCST |
| 19 | DP | Punjab, Saleempura | no | no | no | no | no | - (2003) | PSCST |
| **Duckweed pond and waste stabilization pond** | | | | | | | | | |
| 1 | DP & WSP | Tamil Nadu, Puducherry | yes | yes | no | no | no | 2011 | Fardin (2011) |
| **Soil biotechnology system** | | | | | | | | | |
| 1 | Soil Biotechnology system (SBT)** | Maharashtra, Kimmins | yes | yes | yes | yes | yes | 2009 (2004) | Starkl (2010) |
| 2 | SBT | Bharati | yes | yes | yes | yes | yes | 2009 (2004) | Starkl (2010) |
| 3 | SBT | Bombay Presidency Golf Club | yes | yes | no | no | no | 2008 | Kadam (2008a) |
| 4 | SBT | Housing colony, Kanjurmarg | yes | yes | no | no | no | 2009(2002) | Kadam (2008b), Kadam |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | , eastern suburb of Mumbai | | | | | | | (2009) |
| 5 | SBT | Chembur, eastern suburb of Mumbai | yes | yes | no | no | no | 2009 (1995) | Kadam (2008b) |
| 6 | SBT | Municipal Corporation of Greater Mumbai | yes | yes | no | no | yes | 2009 | Nemade (2009) |
| 7 | SBT | Delhi Travel Tourism Dev Corporation | no | no | no | no | no | | Shankar (2000) |
| 8 | SBT | IIT Mumbai | no | no | no | no | no | | Shankar (2000) |
| 9 | SBT | University of Hyderabad | no | no | no | no | no | | Shankar (2000) |
| 10 | SBT | Vazir Sultan Tobacco, Hyderabad | no | no | no | no | no | | Shankar (2000) |
| 11 | SBT | Jindal Steel, Delhi | no | no | no | no | no | | Shankar (2000) |
| 12 | SBT | Taj Kiran, Gwalior | no | no | no | no | no | | Shankar (2000) |
| 13 | SBT | Beru Ashram Badlapur | no | no | no | no | no | | Shankar (2000) |
| **Planted filters** | | | | | | | | | |
| 1 | Plante d filters (PF) | Gujarat, Rayka village, | no | no | no | no | no | 2006/( 2005) | Wafler (2006) |
| 2 | PF | Tamil Nadu, Chennai | no | no | no | no | no | -/ 2011 | The Hindu (2011 |
| 3 | Plante d filter (post-treatm ent) | Agra | yes | no | no | no | no | 2011 (~2009 ) | NIUA |

* serial number given in Deliverable D3.1

## 8.2 Existing evaluation results - RBF

**Table 28: Documented RBF systems and overview of existing evaluation results**

| | Technology | Case study (bold= Saph Pani case study) | Evaluation conducted? | | | | | Year of evaluation (construction) | References |
|---|---|---|---|---|---|---|---|---|---|
| | | | Technical | Hygienic | Social | Institutional | Economic | | |
| 1 | Bank filtration | **Delhi** | yes | yes | no | no | no | 2008 | Lorenzen et al (2007, 2010), Pekdeger et al (2008),Sprenger et al. 2011 |
| 2 | Bank filtration | **Uttarakhand, Haridwar** | yes | yes | no | no | no | 2010 (6 new RBF wells constructed in 2010) | Dash et al (2010), Sandhu et al (2011a; 2012), Sandhu & Grischek (2012) |
| 3 | Bank filtration | **Uttarakhand, Srinagar** | yes | yes | no | no | no | 2011 (2010) | 9 Sandhu et al (2011a), Ronghang et al (2011), Kimothi et al (2012) |
| 4 | Bank filtration | **Uttarakhand, Nainital** | yes | yes | no | no | no | 2008 (1990 - 2007) | Dash et al (2008) |
| 5 | Bank | Uttar | yes | yes | no | no | no | 2009 | 10 Sing |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | filtration | Pradesh , Mathura | | | | | | | h et al (2010), Kumar et al (2012) |
| 6 | Bank filtration | Gujarat, Ahmedabad | yes | no | no | no | no | - | Sandhu et al (2011a) |
| 7 | Bank filtration | West Bengal, Medinipur and Kharagpur | yes | no | no | no | no | - | Sandhu et al (2011a) |
| 8 | Bank filtration | Bihar, Patna | yes | yes | no | no | no | 2005 | Sandhu et al (2011b) |
| 9 | Bank filtration | Karnataka, Dandeli, | yes | yes | yes | yes | yes | 2008 - 2010 | 11 Cady et al (2010), www.teriin.org , Boving et al (2012) |
| 10 | Bank filtration | Uttarakhand, Dehradun (for rural drinking water) | yes | yes | no | no | no | 2011 | Sandhu and Grischek (2012) |
| 11 | Bank filtration | Gujarat, Vadodara | no | no | no | no | no | 2011 | Sandhu et al (2011a) |
| 12 | Bank filtration | Uttarakhand, Satpuli | yes | yes | no | no | no | -/2010 | Kimothi et al (2012), Ronghan |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | g et al (2011, 2012) |
| 13 | Bank filtration | Uttarakhand, Karnaprayag | no | no | no | no | no | -/2010 | Kimothi et al (2012), Ronghang et al (2011) |
| 14 | Bank filtration | Uttarakhand, Agastmuni | no | no | no | no | no | -/2010 | Kimothi et al (2012), Ronghang et al (2011) |

## 11.1 Existing evaluation results - MAR

**Table 29: Documented MAR systems and overview of existing evaluation results**

| | **Technology** | **Case study (bold= SP case study)** | **Evaluation conducted?** | | | | | Year of evaluation (construction) | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | | | Technical | Hygienic | Social | Institutional | Economic | | |
| **Managed Aquifer Recharge** | | | | | | | | | |
| 1 | Percolation tanks, check dams, defunct dugwells | **Andhra Pradesh, Maheshwaram** | yes | no | no | no | no | 2009 | **Dillon et al (2009), Dewandel (2007)** |
| 2 | Percolation tanks | Maharashtra, Amravati district | yes | no | no | no | yes | 2000 | CGWB (2000) |
| 3 | Percolation ponds, check dams | Tamil Nadu, Coimbatore district | yes | no | yes | yes | yes | 2006 (1978-1998) | Gale(2006) |
| 4 | RWH & groundwater recharge | Maharashtra, Nagpur | yes | no | no | no | no | 2000 | CGWB (2000) |
| 5 | Check dams | Maharashtra, Kolwan valley (various systems) | yes | no | yes | yes | yes | 2006 (1998) | Gale (2006) |
| 6 | Check dams | Satlasana (4 systems) | yes | no | yes | yes | yes | 2006 (2001-2003) | Gale (2006) |
| 7 | Two injection wells, and two lateral recharge shafts with inverted filter | Haryana, Brahm Sarovar, Kurukshetra | yes | no | no | no | no | 2000 | CGWB (2000) |
| 8 | Check | Gujarat, | yes | no | yes | yes | no | - | Sakthivad |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | dams | Sardar Patel Participatory Water Conservation Programme (SPPWCP) | | | | | | | ivel (2007) |
| 9 | Check dams | Haryana, Ambala district „Bunga“ project | no | no | no | no | yes | (~1990) | PSCST |
| 10 | Various measures | Rajasthan, Jhanwar | yes | no | no | no | yes | 2007 (1987-1992) | Bhati (2007) |
| 11 | Percolation tanks, gabions, ponds | Rajiv Gandhi Watershed Mission, two villages in Madhya Pradesh evaluated | yes | no | yes | yes | yes | 2004 (1997 – 2003) | Londhe (~2004) |
| 12 | Check dams, Nala bunds, recharge wells | Rajiv Gandhi Watershed Mission, four districts in Gujarat evaluated | no | no | yes | no | yes | 2001 (~1998) | Shah (2001) |
| 13 | Mainly check dams | Andhra Pradesh, six WDP | yes | no | yes | yes | yes | 2010 (1987 onwards) | LNRMI (2010) |
| 14 | Maharashtra: check dams, Andhra Pradesh: | Maharashtra and Andhra Pradesh, 86 WDP | yes | no | yes | yes | yes | 1997 | Kerr (2002) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | check dams, percolation tanks | | | | | | | | |
| 15 | Check dams, stream channels | Rajasthan | no | yes | no | no | no | 2006 | Edmunds (2006) |
| 16 | Boulder gully plugs, field bunds, contour trenches, farm ponds, percolation tanks | Rajasthan | yes | no | yes | yes | yes | 2001 - 2006 | Sharman & Edwards |
| 17 | Check dams, recharge filters, dams | Gujarat | yes | no | no | no | no | 2003 /200 4 | Sharda (2006) |
| 18 | Subsurface dams | Andhra Pradesh | yes | no | no | no | yes | 2001 /02 | Raju (2006) |
| 19 | Check dams | Madhya Pradesh | yes | yes | no | yes | yes | 2011 (200 9) | Bhagwat (2011) |
| 20 | Percolation tanks | Rajasthan | yes | no | no | no | no | 2007 /200 8 | Perrin (2010) |
| 21 | Anicut, Bandhi, Johad, Talab | Rajasthan | yes | no | no | no | no | 2010 | Glendenni ng (2011) |
| 22 | Johad | Alwar district, Rajasthan | yes | no | no | no | yes | 2011 (sinc e 1985 ) | WSP (2011) |
| 23 | Talab / Chouka | Lapodia village, Rajasthan | yes | no | no | no | no | 2011 (sinc e 1987 ) | WSP (2011) |
| 24 | Oorani | Tamil Nadu | yes | yes | yes | no | yes | 2009 | Bishnoi (2010) |
| 25 | Oorani | Tamil Nadu | yes | no | no | yes | no | 2011 (sinc | WSP (2011), |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | e 2002 ) | www.dhan.org |
| 26 | Oorani | Tamil Nadu | yes | yes | no | yes | no | 2003 (from 1996 up to now) | Pangare (2003) |
| 27 | Nadi, Tanka, Kahdins | Rajasthan, Jodhpur district | yes | no | no | no | no | 2005 | Narain (2005) |
| 28 | Nadis, talabs, tankas and berries | Rajasthan, Marwar | yes | no | no | yes | no | 2010 (2009) | AFPRO (2010) |
| 29 | Nadis, talabs, tankas and berries | Rajasthan | no | yes | no | no | no | 2005 | Reed (2005) |
| 30 | Khadin, Talab | Rajasthan | yes | yes | yes | no | yes | 2009 | Bishnoi (2011) |
| 31 | Johad | Rajasthan | yes | no | no | no | no | 2006 | Sharma (2006) |

## 11.2 A-1 General questionnaire (for all case studies)

**General questions**

1-1. Name of technology to be evaluated:

1-2. Location where technology is being evaluated:

1-3. Number of people being served by the technology:

1-4. Since when is it in operation (approximately)?

1-5. Who designed/planned and who implemented/constructed the technology?

1-6. Please provide a brief summary of the history/evolution of this technology in the selected case study (ie what was the background of its implementation – why was it implemented, since it is in operation, have any changes been made to it – if yes, why?)

1-7. Brief technical description of the technology (please make a flow chart and describe all components, please also take pictures of all components)

1-8. Which were the intended benefits/purposes of this technology?

**Economic aspects**

2-1. What were the investment costs?

2-2. Which are the O&M costs – pls break down in categories as far as known (eg personnel, energy, material, etc.)?

2-3. How are the costs recovered?

2-4. Are the revenues sufficient to cover the O&M costs?

2-5. What is the stakeholder and user perception about costs? * (see guidance questions below) Please ask at least x users

**Social aspects**

What is the stakeholder and user perception about this system?* (see guidance questions in Annex 2) Please ask at least x users.

**Institutional and operational aspects**

4-1. Who is operating/ taking care of the technology now?

4-2. In case a body (water committee or something similar) was constituted, how is it composed (men/women), how did it evolve and what are its responsibilities?

4-3. What are the tasks of the responsible person/body? Please explain the work as detailed as possible.

4-4. Is/are the persons responsible for the O&M work paid for their work?

4-5. In case a person is contracted: for which time period is the contract And how much is the payment/salary?

4-6. Which training did the responsible persons receive? Who conducted the training and and how long was it?

4-7. Are there any standards existing which need to be fulfilled by the technology? (e.g. effluent quality, etc.? If yes, which?)

4-8. - if yes, are these standards monitored?

4-9. Are any other operation and maintenance data records available?

**Problems and reasons for failure and success**

5-1 Did you experience any problems so far?

5-2 Are there any perceivable risks which could endanger the functioning of the system in the future?

5-3 Have the intended benefits been fulfilled?

| Intended Benefit/purpose | Fulfilled (yes/no) | Comments (pls explain why it is fulfilled or not) |
|---|---|---|
| | | |
| | | |

5-4 What do you think are the reasons for success/failure?

5-5 Please insert some pictures which depict all above mentioned problem/reasons for success.

## 11.3 A-2: Questionnaire for assessing user perception for river bank filtration case studies (Questions 2-4 and 3-1):

1. Pls briefly describe the different user groups in the case study location:
2. Selection of sample for interviews
3. Guidance for questions to users (Q):

a) What are your water sources (e.g. rainwater, surface water, groundwater, bank filtrate, spring water, treated wastewater) and how is the water provided (e.g. piped water supply network, tanker, bottled water, etc.)?

b) Do you know how the bank filtration system works?

c) What do think about the bank filtration system?

  a. Is it a reliable and safe water source?

  b. Would you prefer other sources?

d) What were your water sources before the bank filtration system was implemented and how urgent was it to improve the original situation?

e) How did/do you participate during:

  a. Planning:

  b. Implementation:

  c. Operation:

f) How satisfied are you with your participation?

g) Which is your preferred water source? Please make a ranking.

Are you happy with the provided water/etc. (if yes why, if no, why not)?

h) Did you experience any problems with the provided water (quality, quantity, availability)

i) Are you using the water from the bank filtration system (regularly)?

j) Is there anything which may prevent you from using the water from the bank filtration system (regularly), if yes, what?

k) Is there anything which you may not like with the water or which could be improved (if yes, what and how)?

l) How much do you pay for your water?

m) Do you pay different prices for your water? (e.g. depending on source or season)

n) Do you think the price is reasonable? (please ask for all water sources)

## 11.4 A-3: Questionnaire for assessing user perception for natural wastewater treatment systems case studies (Questions 2-4 and 3-1):

1. Pls briefly describe the different user groups in the case study location:
2. Selection of sample for interviews
3. Guidance for questions to users (Q):

a) What are your water sources? (e.g. rainwater, surface water, groundwater, bank filtrate, spring water, treated wastewater)

b) Do you know how the natural wastewater treatment system (please replace with name of system) works?

c) Are you using the treated water? Yes / no

i. No: In case treated water is not used: why do you not use the treated water?

The following questions are only applicable in case the water is reused:

d) Yes: In case treated water is used: for which purposes are you using the treated water?

e) Do you think that treated wastewater is safe to use for this purpose?

f) Would you prefer other water sources for this purpose
Which would be your preferred water source(s) for this use ? Please make a ranking.

g) Is there anything which prevents you from using the treated water regularly, if yes, what (e.g. bad quality, variable quantity, etc.)?

h) Do you pay for the treated water and if yes, how much?

i) Do you think the price is reasonable?