Saph Pani

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

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Report on integration of results and final recommendations

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1 Introduction

1.1 Scope of the report

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.

Task 1 of WP6 consisted of an initial sustainability appraisal of currently existing natural treatment systems (Deliverable D6.1, Starkl et al., 2013a, Starkl et al., 2013b, Essl et al., 2014). It highlighted the importance of these non-technical aspects for the overall sustainability of natural treatment systems. Tasks 2-5 consisted of a more detailed investigation on those sustainability aspects in selected Saph Pani case studies (Deliverable D6.2, Sakthivel et al., 2013, Sakthivel et al., 2014).

Building on the results of tasks 2-5, the following task 6 consisted in integrating the results of tasks 2-5 by using an appropriate integration framework. Task 8 then consisted in developing policy recommendations for each of the studied case study sites (details on the studied case study sites can be found in Deliverable D6.2), building on the outcomes of the integration of results. This deliverable encompasses these two tasks (6&8). The case study sites were Hyderabad, Chennai and Haridwar. The work and the frame conditions will briefly be described.

1.2 Case study Hyderabad

In Hyderabad the main research question for the case study was about whether a constructed wetland is feasible to treat the Musi river water in order to reduce microbial contamination before it is used by farmers for irrigation. Deliverable D6.3 is based on a cooperation with WP3 partners which conducted a technical feasibility study of a constructed wetland and which hence was summarized in this deliverable. Based on the technical feasibility study, the costs of the constructed wetland were estimated, and qualitative farmer and consumer surveys were carried out to find out about the perceptions of both groups on the current practice and their willingness to pay for a constructed wetland for wastewater treatment and for the resulting products, respectively. The results were then presented to and discussed with stakeholders in the course of a policy workshop, and final policy recommendations were elaborated. The main results this case study was submitted to and accepted for publication in the peer reviewed and open access journal Water (Starkl et al., 2014)

1.3 Case study Chennai

In Chennai the main research question for the case study was about the potential of the Saph Pani technology “Managed Aquifer Recharge (MAR)” compared to other options for securing water supply. Building on the assessment results for MAR (see deliverable D6.2), an aggregation was carried out. The results were then presented to and discussed with stakeholders in the course of a policy workshop, and final policy recommendations were elaborated. The main results this case study was submitted to and accepted for publication in the peer reviewed and open access journal Water (Brunner et al., 2014)

1.4 Case study Haridwar

In Haridwar, partner UJS possesses large experience with respect to river bank filtration. Therefore no stakeholder and policy workshops were carried out(see also D6.2). Instead, a brief summary of the key policy recommendations that stems from the work of UJS, HTWD and NIH, is provided. Additionally, the participation of Saph Pani project partners from applied research, academia and a water supply service provider in various activities in Haridwar (HTWD, NIH, IITR and UJS) resulted in numerous meetings on a regular basis amongst them and with various other state, district and municipal administrative bodies. Consequently the interaction between these partners and the various civic bodies was intensified significantly. Furthermore, multiplier effects arose out of the cross-cutting activities (projects, meetings) of the partners HTWD, UJS, IITR and NIH with the Central Ground Water Board (CGWB), the Uttarakhand Renewable Energy Development Agency (UREDA) and the Uttarakhand State Council for Science and Technology (UCOST). A focus was also set for a better integration of scientific research in daily water management of the water company. In this context, detailed site-specific information and related information on integrated sustainability assessment (science, technology, practical, social, policy and management aspects) can be found in the Saph Pani Deliverables D1.1 (2012) and D1.2 (2013) of the Work Package 1.

2 Case Study Hyderabad (Natural Wastewater Treatment System)

2.1 Integration of Assessment Results

2.1.1 Review of the Problem

Hyderabad in Telangana state (the state was established on 02.06.2014) is the common capital of Telangana and Andhra Pradesh states. With a population of 6.8 million (2011 census) and 650 km^2 it is one of the four metropolitan cities of India. It is situated along the banks of the Musi River.

Water from the Musi River is discharged into canals on both sides of the river and used for irrigation within Hyderabad's city boundaries for growing para-grass (used for fodder) and downstream for growing rice, vegetables and also para-grass. However, due to pollution and the resulting health hazards, this water is not suitable for irrigation (see section 4 of deliverable D 6.2).

Using a natural wastewater treatment system (NWTS) comparable to constructed wetlands for treating river water prior to its use for irrigation could resolve the health and soil salination problems. To assess such a solution in comparison to the status quo, section 4 of deliverable D 6.2 analyzed the relevant criteria as follows: Information about costs was not reliable, but with respect to costs the willingness to pay was investigated. Based on a rough estimation, costs of 1.4 to 9 INR per m^3 of treated water, the prospect for cost recovery could be assessed (Task 6.5 by BRGM on social risk acceptance aassessment). To verify this, the present policy analysis conducted another estimate based on a survey among farmers. Further criteria were risks and benefits for human health (Task 6.2 by CSIRO on risk assessment to health and environment), the environmental benefits of pollution control (again: Task 6.2), possible institutional problems, including ease of operation (Task 6.4 by CEMDS and IWMI on institutional viability) and the acceptance by users (again: Task 6.5).

2.1.2 Stakeholder Preferences and Criteria Weights

2.1.2.1 Data

In order to explore the possibilities for an integrative assessment, for example if there are possible trade-offs that the stakeholders can accept, a participative method of elicitation of criteria weights was applied: POSAF (*Starkl et al.*, 2013c). It was used to assess the relative importance of the following key criteria: pollution control, costs, acceptance by users, ease of operation (low efforts), and safety for health.

This research was based on 25 responses by stakeholder representatives, who filled in questionnaires to inform about their perception of the future development of the Musi river catchment. Respondents were aged 27 to 60, but this information is not displayed to protect the anonymity of respondents. Table 1 informs about the gender and the institutional affiliation: A third of the respondents were women; 14 respondents came from academia, 7 from government and 4 from other institutions (NGOs, water user associations).

2.1.2.2 Method

In order to derive criteria weights for multi-criteria decision aid the analytical hierarchy process (AHP) was applied (*Saaty*, 2010). AHP translates individual qualitative assessments into individual quantitative criteria weights. Respondents were asked, for each pair of criteria, if one criterion was much more or more important than the other, or if both criteria were equally important. These data were processed as follows: The pair-wise comparisons were translated into ratios of importance; this defined a 5×5-matrix. (Here, each comparison, much less/less/equally/more/much important, was recorded by an entry of 0.25, 0.5, 1, 2 or 4.) The largest real eigenvalue, EV, of this matrix was computed and the corresponding eigenvector (normed to sum 1) defined criteria weights.

However, in applying AHP, certain problems need to be addressed. First, respondents not answering all AHP-relevant questions need to be eliminated; here all respondents answered all questions. Second, some respondents confused the direction of comparison. Therefore the ranking of importance by criteria weights was compared to the stated ranking. If the reversal of all pair-wise importance comparisons resulted in a closer approximation (measured by the mean squared error), then it was used but noted as a problem. Third, inconsistencies may make a response difficult to interpret. An example of an inconsistency is lack of transitivity of the pair-wise comparisons: If A is more important than B and B more important than C, than A should be much more important than C. To assess the level of inconsistency, the consistency ratio $CR = (EV - 5)/4.48$ of each response was assessed and an inacceptable inconsistency was noted, if $CR > 10\%$ (for the derivation of this CR formula, see *Alonso & Lamata*, 2004). The subsequent analysis singled out responses without such problems (each question was answered, no reversal of preferences was needed, and responses displayed no inacceptable inconsistency) and analyzed them in parallel to the full data set.

The subsequent aggregation used outranking (essentially ELECTRE-I), which combines weighted majority voting with veto rules (first proposed by *Roy*, 1968, and developed at LAMSADE as decision aid software: *Mousseau & Dias*, 2004).

The computations of the AHP weights were done in Microsoft Excel, using its Solver add-in. Statistical tests were done with XLStat, another commercially available Excel add-in.

Table 1: Criteria Weights from the Hyderabad Stakeholder Survey

No	Institution	Gender	Cluster	Weight pollution	Weight costs	Weight acceptance	Weight efforts	Weight health	CR	Problem
1	O	F	O	32%	12%	14%	14%	28%	1%	Y
2	A	M	O	27%	18%	21%	13%	21%	89%	Y
3	G	M	H	29%	9%	19%	19%	25%	3%	N
4	O	M	H	20%	18%	26%	17%	18%	37%	Y
5	O	M	H	40%	16%	20%	14%	10%	3%	Y
6	A	M	C	22%	22%	11%	22%	22%	0%	N
7	A	M	H	11%	31%	19%	27%	12%	7%	Y
8	G	M	O	57%	25%	11%	5%	2%	44%	Y
9	A	F	H	45%	9%	5%	15%	26%	18%	Y
10	A	F	C	41%	13%	11%	13%	21%	5%	N
11	A	F	C	17%	23%	20%	23%	17%	3%	Y
12	A	F	H	25%	9%	22%	19%	25%	5%	N
13	A	F	H	49%	11%	12%	9%	19%	3%	N
14	G	F	H	37%	13%	13%	13%	24%	13%	Y
15	A	M	O	31%	16%	22%	9%	23%	12%	Y
16	A	F	H	30%	15%	25%	12%	19%	6%	N
17	G	M	H	19%	22%	19%	29%	11%	2%	Y
18	G	M	O	12%	26%	14%	32%	16%	7%	Y
19	G	M	H	23%	7%	20%	18%	32%	7%	N
20	G	M	H	25%	11%	14%	21%	29%	5%	N
21	A	M	O	28%	29%	19%	12%	12%	18%	Y
22	A	M	C	27%	19%	17%	22%	15%	7%	N
23	A	M	H	24%	8%	17%	9%	42%	8%	N
24	A	M	H	39%	9%	17%	12%	23%	3%	N
25	O	M	H	36%	16%	21%	16%	11%	3%	Y

Explanations: Institutions: O Other, A Academia, G Government, CR consistency ratio, cluster: C costs, H health, O other. Problems: Y = missing answer, inconsistency or rank reversal, N = no such problem

2.1.2.3 Results

In deliverable D 6.2, an initial qualitative analysis of the respondents' attitudes identified two clusters, namely cost-conscious and health-conscious respondents. The 'cost conscious cluster' refers four respondents (all in academia), to whom costs mattered (criterion ranked as first or second most important), whereas health was not so important (ranked third to fourth). The 'health-conscious cluster' refers to 15 respondents (from all types of institutions), for whom health mattered (criterion ranked as first or second most important), whereas costs were not so important (ranked third to fourth). Two respondents stated no preferences and four others put pollution or ease of use (2 respondents each) in number-one position.

In terms of (computed) weights for technology selection, and in the average of the full data set of 25 responses, pollution had highest weight (mean 29.9% with a 95% confidence interval between 25.3% and 34.6%), followed by health (mean 20.1% with a 95% confidence interval between 16.7% and 23.6%) and the other criteria weights (means ranging from 16.3% to 17.5% and 95% confidence intervals within 13.4% and 19.3%). Also Milton Friedman's non-parametric test confirmed at 95% significance (with a Bonferroni correction of the significance level) that the weight for pollution was significantly higher than the other criteria weights.

Using non-parametric Mann-Whitney test (95% level of significance), health conscious respondents had significantly lower criteria weights for costs (average 14%), than the cost conscious respondents (average 19%), but there was no significant difference with respect to the criteria weights for the two key criteria pollution or health.

As to the quality of the answers, eleven responses were ‘unproblematic’, as defined above. These respondents appear to have a clear understanding of the criteria. For them, in the average the relative importance of pollution and health was even higher; pollution had highest weight in average (mean 30.4%), followed by health (mean 24.7%). Again, there was a significant difference in the importance of costs: Three of the ‘unproblematic’ respondents were cost-conscious and eight health-conscious. Of them the seven health-conscious respondents weighed costs at below 11.9%, two cost-conscious respondents weighed costs with 16.8% or more, and one respondent of each cluster had weights for costs in between.

2.1.3 Integration and Discussion

With respect to the assessment by the individual criteria, it follows from the above analysis that in the overall assessment the most important criteria are pollution and health. As follows from section 4 of deliverable D6.2, both criteria support the water treatment plans:

- In Deliverable D6.2 problems with the current river water are described. It follows that for some of these problems one may expect environmental benefits from treating river water prior to its use for irrigation.
- Amongst the problems that are not addressed by NWTS is water salinity (exacerbated by flood irrigation practice and arid climate conditions), which has caused severe soil salination, exceeding guideline values for rice and vegetables. Also nitrogen and

phosphorus concentration are above recommended guideline values.

- The key problem addressed by the project are the health risks, which were identified in Deliverable D6.2: Currently pathogens, in particular *E.coli* and rotavirus (causing childhood diarrhea: *Parashar et al.*, 2006), pose a high risk for farmers, and treatment can only improve the situation. However, deliverable D6.2 cautions that benefits are not proven yet and additional measures might be needed:

The other criteria, in particular costs, need to be considered, too. However, even for the cost-conscious respondents the criteria weights for costs were not dominant. This results in the following overall assessment:

- Deliverable D6.2 concludes that cost recovery cannot be expected, as citizens (higher water and sewerage tax) and farmers (charges for using treated water) would not be willing to pay enough to cover the estimated costs of 1.4 to 9 INR per m^3 of treated water.
- As for institutional issues, NWTS (like constructed wetlands) are much easier to maintain than high-tech systems (although there may be problems, too: Deliverable D3.1) and deliverable D6.2 outlines that the Indian Water Policy is favorable for the use of treated water in agriculture.
- Deliverable D6.2 explains that treatment of river water prior to irrigation is generally accepted as beneficial, but also the current situation seems to be accepted: Farmers are willing to use untreated river water for its nutrient content. For them this outweighs the health risks, the disgust of using dirty water, and the risk of soil salination. Also only 10% of citizens are concerned about possible health risks from farm products, irrigated with untreated river water.

An aggregation of these partial assessments in terms of the individual criteria leads to an overall assessment: Such an aggregation helps in better understanding, for what reasons stakeholders may arrive at a decision concerning e.g. treatment of river water. However, as the expected costs (deficit) and benefits could not be quantified with sufficient accuracy, only such aggregations could be used, that remain meaningful with ordinal data (*Brunner & Starkl*, 2004). Therefore, the aggregation used the criteria weights as in the ELECTREE-I method as voting weights, adding up the weights of the pros and subtracting the weights of the cons: This was done individually, for each stakeholder respondent, and collectively with the average weights.

Focusing first on the three key criteria pollution, health, and costs, then from the above, NWTS are assessed as positive for health, as not negative for the environment (the salinity problem is not resolved, but treatment causes no additional problem) and as negative with respect to costs. Thereby, for all respondents, except one, adding the weights for pollution and health (benefits) and subtracting the weight for the costs (no full cost recovery) was positive. The same is true for the average weights, interpreting them as societal preferences. In this respect, *using the criteria weights derived from the stakeholder preferences, treating river water prior to irrigation would be recommendable*.

Using also the remaining criteria reinforces this conclusion. Such an investment into river water treatment would also mean that the Musi river banks could be preserved as a natural habitat for future generations.

Figure 1: Present State and a Development Scenario for Musi River, Hyderabad

In interpreting this result it should be cautioned that the respondents were participants of a stakeholder workshop with an environmental agenda. Thus, the participants came from government institutions with an environmental mandate and other institutions with interests in preservation of the habitat. Therefore, the subsequent analysis was based on the assumption that the common interest of the surveyed stakeholders was in environmental preservation (100% agreement), whereas representatives from other government departments may not be interested in that issue.. In particular, development plans exist, which intend the urbanization of the river front by 2025; see Figure 1. Under this development perspective, the assessment of river water treatment would be quite different: As development would be people-centric, it would be acceptable to people, whose livelihoods it supports. Environmental benefits would be low on the priority agenda, unless landscaping, i.e. beautification of river fronts (removal of farmland), were undertaken as part of development. Thereby, indirect health benefits could be expected (e.g. the mosquito nuisance and associated diseases may be addressed). *Under this alternative perspective, building NWTS for treating river water for the purpose of irrigation might not be recommendable.*

2.1.4 Conclusions

As follows from the above discussion, the question, if river water shall be treated prior to irrigation is largely dependent on a political decision between two development scenarios: If the habitat should be preserved, a NWTS would support this. If the riverfront shall be urbanized, a NWTS is not needed.

The further work is done under the presumption that the natural habitat shall be preserved and therefore, that river water shall be treated prior to its use for irrigation. The treatment may be decentralized, using constructed wetlands on the farmers' own plots, or centralized, letting farmers feed irrigation channels with treated wastewater.

2.2 Policy Recommendations

The policy recommendations were based on a survey of consumers and farmers, exploring in particular, if farmers and consumers (via higher food prices) could finance river water treatment without public support – and if they were willing to do so.

2.2.1 Consumer Survey

2.2.1.1 Data

A consumer survey was conducted to analyze the consumers' attitudes with respect to irrigation with clean water. It linked their opinions about policy options with their willingness to pay more, if vegetables were grown with clean water (refining task 6.5 of deliverable D6.2). At a local market, a sample of 24 consumers was interviewed; details are in Table 2. 63% (15 of 24) of the respondents visited that market four to five times per month to buy vegetables, for which they spent in average 1'031 INR.

The respondents were of age 24 to 55, 83% (20 of 24) were men, 63% (15 of 24) had earned an academic degree (only one respondent was illiterate) and they lived typically (median) in a four person household. This sample is atypical for India, as the interviews were conducted on Uppal market, in the vicinity of government research institutions and software companies, where it was likely to find respondents interested in cleaner food production. Thus, the consumer survey informs about maximum willingness to pay, only.

All respondents were willing to pay more for their vegetables, if clean water would be used for irrigation. As to the amount, six gave a maximal limits (for all vegetables) between 1,000 and 2,000 INR.

Table 2: Willingness of Hyderabad Consumers to Pay for Cleaner Irrigation Water

No	Gender	Age	Education	Household size	How often here	Vegetables here (INR/month)	Vegetables total (INR/month)	Willing to pay how much more	Safe source	Unhealthy (irrigate with polluted water)	Quality (other than health: shape, taste)	WTP, where relevant (INR/month)
1	M	27	S	5	10	2'000	3'500	<25%	no	no	T/-	0
2	M	32	U	6	8	2'200	3'000	<10%	no	no	G/+	0
3	M	24	U	6	10	2'000	2'500	<100%	Y/H	C	NE	0
4	M	52	S	7	15	3'000	3'000	<25%	Y/H	no	G/+	0
5	M	35	U	4	5	1'000	1'500	<25%	no	Y	NE	300
6	M	43	S	4	4	600	NA	<50%	NI	UN	NE	0
7	M	44	U	4	4	1'500	1'500	<50%	no	Y	T/-	750
8	M	52	U	6	5	400	1'500	<25%	no	Y	UN	375
9	M	27	U	4	4	1'000	NA	<10%	Y/A	no	UN	0
10	M	27	U	5	4	1'000	1'000	<10%	Y/H	no	T+	0
11	F	28	S	4	3	200	1'000	>0%	Y/H	no	UN	0
12	M	44	S	4	5	200	1'000	>0%	Y/H	no	G/+	0
13	M	55	S	4	4	300	NA	<10%	UN	no	NE	0
14	M	48	U	3	4	250	1'000	>0%	no	no	G/+	0
15	M	32	U	5	4	600	NA	<10%	Y/A	no	NE	0
16	M	30	U	3	5	700	1'200	<10%	UN	Y	T/-	120
17	M	28	U	5	5	1'000	1'500	<10%	UN	Y	G/+	150
18	M	33	no	4	6	1'500	2'000	<25%	UN	Y	UN	500
19	F	31	U	2	8	1'000	1'500	<25%	Y/H	Y	UN	0
20	M	39	S	4	4	800	2'000	<10%	UN	no	NE	0
21	F	28	U	4	2	500	1'500	<25%	no	Y	T/-	375
22	M	45	U	5	5	1'500	2'000	<25%	UN	Y	UN	500
23	F	36	S	4	4	1'000	1'500	<10%	UN	no	NE	0
24	M	32	U	2	3	500	1'000	<25%	Y/H	Y	T/-	0

Explanations: UN do not know; Gender: M male, F female; Education: U university degree or comparable, S some school, no illiterate; Safe source: Y/A yes, this market, Y/H yes, this dealer, no (upset about this), NI no interest; Unhealthy: Y yes, should not be sold, C cooking suffices, no (no negative impact); Quality & taste: NE no effect, G/+ grows better, T/+ respectively T/- tastes better respectively worse

As this was out of proportion to the overall expenditures for vegetables, these respondents apparently wished to promote change (*Hanemann & Kanninen*, 1999). More informative was the question, how much they would be willing to pay more in relation to present expenses, with possible answers from 'little, less than 10%' to 'more than double' (for no respondent).

Table 3: Views of Hyderabad Consumers on Policies

No.	1st important	2nd important	3rd important	Treated wastewater OK	Law: only clean water for irrigation	Fines: if irrigation water not clean	Support: govt. pays farmers	Information: about dangers	Rank Law	Rank Fine	Rank Support	Rank Information	Beneficiaries
1	H	P	C	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	NA	C
2	P	H	C	Y/+	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	C
3	H	P	C	Y/0	Y/0	Y/0	Y/0	Y/0	NA	NA	NA	NA	UN
4	H	P	C	Y/+	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	F
5	H	P	C	Y/0	Y/+	Y/+	Y/+	Y/+	2	3	1	4	C
6	H	P	C	Y/+	Y/0	N/0	N/0	Y/+	4	2	1	3	C
7	H	P	C	NA	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	F
8	H	NA	NA	Y/+	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	F
9	H	C	P	Y/+	Y/+	Y/+	Y/+	Y/+	NA	NA	NA	NA	C
10	H	P	C	Y/+	NA	Y/+	NA	NA	NA	NA	NA	NA	C
11	H	C	P	Y/0	Y/+	NA	NA	NA	NA	NA	NA	NA	C
12	H	C	P	Y/+	NA	Y/0	Y/+	NA	NA	NA	NA	NA	no
13	H	P	C	Y/+	NA	N/0	Y/+	NA	NA	NA	NA	NA	C
14	H	C	P	Y/+	NA	Y/0	Y/+	NA	NA	NA	NA	NA	C
15	H	P	C	Y/+	Y/0	Y/0	Y/+	Y/0	3	4	2	1	C
16	H	P	C	Y/+	Y/0	Y/0	Y/+	Y/+	3	4	1	2	C
17	H	P	C	Y/0	Y/0	N/0	Y/+	Y/+	2	4	1	3	C
18	H	P	C	Y/+	Y/0	N/0	Y/+	Y/+	4	3	1	2	F
19	H	P	C	Y/+	Y/0	N/0	N/0	Y/+	4	3	2	1	C
20	H	P	C	Y/0	Y/+	Y/0	Y/+	Y/+	4	3	1	2	F
21	H	P	C	Y/+	Y/0	N/0	Y/+	Y/+	3	2	1	1	F
22	H	P	C	Y/0	Y/0	N/0	Y/0	Y/+	NA	NA	2	1	C
23	H	C	P	Y/0	NA	N/0	Y/0	Y/0	NA	NA	NA	NA	C
24	H	P	C	Y/0	Y/+	N/0	Y/+	Y/+	4	3	1	2	C

Explanations: UN do not know, NA no answer; Importance of criteria for buying vegetables: H safe for health, P production clean, C cheap price; Treated wastewater OK (would buy such irrigated vegetables) respectively suitability of policies: Y/+ yes/suitable, Y/0 rather yes/suitable, N/0 rather no/not suitable, N/- no/not suitable; Beneficiaries (1st) of irrigating with cleaner water: F farmers, C consumers, no: no benefits

2.2.1.2 Method

The sample was analyzed using statistical software (XL-Stat). However, in view of the atypical character of the sample it should be cautioned that it informs only about the views of those interested in a NWTS of river water. Further, the actual willingness to pay was tested by additional question for the motivation to make sure that the genuine views of the respondents are identified, even if they may have given answers, of which they thought that the surveyor wished to hear (*Merrett*, 2002). As the purpose of the sample was to verify the observations of an earlier survey (reported in deliverable D6.2), this sample size was sufficient: 10 to 30 respondents are generally acceptable in social sciences (*Isaac & Michael*, 1995).

2.2.1.3 Results

Why should consumers pay for better irrigation, if it does not benefit them? In order to single out respondents with a genuine reason for paying more, their motivation was inquired and for 67% (16 of 24) of respondents. For those without a reason to pay, ‘genuine willingness to pay’ (GWTP) was defined to be zero. For the others, the maximal stated willingness to pay was assumed (e.g. ‘willing to pay up to 10% more’ was GWTP = 10% and ‘willing to pay little, not more than 10%’ was GWTP = 0%).

- They were asked, if they thought that at the market, where the interview was conducted, vegetables might be sold that have been irrigated with polluted water. Thereby, 42% of respondents were not interested in this question or they thought to have safe sources at the present market. Their GWTP was defined to be zero.
- Further, respondents were asked about their opinion with respect to health, if vegetables are irrigated with polluted water. 50% (12 of 24) were of the opinion that there was no negative impact on health. They were also asked about their opinion with respect to other aspects of quality (taste, shape and growth of vegetables) and 58% (14 of 24) were of the opinion that polluted irrigation water did not have negative impact on quality. For 42% of respondents, polluted irrigation water did neither affect health nor quality in the negative; for them GWTP was defined to be nil.

There remained 8 (33% of 24) respondents with a genuine interest in using cleaner water for irrigation. 63% (5 of 8) were willing to pay up to 25% higher vegetable prices, two up to 10% and one up to 50%. The genuine willingness to pay of their households was computed from this GWTP and their average expenditures for vegetables. In average, it was 384 INR per month.

As to the motivation of the 24 respondents, the percentage of their willingness to pay was contingent on health (95% significance, Fisher exact test); those with health concerns were rather willing to pay more than 10% of the food price (Table 4). Further, those with health concerns have a stochastically higher willingness to pay (95% significance, Mann-Whitney test). As this was out of proportion to the overall expenditures for vegetables, these respondents apparently wished to promote change (*Hanemann & Kanninen*, 1999). More informative was the question, how much they would be willing to pay more in relation to present expenses, with possible answers from ‘little, less than 10%’ to ‘more than double’ (for no respondent).

Table 3 confirms this: For 96% (23 of 24) respondents, safety for health was the most important criterion for buying vegetables, followed for 71% (17 of 24) by clean production (no pollution of e.g. groundwater), while the price was least important for 75% (18 of 24). Vegetables irrigated with treated wastewater would meet these citeria and 63% (15 of 24) respondents would have no concerns (also not 50% = 4 of 8 of those genuinely willing to pay).

Table 4: Contingency between Willingness to Pay and Health Concerns

Considering health, untreated irrigation water is:	WTP up to 10%	more
perhaps tolerable	10	4
unhealthy; vegetables should not be sold	2	8

Amongst policies to implement water treatment of river water prior to irrigation, there are clear preferences: 67% (16 of 24) considered that it mostly in the interest of consumers. Accordingly, 71% (17 of 24) considered that government support for the farmers in setting up the needed infrastructure would be suitable; 33% (8 of 24) ranked it first. 63% (15 of 24) considered information (e.g. health risks for farmers handling river water) as suitable; 33% (8 of 24) ranked it first or second. Laws commanding the use of cleaner water for irrigation was suitable for 42% (10 of 24) respondents; 21% (5 of 24) ranked it second or third. For 38% (9 of 24) respondents, fining farmers for using untreated river water was rather unsuitable and 33% (8 of 24) ranked it last or third.

2.2.1.4 Discussion

As follows from the following example, and similar to organic food marketing, farmers treating irrigation water on their own plot could achieve the higher price needed for river water treatment. For, using the virtual water content of vegetables, the added costs for treating river water before irrigation can be assigned to each vegetable. 1 kg of tomatoes needs between 75 (*Chapagain & Orr*, 2009) and 97 liters (*Chico et al.*, 2010) irrigation water. For this, farmers could afford treatment costs of up to 25 INR/m^3 (compare to

9 INR/m^3 according to deliverable D6.2), which would amount to an additional 2.4 INR or 10% increase in tomato-price (ca. 25 INR/kg), which all eight respondents consumer with genuine interest in treated irrigation water were willing to pay.

2.2.2 Farmer Interviews

2.2.2.1 Data

In relation to the implementation of a NWTS, a survey of farmers was conducted.

Table 5: Views of Hyderabad Farmers about Treatment of River Water

No.	Gender	Age	Literacy	Quality river water	eat own vegetables	WTP water treatment	WTP invest	WTP running/year	Who should pay?	Provide land for CW?
01	F	58	no	C	yes	yes	NA	NA	govt	yes
02	F	36	no	B	yes	no	0	0	NA	no
03	M	52	no	B	yes	yes	0	2'400	NA	lease
04	M	30	no	C	yes	yes	0	4'800	govt	yes
05	M	30	yes	B	yes	yes	0	2'400	govt	lease
06	F	30	yes	B	yes	yes	1'000	3'600	NA	yes
07	M	32	yes	B	yes	yes	0	3'600	govt+owner	lease
08	F	38	no	C	yes	yes	NA	2'400	NA	lease
09	M	36	no	C	yes	no	0	0	govt	lease
10	M	32	yes	B	yes	NA	0	2'400	govt+owner	yes
11	M	34	yes	C	yes	yes	0	1'200	govt	no
12	F	36	no	C	yes	yes	0	2'400	NA	lease
13	M	31	yes	B	yes	no	0	0	govt	lease
14	M	54	yes	B	yes	yes	500	1'200	local	yes
15	F	30	yes	A	yes	yes	0	1'200	NA	yes
16	M	51	no	B	yes	no	0	0	govt	lease
17	M	33	yes	C	NA	yes	0	2'400	govt	yes
18	M	32	yes	B	yes	yes	0	1'200	govt+local	yes
19	M	30	yes	C	yes	yes	1'500	2'400	govt+owner	yes
20	M	50	no	D	yes	yes	0	2'400	govt	lease
21	M	41	no	D	yes	yes	NA	NA	govt	no

Explanation: NA no answer; Gender: F female, M male; Quality: A very good, B good, C average, D poor; Who should pay: govt government, local = local agency, Provide land: lease = 'cannot decide, because not the owner' (however, all leased the land).

2.2.1.4 Method

The survey linked farmers' preferences for using treated or untreated river water (see deliverable D6.2), their willingness to pay for treating irrigation water, and their preferred policy options. Only farmers were selected, who used river water for irrigation (one in addition groundwater) of a small piece of land (median ¼ acre, approximately 1,000 m^2), which they leased. The sample was analyzed using statistical software (XL-Stat).

However, the purpose was to verify a previous study (see deliverable D6.2), whence a small sample was chosen. However, similar to the consumer survey, the genuine willingness to pay was asked for, using additional test questions.

Of the 21 respondents, 15 were men and 6 women, they were of age 30 to 58 (median 34), and 48% were illiterate.

2.2.1.3 Results

Around 52% (11 of 21) interviewed farmers considered that river water was of good or very good quality, meaning the nutrient content. They had also no concerns with their products; 95% (20 of 21) eat their own vegetables. Consequently, 19% (4 of 21) were not willing to pay at all for cleaner irrigation water. However, 71% were willing to pay 100 to 400 INR/month for using treated water for irrigation; average: 200 INR/month. This confirms with the results of a previous study (*Jampani et al*, 2014).

Further, only 43% (9 of 21) would provide land for a constructed wetland; most of the others were not sure about the land owners' opinion. And only 14% (3 of 21) were willing to contribute to the construction costs of a river water treatment system: 57% (12 of 21) hold the government or local agencies for responsible.

What farmers might remain genuinely willing to pay during the implementation of water treatment? Removing those, who stated that others (government, local agency) should pay, or who considered that river water was of a good or very good quality (whence there is less reason to pay for a change), there remained three farmers (14% of 21) with willingness to pay 200 INR/month. Thus, the willingness of farmers to pay is not so clear, considering also, that water is paid with the lease.

2.2.3 Cost Consideration for Farmers

2.2.3.1 Data and Method

An analysis of the income situation of farmers allows assessing the feasibility of financing by farmers and consumers. Despite high land leasing costs (they depend on factors, such as accessibility by roads), farmers considered growing vegetables as profitable, with up to 10 crops harvested per year. Would this profit suffice, so that each farmer could finance a constructed wetland on the own plot without public support and only moderate increases of vegetable prices?

This question was analyzed for each of the farms, assuming that each farmer treat the own water. In order to estimate the costs of water treatment (which depends on the need for irrigation water) and the financial implications for farmers, the above survey included questions about the farm size and income, including costs for lease and for crop (fertilizers, etc.).20 farmers provided the needed information.

Table 6: Economic Situation of the Farmers in the Hyderabad Study Area

No.	Crops / year	Land area (acres)	Lease INR per year	Cultivation costs INR per year	Annual profit in INR	Annual Sales INR/year	CW: Reduced sales INR/year	Direct annual CW costs in INR	CW: Reduced profit in INR	Fair compensation (for CW) INR/year	Fair price increase %
01	7	0.40	14'400	56'400	72'000	142'800	140'480	5'200	65'396	6'604	5
02	10	1.50	84'000	84'000	96'000	264'000	259'710	19'500	73'575	22'425	9
03	8	0.25	18'000	60'000	60'000	138'000	135'758	3'250	55'483	4'518	3
04	8	0.15	36'000	28'800	92'400	157'200	154'646	1'950	88'364	4'037	3
05	7	0.15	6'000	24'000	60'000	90'000	88'538	1'950	56'978	3'023	3
06	10	0.25	12'000	26'800	60'000	98'800	97'195	3'250	55'580	4'420	5
07	10	0.20	7'200	60'000	60'000	127'200	125'133	2'600	56'308	3'692	3
08	9	0.20	24'000	16'350	84'000	124'350	122'329	2'600	79'645	4'355	4
09	9	0.25	30'000	72'000	84'000	186'000	182'978	3'250	78'898	5'103	3
10	9	0.30	36'000	72'000	108'000	216'000	212'490	3'900	101'760	6'240	3
11	9	0.10	4'800	18'000	12'000	34'800	34'235	1'300	10'427	1'573	5
12	9	0.25	12'000	36'000	36'000	84'000	82'635	3'250	31'970	4'030	5
13	9	0.30	14'400	60'000	60'000	134'400	132'216	3'900	54'891	5'109	4
14	9	0.20	12'000	48'000	60'000	120'000	118'050	2'600	56'230	3'770	3
15	9	0.20	12'000	54'000	60'000	126'000	123'953	2'600	56'230	3'770	3
16	9	0.25	12'000	15'850	40'800	68'650	67'534	3'250	36'692	4'108	6
17	10	0.20	12'000	48'000	60'000	120'000	118'050	2'600	56'230	3'770	3
18	10	0.20	12'000	54'000	60'000	126'000	123'953	2'600	56'230	3'770	3
19	10	0.22	12'000	60'000	60'000	132'000	129'855	2'860	55'970	4'030	3
20	10	2.00	30'000	96'000	120'000	246'000	242'003	26'000	91'563	28'438	12

Explanation: Same respondents as in Table 5 (#21 removed: incomplete answers). Lease, cultivation costs (seeds, fertilizer, pesticide) and profit (without considering taxes or own labor costs) were inquired. Annual sales = sum of costs and profit; reduced sales = 98.375% of sales (assuming CW = constructed wetland needs 1.625% of plot size); direct annual CW costs = 13,000 INR/acre; reduced profit = reduced sales minus lease minus direct annual CW costs minus 98.375% of cultivation costs; fair compensation = profit (present) minus reduced profit; fair price increase = fair compensation as percent of reduced sales (assuming that consumers pay CW via higher prices).

2.2.3.2 Results and Discussion

As for the water needs, typically a farmer with ¼ acre of land spends ½ hour per week for pumping irrigation water. Based on a pumping rate of 20 liters per second, this amounts to the use of 7,488 m^3 irrigation water per year and ace; i.e. 21 m^3 per day and acre.

For the treatment of this water, a constructed wetland of horizontal-subsurface-flow type would be considered, as this is not so affected by the mosquito problem. For the estimation of its design parameters, the first-order plug flow kinetics model may be applied (*Arceivala & Asolekar*, 2006).

First, from the equation $C_T = C_0 \cdot \exp(-K \cdot T)$, depending on the observed inlet and the desired outlet concentrations C_0 and C_T of pollutants (in mg/liter or CFU/100 mL), the hydraulic retention time T (day) is computed, using the reaction specific constant K (1/day) for the pollutant under question, based on literature data. For the river water treatment, removal of pathogens is a key issue. However, as river water is of a better quality than domestic sewage, a moderate treatment suffices (reducing fecal coliforms from 1,600 MPN/100 mL to the Indian standard of 1,000 MPN/100 mL for irrigation water). Thus, T = 1 day retention time suffices: Assuming 0.15/h inactivation rate for fecal coliforms (*Struck et al.*, 2006), a reduction by 97% is reached.

From this the volume $V = Q \cdot T/\eta$ of the wetland bed is computed. Here, Q is the flow of wastewater in the system (m^3/day) and η is the porosity of the packed bed (%). For the considered system sand and gravel with porosity η = 42% was considered (100% is open water); with Q = 21 m^3 river water used for irrigation, V = 50 m^3. Using the height H = 0.8 m (a larger value is used to save space), the plan area of the wetland would be A = V/H = 63 m^2. Taking into account evaporation losses of T = 1 day (in India up to 30 mm of the water level per day), an inflow of Q = 21.8 m^3 is needed to ensure an output of 21 m^3 treated water per acre. Thus, the area is corrected to A = 65 m^2 per acre.

A constructed wetland area of 65 m^2 for a plot of size 1 acre would cost 325,000 INR (about 3,900 €) for construction, based on the estimate of 5,000 INR/m^2 for rural India (*Kalbar et al*., 2013). Assuming that the farmer finances this without public support, distributing costs over an assumed lifetime of 25 years for the wetland would result in yearly costs of 13,000 INR per acre. This is proportionally adapted to the actual plot sizes. As the considered type of constructed wetlands needs no skilled personnel, the operation and maintenance could be done by the farmer and no costs are assumed for this work. As for land use costs, the farmer would still pay the full lease, but for could not use ca. 98% of the land (the wetland cannot be used for planting crop), which reduces the sales accordingly. However, also costs for seeds and pesticides would be ca. 2% lower, as less land is cultivated. The concern of farmers, that they would need more fertilizers, if they used treated water, is questionable, as on the contrary, current nutrient content is high (contributing also to soil salinity, which may hinder growth). Further, for substantial nutrient reduction longer retention times would be needed. Therefore also a ca. 2% cost reduction for fertilizers is assumed for the reduced cropping area.

Table 6 summarizes these cost computations for each surveyed farmer. If the farmers would have to pay for their own constructed wetlands, they would face a reduction of profits by up to 28,000 INR/year (median 4,072 INR), which exceeds by far the willingness of farmers to pay. (Thereby, in the median, the land use costs would amount to ca. 29% of profit reduction.)

However, if farmers could increase the price of vegetables to compensate for the costs and lost profits, then by Table 6 price increases between 3 and 12% would suffice (median 3.4%), whereby 95% of farmers (all except one with relatively low lease/acre) could remain at or below 10% price increase. It follows that these farmers, if wishing to serve consumers interested in cleaner production, could start water treatment on their own initiative, and the needed price changes would be acceptable for a certain segment of upscale consumers with interest in cleaner production.

The volumetric water treatment costs (computed from the lost profits) would range between 1.9 and 3.6 INR/m^3 (median 2.5 INR/m^3), which confirms the estimate of 1 to 9 INR/m^3 used in deliverable D6.2.

2.2.4 Policy Workshop

Discussions with high level decision makers and a workshop in September 2014 (representatives from administration and academia) show that the state and municipal governments are aware of the health problems caused by using untreated river water for the irrigation of vegetables and that they want to end that practice. For, even though industrial discharges would be largely treated, traces of heavy metals and other toxic elements might remain in river water. Therefore they approve of the idea to treat river water prior to irrigation. Yet, for the implementation some issues need to be resolved: If water shall be treated, the use of treated water should be prescribed by the law and inform farmers and consumers should be informed about the risks of using untreated river water. Further, in view of the industrial discharges in river water, a continuous quality monitoring of treated water would be required. Also the high level decision makers are skeptical about fining farmers, as currently they have no other choice than using river water. As to the financing, government should support farmers in setting up a treatment plant, but farmers (and indirectly consumers) should pay for the operation and maintenance.

2.2.5 Policy Recommendations

Assuming that the natural habitat shall be preserved, treating river water prior to its use for irrigation would be beneficial for the health of farmers and possibly also of consumers, and it would have positive impacts for the environment.

With respect to the implementation, there may be a decentralized treatment, where farmers build small constructed wetlands on their own plots. However, many farmers only lease the land, and their landlord might not accept, if they build a constructed wetland. Another option is to build a centralized system, where farmers feed irrigation channels with treated river water. For such a system also monitoring of water quality would be easier. However, such a centralized constructed wetland requires huge land space, which is only feasible if there is a suitable natural wetland system, as in the study area.

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

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

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

3 Case Study Chennai (Managed Aquifer Recharge)

3.1 Integration of Assessment Results

3.1.1 Review of the Problem

Chennai is the capital of Tamil Nadu state. With 6.7 million people (2011 census) and 426 km^2 it is one of the four metropolitan cities of India.

As section 5 of deliverable D6.2 outlines, over 90% of its water supply comes from reservoirs, which are depending on the monsoon rains. If the reservoirs are empty, then groundwater should be available to cover the gap in water supply. However, due to exploitation of the groundwater resources (for domestic, industrial and agricultural water supply), the contribution of groundwater to the water supply of Chennai is diminishing, from a maximum of 25% to a currently installed capacity of around 6%. This demonstrates the vulnerability of the Chennai water supply. Further, the decline of the groundwater level has led to the intrusion of seawater in the coastal area.

Traditional technical approaches to overcome the water shortages during summer were the construction of new reservoirs, the increase of the capacity of existing reservoirs, and the provision of desalination plants. A policy measure to promote water saving was water pricing. Further, industry is using recycled water. Another measure was mandatory rainwater harvesting (RWH) in all buildings. More recently, managed aquifer recharge (MAR) has been introduced to increase the groundwater level and to mitigate seawater intrusion. Thereby, two technologies have been implemented: check-dams and infiltration ponds. While there are already several check dams at Arani and Koratallai rivers north of Chennai and at Palar river south of Chennai, currently there is only one pilot infiltration pond of Anna University.

To compare the different options, section 5 of deliverable D 6.2 analyzed the relevant criteria as follows: There was no work under task 6.2, as with respect to impact on human health, there was no conceivable difference to be expected. Further, with respect to the protection of the environment, it was assumed that only environmentally friendly approaches shall be implemented. For costs and economic impacts, CEMDS and SPT used a simplified approach under task 6.3, comparing unit costs for recently completed infrastructure. With respect to institutional and practical issues, CEMDS, Anna University and SPT conducted an extended analysis under task 6.4 (institutional viability), which also included relevant aspects (e.g. equity of cost sharing) under task 6.5 (social acceptance), whence there was no need for additional work under task 6.5.

3.1.2 Stakeholder Preferences and Criteria Weights

3.1.2.1 Data

As in section 3, POSAF (*Starkl et al.*, 2013c) was applied to quantify the preferences for stakeholders. Thereby the relative importance of the following key criteria was assessed: human health, protection of the environment, costs and economic impact of the solution (infrastructure or policy), equity of users and practical issues (e.g. institutional: need for capacity building). In addition, the strength of their preferences for the following options was assessed: desalination plants, non-structural policy instruments (water pricing, banning or licensing of groundwater extraction, policies to enforce or support changing to less water demanding crops), increasing capacity of reservoirs, urban rainwater harvesting (RWH) on roofs, groundwater recharge through check dams, and groundwater recharge through newly constructed ponds.

This research was based on 25 responses by stakeholder representatives, who answered about 120 questions asking about the opinion about different approaches and criteria to assess these approaches. Of the 25 respondents, four came from academia (students, professors), eleven were experts working directly (e.g. as hydrologists) or indirectly (e.g. as consultants) for the municipal, state or national government, seven were rural practitioners (farmers, landlords) and three suppressed that information; see Table 7 and Table 8. In order to protect the anonymity of respondents, their age (between 20 and 70+) and gender (four women) are not reported.

3.1.2.2 Method

In order to quantify the strength of these preferences, a method of multi-criteria decision aid, the analytical hierarchy process (AHP), was applied, which translates individual qualitative assessments into individual quantitative preference weights for alternatives (see section 3). Respondents were asked, for each pair of criteria, if one criterion was much more or more important than the other, or if both criteria were equally important; similarly for the different approaches. As explained in section 3, these 10 respectively 15 pair-wise comparisons were translated into ratios of preferences, defining a 5×5-matrix for criteria and a 6×6-matrix for the approaches. The largest real eigenvalue (EV) of this matrix was computed and the corresponding eigenvector, scaled to sum 1, defined preference weights. Computations used the Solver add-in of Microsoft Excel and statistics used XL-STAT of Addinsoft.

Table 7: Preference Weights of Options to Mitigate Water Scarcity in Chennai

No	Preference Weight of Option (<100% is highest)						Quality of response		Stakeholder Group
	Desalination	RWH	check dams	ponds	reservoirs	Policies	*CR*	AHP Problem	
1	-	-	-	-	-	-	-	Problem	Unknown
2	9%	20%	23%	22%	20%	5%	9%	OK	Expert
3	36%	15%	19%	8%	9%	13%	6%	OK	Academia
4	8%	12%	19%	18%	25%	17%	14%	Problem	Expert
5	10%	13%	17%	24%	23%	13%	14%	Problem	Academia
6	9%	28%	15%	16%	20%	12%	3%	OK	Expert
7	-	-	-	-	-	-	-	Problem	Unknown
8	15%	13%	22%	15%	20%	16%	17%	Problem	Practitioner
9	12%	22%	24%	13%	10%	19%	13%	Problem	Expert
10	10%	16%	19%	21%	18%	16%	3%	Problem	Expert
11	8%	18%	19%	14%	22%	19%	12%	Problem	Practitioner
12	4%	9%	41%	19%	19%	7%	12%	Problem	Practitioner
13	7%	12%	40%	19%	17%	6%	16%	Problem	Practitioner
14	-	-	-	-	-	-	-	Problem	Expert
15	23%	14%	10%	21%	16%	16%	4%	OK	Academia
16	4%	36%	19%	18%	12%	10%	12%	Problem	Practitioner
17	14%	38%	14%	14%	14%	6%	8%	OK	Expert
18	-	-	-	-	-	-	-	Problem	Practitioner
19	8%	15%	18%	22%	18%	19%	12%	Problem	Practitioner
20	8%	22%	11%	17%	22%	20%	4%	OK	Expert
21	10%	13%	16%	23%	20%	18%	3%	OK	Expert
22	16%	17%	11%	12%	21%	23%	12%	Problem	Expert
23	-	-	-	-	-	-	-	Problem	Expert
24	5%	39%	21%	15%	12%	8%	10%	Problem	Academia
25	9%	18%	19%	13%	22%	19%	12%	Problem	Unknown

Explanation: CR is the consistency ratio; for a 6×6-matrix CR = (EV – 6)/6.2, where EV is the eigenvalue; see Alonso & Lamata, 2004.

Table 8: Criteria Weights from the Chennai Stakeholder Survey

No	Weight					Quality of Response		Stakeholder
	Health	Environment	Costs	Equity	Practical	*CR*	Problem	
1	-	-	-	-	-	-	Problem	U
2	24%	24%	12%	25%	16%	20%	Problem	E
3	40%	20%	8%	22%	9%	6%	OK	A
4	29%	22%	17%	16%	17%	9%	OK	E
5	24%	27%	19%	18%	11%	9%	OK	A
6	-	-	-	-	-	-	Problem	E
7	-	-	-	-	-	-	Problem	U
8	-	-	-	-	-	-	Problem	P
9	32%	24%	19%	14%	11%	4%	OK	E
10	26%	25%	19%	17%	13%	10%	OK	E
11	19%	33%	19%	14%	14%	3%	Problem	P
12	5%	12%	31%	12%	40%	9%	Problem	P
13	47%	25%	8%	14%	7%	13%	Problem	P
14	26%	19%	20%	18%	17%	6%	Problem	E
15	32%	36%	12%	5%	14%	9%	OK	A
16	34%	27%	10%	19%	11%	29%	Problem	P
17	49%	14%	14%	16%	7%	4%	OK	E
18	17%	23%	20%	20%	20%	1%	OK	P
19	25%	20%	20%	15%	19%	19%	Problem	P
20	33%	21%	14%	21%	11%	3%	OK	E
21	19%	29%	15%	19%	17%	7%	Problem	E
22	26%	15%	16%	20%	23%	17%	Problem	E
23	9%	24%	21%	28%	19%	7%	Problem	E
24	33%	19%	25%	15%	9%	17%	Problem	A
25	18%	28%	18%	19%	18%	8%	Problem	U

Explanation: *CR* = consistency ratio; for a 5×5-matrix $CR = (EV - 5)/4.48$, where *EV* is the eigenvalue (*Alonso & Lamata*, 2004). Stakeholder A academia, E expert, P practitioner, U unknown

3.1.2.3 Results

The quantification of the pair-wise comparisons indicated that no option had overwhelming support and that no criterion dominated; rather the preference weights were close to indifference.

- Amongst 20 respondents, who answered all 15 questions comparing the six options for improving the water supply system, rainwater harvesting (RWH) and check dams had in average highest preference weights; the 95% confidence interval was 20 ± 4%. It was followed by reservoirs (18 ± 2%), ponds (17 ± 2%), non-structural policies (14 ± 3%), and desalination (11 ± 4%). Milton Friedman's non-parametric test was used to check, if respondents consistently weighed a certain alternative higher than another. At 95% significance (using Bonferroni correction) one could distinguish only a significantly lower preference weight for desalination than for all other options, except non-structural policies. Somewhat stronger conclusions were found in D6.2 for the potentials and ranks.

- For the five criteria, 21 respondents answered all ten questions. The 95% confidence intervals for the criteria weights were 27 ± 5% for health, 23 ± 3% for environmental impact, 17 ± 3% for social equity and for costs and economic impact, and 15 ± 3% for practicability. Friedman's non-parametric test identified at 95% significance (using Bonferroni correction), that health had a significantly higher weight than costs and practicability, and that environment had significantly higher weight than practicability. Similarly for the ranks (see deliverable D6.2).

As to the quality of the responses, deliverable D 6.2 noted that respondents had no common understanding of the meaning of the criteria, if they were to be applied in a concrete context. This was illustrated for health: Some approved of desalination, as it provides clean water, while others disapproved, as it does not provide natural water (perceived as healthy). Some were concerned about possible contamination, if rain water was used as drinking water, while others, who focused on other domestic uses of rain water, were not concerned. The analysis of the AHP questions confirmed this difficulty:

- Not all respondents answered all questions about pair-wise comparisons. 20 answered all questions about the options and 21 about the criteria.
- Some respondents apparently confused the direction of comparison. This concerned three responses for the options and seven for the criteria. Therefore, the ranking of importance by criteria weights was compared to the stated ranking. If the reversal of all pair-wise importance comparisons resulted in a closer approximation (measured by the mean squared error), then it was used.
- Inconsistencies may make a response difficult to interpret, whence inconsistency is not acceptable, if CR > 10%. For eight responses about the options inconsistency was acceptable and for 15 about the criteria. Thereby most responses were borderline cases for inconsistency; the 95% confidence interval for CR was 10 ± 2%.

- Overall, only seven (28%) of 25 respondents answered the questions about the options without such problems, and nine (36%) about the criteria.

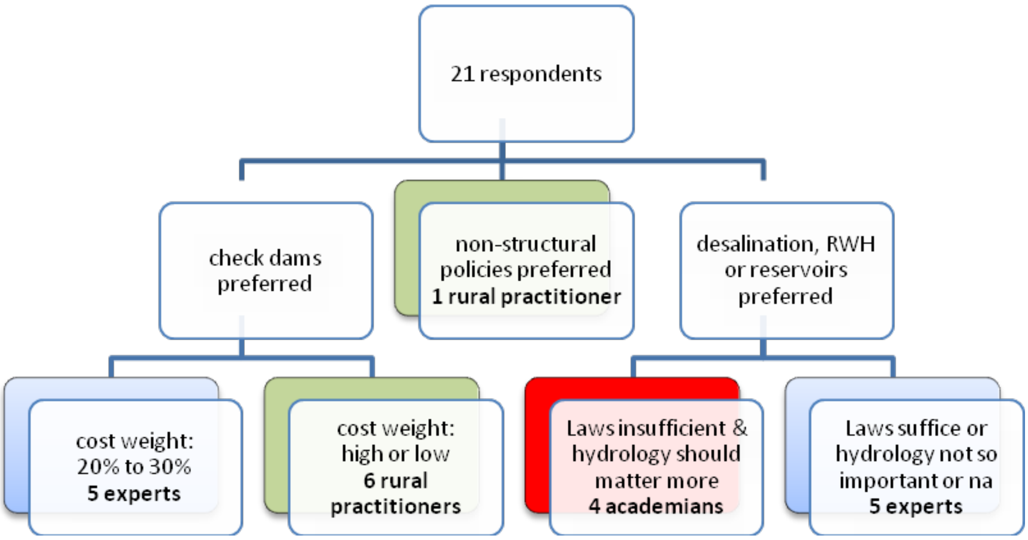


Figure 2: Stratification of Chennai Respondents

Note: The classification tree was computed with XL-Stat and simplified manually. The classification first distinguishes respondents by their top preferred option and then differentiates them by other interests (preference for costs, views on laws). Three respondents suppressed information about their professional background and one expert did not identify a preferred option, whence these four of 25 respondents were not considered.

Although the quantitative strength of the preferences was similar for the different options and over the different criteria, Figure 2 points out that the relevant stakeholder groups have markedly different preferences, which may be characteristic for them:

- For most rural practitioners (i.e. farmers), and also some experts (government, consultants, NGOs), groundwater recharge by check dams was the most preferred option. Thereby farmers could be distinguished from experts with similar preferences by their more extreme valuation of the importance of costs.
- Academia and also some experts had other technical options as top preferences, even desalination. Academia could be distinguished from experts by their negative attitude towards current regulations and practices.
- Experts were split with respect to their top preferences, but could be distinguished by their other interests from academia and rural practitioners, as explained above.
- No respondent had a top-preference for groundwater recharge by ponds and one preferred non-structural policies most.

3.1.3 Integration and Discussion

With respect to the assessment by the individual criteria, the criteria human health and environmental impact were the two most important criteria for the stakeholders, but they were not decisive, as the alternatives did not differ with respect to these criteria, as explained again below.

- Human health (water quality) had in average highest criteria weight and by deliverable D 6.2 it was most important for 64% of respondents, but as outlined in section 4.1.1, there are no conceivable differences between the approaches: After all, the city aims at providing clean water. However, there may be psychological differences (e.g. comparing desalinated water with spring water), which were addressed in task 6.4 as part of a stakeholder survey. Thus, this criterion is not decisive.
- Impact on the environment had in average second highest criteria weight and (deliverable D 6.2) it was most important for 16% of respondents. Yet again, it was assumed that only environmentally friendly approaches are feasible. Thus, this criterion is not decisive, either.
- By deliverable D 6.2, in terms of the cost-benefit ratio (capital costs per capacity = unit costs), building new infiltration ponds and increasing the storage capacity of existing reservoirs were the most cost-effective approaches. Desalination and check dams were by far the least cost effective approaches. The unit costs for building new surfage storage reservoirs were in betwen. Non-structural policy measures were not assessed her, as they are not comparable to infrastructure approaches. Rainwater harvesting is compulsory, and therefore was not assessed, either.
- With respect to acceptability and equity of users, rainwater harvesting was accepted by the respondents (in average highest preference weights) and it is a generally accepted state policy. In terms of average criteria weights, also check dams, infiltration ponds and enlarging reservoirs were accepted, as confirmed in deliverable D 6.2 with respect to the responses about the perceptions about the potentials of these technology options. However, for check dams and infiltration ponds farmers were concerned about equity: Farmers at the workshop feared that they will not be adequately compensated for the loss of arable land that is used for infiltration ponds or check dams. For instance, for check dams it is known that due to increased yields landowners benefit most from them (*Sen et al.*, 2006), but those close to the river may indeed suffer losses of land. This problem has already caused conflicts, resulting in a delay of the construction of the planned Thirukandalam check dam near Chennai. Similarly, in order to have any effect, about 10,000 infiltration ponds would be needed, whence about the same number of farms would be concerned (and they may oppose).

Desalination had in average the lowest preference weight of all options and (see deliverable D 6.2) 56% of respondents considered that desalination had low or very low potential and they ranked it low. In addition to the high costs there are psychological reasons for this lacking acceptance (e.g. respondents stating that water from desalination plants would not be healthy); this is known also from other studies (*Dolnicar & Schäfer*, 2009). Non-structural policy measures had in average second lowest preference weights and (see deliverable D 6.2) also the rate of acceptance was low, when compared to the other options. This was in part due to controversial discussions about water pricing. (By deliverable D 6.2, water tax and other water-related income for the city did not cover the costs of water provision.) Further, stakeholders considered such measures rather as supplements to enhance the benefits of new infrastructure.

- Practical and institutional aspects had in average lowest criteria weight and they were least important for 60% of respondents. However, the approaches differ considerably in this aspect (*Sakthivel et al.*, 2013; *Sakthivel et al.*, 2014): Rainwater harvesting is obligatory, the legal framework concerning reservoirs or desalination is well-established, but as deliverable D 6.2 concluded, while water policies are favourable for managed aquifer recharge (check dams, infiltration ponds) and for non-structural policies, but the laws do not support it. For, the Tamil Nadu Groundwater Development & Management Act of 2003 that supported such policies was never notified and it was finally repealed in 2013. Only certain aspects were preserved in the form of Government Orders.

There is no societal consensus about possible trade-offs for the aggregation of these partial assssments in terms of the individual criteria to an overall assessment. Instead, Figure 2 demonstrates that the preferences depend on the stakeholder group. Further, the discussion about the quality of responses indicates that even if there were a consensus about the criteria weights, there would be no consensus about the meaning of the criteria. However (*Brunner et al.*, 2014), the issue is not the choice of one alternative, but the definition of an acceptable mix of options, whence an aggregation is not needed. Instead, in such a context, the analysis of preferences has the purpose to identify possible antagonisms and support strategies to overcome such antagonisms (*Simon et al.*, 2004).

In defining such a mix of options, urban rainwater harvesting is already mandatory and accepted, but deliverable D 2.6 pointed out deficiencies; it needs to be made more effective by continuous enforcement (monitoring). As observed above, another 'traditional' approach for securing water supply, enlargement of existing reservoirs, is cost effective, consistent with the legal and institutional framework and generally acceptable. For all other approaches there are still concerns: Desalination plants are too costly solutions to cover the basic demand. Building new reservoirs for additional water or building check dams for groundwater recharge are costly, too, and in similar projects conflicts about land acquisition have caused substantial delays. For the same reason, infiltration ponds could meet resistance by farmers, as thousands of ponds would be needed. Non-structural policy measures are not accepted, either.

3.1.4 Conclusions

It follows from the difference of preferences between stakehoder groups (Figure 2) that in future decision-making conflicts between stakeholder groups are possible (e.g. urban vs. rural, government experts vs. academia). Thereby urban rainwater harvesting and enlargement of existing reservoirs are the least problematic amongst the considered options. For the other options, conflicts are possible and to resolve them, participative approaches might help in for future decision making. The subsequent work focuses on the question, what policy measures are feasible and needed to support the implementation of infiltration ponds.

3.2 Policy recommendations

3.2.1 Policy workshop

3.2.1.1 Data

The above analysis of the legal and policy issues of implementing infiltration ponds in the area surrounding Chennai was input to a policy workshop with representatives from government organizations and civil society. The project team presented these results and a judge of Madras High Court gave a presentation about the legal situation. At the end of the workshop 29 questionnaires were answered. In addition to the questions relating to the opinion about the different managed aquifer recharge (MAR) approaches and the relevant criteria to assess these approaches, a set of questions inquired specifically about infiltration ponds as well as legal and policy issues to implement them.

Participants of the workshops came from the stakeholders groups, who would be decisive for implementation of MAR plans. For the government, these were members of the Chennai branch of Central Groundwater Board for the central government, from Madras High Court for the jurisdiction, and several Tamil Nadu government departments for the state government of Tamil Nadu, and from Chennai Metropolitan Water Supply and Sewerage Board for the city. From civil society, there were representatives from business (e.g. consultants, advocates) and NGOs (e.g. Alacrity Foundation, DHAN Foundation), as well as students and scientists from research institutions (e.g. Tamil Nadu Law University, National Geophysical Research Institute, Indian Institute of Management). Also farmers took part, whose land might be used for MAR structures.

The 29 respondents of the survey were of age 28 to 77, median 51, with two women. 41% came from different branches of government and jurisdiction, 14% from academia, 24% were experts from business or NGOs, and 17% were farmers. One respondent did not disclose the affiliation (and did not respond to most questions). Respondents of the survey of the (first) stakeholder workshop did not take part and also the members of the project team assisting in filling out the questionnaire did not take part.

3.2.1.2 Method

For the interpretation it should be recalled that the survey was not intended to be representative opinion polls for any specific group, and no concrete decision should be prepared. In order to identify explanatory structure, the survey data were analyzed by methods of pattern recognition, data mining, and social network analysis, using preferably non-parametric tests suitable for small sample sizes. For confidence intervals, Clopper-Pearson method was applied, as it is conservative (higher confidence level than stated as the nominal level). The significance level was uniformly 95% (with the Bonferroni correction for significance of multiple comparisons, e.g. Milton Friedman's test). Software used was XL-STAT of Addinsoft for statistical tests and data mining, and UCINET 6 of Analytic Technologies for social network analysis.

3.2.1.3 Results on the acceptance of MAR related options

As for the first workshop, respondents were asked about the acceptance of six MAR-related approaches: increasing the capacity of reservoirs (representative of the traditional approaches), desalination, RWH, groundwater recharge through check dams, groundwater recharge through infiltration ponds, and in addition non-structural policy instruments (e.g. water pricing, banning/licensing groundwater extraction or changing to less water demanding crops). These above options were chosen, because they were practiced or considered in the political discourse and as they are typical instruments for different policy approaches.

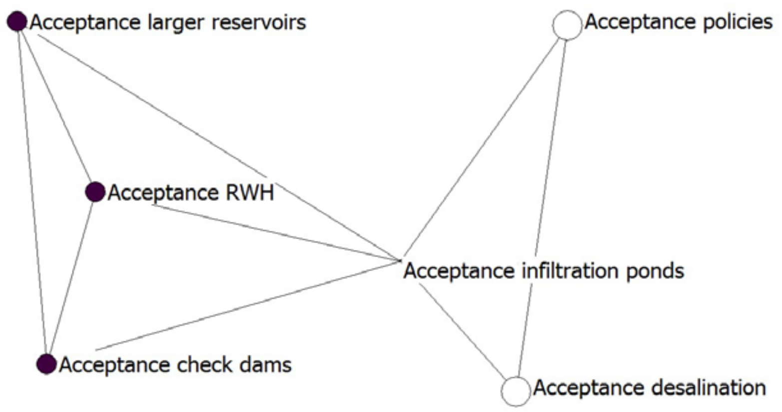
Respondents were asked to assess the potential of these options for securing the water supply (very high, high, low, very low) and to rank the options in terms of their individual preferences (from 1 = highest preference to 6 = lowest), using the rank function of Microsoft Excel (1224 competition ranking) to handle equals. From these answers, low acceptance (–1) of an option was defined, if it was of low or very low potential and the ranking was five or six, and high acceptance (+1) was defined symmetrically (high or very high potential and rank one or two); the other answers were interpreted as indifference (0).

The responses of the stakeholder workshop and the policy workshop were pooled; of them 50 responses were analyzed (for four other responses certain answers were missing), namely 23 of the first and 27 of the second workshop. Of these respondents, 6 were women, 19 were from government or courts, 8 from research institutions, 9 from (other) NGOs, and 14 were farmers. The data are in Table 12 (see Appendix).

Table 9 One-Sided 95% Confidence Intervals for the Acceptance of Chennai Options

Option	High Acceptance		Low Acceptance	
	Lower	*Upper*	*Lower*	*Upper*
RWH	34%	59%	0%	6%
Enlarge Reservoirs	34%	59%	3%	17%
Check Dams	38%	62%	4%	20%
Infiltration Ponds	13%	34%	1%	12%
Desalination	14%	36%	34%	59%
Non-Structural Policies	2%	15%	28%	53%

Figure 3 Pair-wise Tests for Differences in Acceptance of Chennai Options



Explanation: Based on 50 responses, nodes represent options for securing water supply and links indicate, that 'there is no 99.7% significant difference by Friedman's test', as computed with XL-Stat (correcting significance for 15 pair-wise comparisons). Colors identify two K-cores (clique-like structures) and node size is by closeness (a measure of centrality, which identifies far-off and thus rather different options), as computed with UCINET 6.

Summarizing, except for desalination plants and non-structural policies, all other options appeared to be acceptable. Table 9 and Figure 3 confirm this for the pooled sample from two workshops, where desalination and policies had stochastically lower acceptance than RWH, building new check dams or enlarging reservoirs. For infiltration ponds (11 with high acceptance, 2 with low acceptance, and 37 indifferent) there were no significant differences in acceptance to any other option.

Although only six respondents of the two surveys were women, significant differences were detected for gender: When compared to men, women had a stochastically higher acceptance for RWH and a stochastically lower acceptance for building check dams or enlarging reservoirs (Mann-Whitney test, correcting significance to 99.6% for 12 comparisons). Further, the participants of the second workshop had a stochastically higher acceptance for RWH than those of the first workshop. Perhaps this was due to the focus of the second workshop on infiltration ponds, which are conceptually similar (decentralized systems) to RWH.

With the exception of RWH and policies, acceptance of an option was negatively correlated with the acceptance of another option (T-test at 95% significance, based on 50 responses); correlation coefficients for acceptance were significantly negative between: infiltration ponds and enlarging reservoirs, enlarging reservoirs and desalination, desalination and check dams. This indicates that respondents were not expecting the implementation of a technology mix; rather they perceived technologies as competing. RWH and policies were exceptions, as they were generally accepted respectively not accepted.

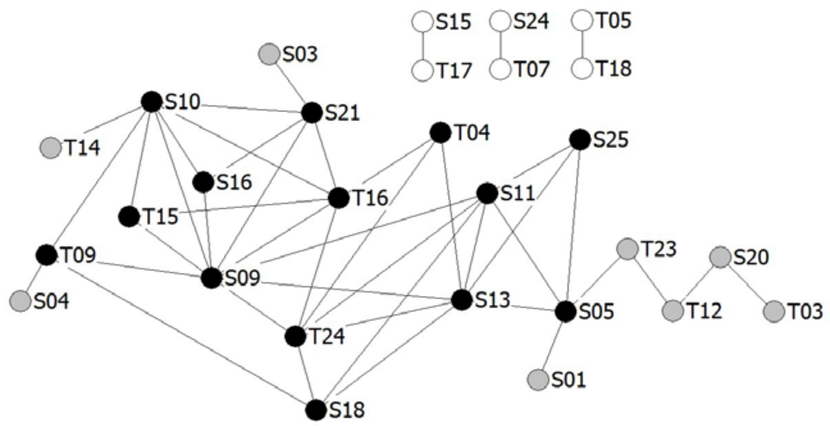
3.2.1.4 Results on stakeholder preferences

To explore the motivation, respondents were asked to rank key-criteria by their importance. As expected, in average human health (water quality) was most important, followed by the impact on the environment, social aspects (equity), impact on economy (costs, development), and practical issues (implementation, readiness of institutions). While between two consecutive criteria (e.g. health and environment) the difference was not significant, the criterion after the next one (e.g. social compared to health) had a stochastically higher (i.e. worse) rank for importance (Friedman's test at 99.5% significance to correct for ten pair-wise comparisons).

However, additional questions at the first workshop indicated that in applying these criteria to specific options, respondents lacked a common understanding about the meaning of the criteria. For instance, with respect to health, some approved of desalination, as it provides clean water, while others disapproved, as it does not provide natural water, perceived as healthy. Also for RWH, some were concerned about possible contamination, if collected rainwater was used for drinking, while others focused on other domestic uses and were not concerned. Similarly for reservoirs and to a lesser extent for infiltration ponds, some were concerned about risks due to water contamination and dumping of waste. In view of these experiences, at the second workshop on infiltration ponds elaborated more on these criteria.

The above mentioned responses (ranks of criteria, potentials, ranks, and acceptance of options) were positively correlated, which indicates some consensus amongst respondents. A cluster analysis based on high correlations identified 22 respondents ('cluster respondents') with similar views (Figure 4). However, it also singled out 28 'non-cluster respondents', of them 22 idiosyncratic (no high correlation to any other response) and six almost idiosyncratic (highly correlated to only one other response). A subsequent analysis characterized the cluster-preferences (XL-Stat, using regression trees): Typically, 91% (20 of the 22) cluster respondents had low acceptance for desalination and they ranked health first or second. Non-cluster respondents were expected to be more diverse, but typically, 68% (19 of 28) non-cluster respondents were indifferent or positive (high acceptance) about desalination and indifferent or negative (low acceptance) about check dams. Further, the 20 typical cluster respondents had a stochastically lower acceptance for RWH (Mann-Whitney test at 99.6% significance); also a higher acceptance for check dams was notable (at a lower significance).

Figure 4 Cluster Analysis of Respondents to Identify Consensus



Explanation: Nodes Sxx respectively Txx denote participants of the stakeholder respectively policy workshop. Based on the preferences for options (potential, rank, and acceptance) and criteria (importance rank), for each pair of responses the correlation coefficient was computed. Links indicate a 99.99% significant positive correlation coefficient of 0.9 or higher between responses (T-test, XL-Stat). For the figure, 22 isolated responses were removed (not highly correlated to any other response) and for six (white) nodes there is a link to one other node only. The remaining 22 nodes identify 'cluster respondents' with similar views. Within this group, 14 black nodes represent a K-core (a clique like structure) and 8 grey nodes peripheral respondents; they would be disconnected upon removal of a node (computations with UCINET 6).

As to the 11 exceptions, two cluster-respondents (S01 and T24 in Figure 4) were indifferent about desalination; they had high acceptance for check dams, but only with 'high potential'. Three non-cluster respondents had low acceptance for desalination, but they ranked health at three to five. Six non-cluster respondents were indifferent about sanitation and they accepted check dams, but (differently from cluster respondents) with 'very high potential'.

3.2.1.5 Results on infiltration ponds

The policy workshop focused on the stakeholder views concerning the implementation of infiltration ponds. For 24 respondents, who answered all relevant questions, Table 10 summarizes their views, indicating significant differences between cluster and non-cluster respondents. The data for these respondents are collected in Table 13.

Table 10 Chennai Policy Workshop Responses on Infiltration Ponds

Question	Mean Value		Significant difference?
	Non-Cluster	Cluster	
Water Supply: improvements needed	0.69	0.56	Yes
Infiltration ponds: want them	0.50	0.75	No
Policies & laws support infiltration ponds	0.22	0.38	No
Farmers should drive pond development	–0.13	0.25	Yes
Government should drive pond development	–0.25	–0.25	No
Taxpayer should drive pond development	–1.00	–1.00	No
Consumers should drive pond development	–0.75	–0.75	No
Others should drive pond development	–0.63	–0.75	Yes
Farmers should pay pond construction	–0.50	–0.50	No
Government should pay pond construction	0.38	–0.25	Yes
Taxpayer should pay pond construction	–0.88	–0.25	Yes
Consumers should pay pond construction	–1.00	–0.75	Yes
Others should pay pond construction	–0.63	–1.00	Yes
Farmers should pay O&M of ponds	0.13	0.50	Yes
Government should pay O&M of ponds	–0.50	–1.00	Yes
Taxpayer should pay O&M of ponds	–0.88	–0.50	Yes
Consumers should pay O&M of ponds	–0.88	–1.00	Yes
Others should pay O&M of ponds	–0.63	–1.00	Yes
Farmers should operate ponds	0.38	1.00	Yes
Government should operate ponds	–0.63	–1.00	Yes
NGOs should operate ponds	–0.88	–1.00	Yes
Others should operate ponds	–0.88	–1.00	Yes

Explanation: Mean values are of yes = 1, no = –1, yes/no with reservations = ±0.5. For 'significant differences', 'Yes' means: Mann-Whitney test confirmed at 99.99% significance that mean values differed.

While all respondents were critical about water supply, non-cluster respondents felt a more urgent need for improvement. Further, 88% supported 'the proposal to construct thousands of infiltration ponds in agricultural areas around Chennai' (interview question), whereby for 50% (significantly more for cluster respondents) the farmers should take the initiative to implement them, for 58% the government should finance a substantial share of the construction costs (cluster respondents were split about financing), for 63% (significantly more for cluster respondents) the farmers should be responsible for the operation and maintenance costs and for 79% (100% of cluster respondents) farmers should also operate and maintain their infiltration ponds.

3.2.1.6 Results concerning legal regulations and policy instruments

Table 11 summarizes the acceptance for instruments that support implementation of infiltration ponds, based on 26 responses at the second workshop answering the respective questions. Thereby, the acceptance for policies was defined from the answers about the suitability (suitable, rather suitable, rather not suitable, not suitable) and the rank (1 = highest to 5 = lowest preference; respondents could propose as fifth category ‘other’) of the policy instruments: High acceptance means suitable and rank one or two, low acceptance means not suitable and rank four or five.

Three policy instruments to promote infiltration ponds were rather acceptable: 54% had a high acceptance for supporting ponds using public funds, no respondent had a low acceptance for information campaigns (42% had high acceptance) and 88% were indifferent or had a high acceptance (38%) for making infiltration ponds mandatory for farms with more than one acre (about 4,000 m^2). Rather not acceptable was fining farmers, who do not have infiltration ponds: No respondent had a high acceptance for it, but 38% had a low acceptance. ‘Other’ is not displayed, as only 7 of 26 respondents considered it.

Table 11 One-Sided 95% Confidence Intervals for the Acceptance of Policies

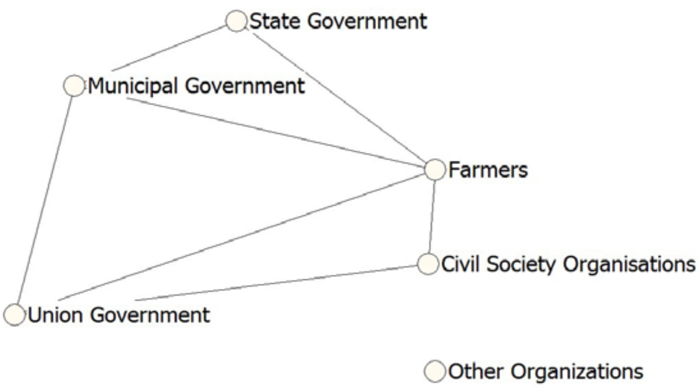
Policy Instrument	High Acceptance		Low Acceptance	
	Lower	*Upper*	*Lower*	*Upper*
Public support for infiltration ponds	33%	67%	0%	17%
Information about ponds	26%	60%	0%	17%
Mandatory ponds (farms: 1+ acre)	23%	56%	5%	32%
Fine farmers without a pond	0%	11%	23%	56%

Most respondents of the policy workshop (66% of all, 71% of the ones selected for Table 10) considered the current situation as supportive for infiltration ponds and 50% considered that the present groundwater recharge measures in Chennai would be adequate. Further, despite criticism by the project team, only for 59% the current groundwater law was not adequate.

Yet, with respect to MAR-related institutions, 79% wished a law resembling the Tamil Nadu Groundwater Development and Management Act of 2003, which was never notified and finally repealed in 2013 (Groundwater Development and Management Repeal

Ordinance). That Act would have foreseen an authority for MAR and Madras High Court repeatedly urged the state to notify it. 69% would also approve of a law similar to the Model Bill for the Conservation, Protection and Regulation of Groundwater. This draft bill by the National Planning Commission of India is favorable for MAR. With respect to the characteristic features of these proposals, 78% support the establishment of a state authority responsible for water allocation. If there were such an authority, its agenda should include for 84% the regulation of groundwater extraction and for 79% the stipulation of managed aquifer recharge measures. Further, for 93% of respondents, that law should be effective against encroachers, who endanger groundwater, for 86% respectively 90% the legal regulations should be specific for regions with respect to MAR respectively pollution control, and for 82% also land utilization policies should be based on water availability.

Figure 5 Pair-wise Tests for Differences in Importance for Groundwater Conservation

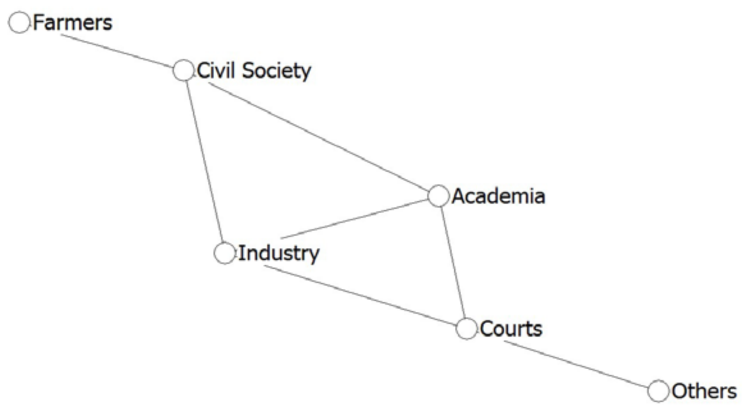


Explanation: Based on 25 responses, nodes represent institutions and links indicate, that 'there is no 99.7% significant difference by Friedman's test' for the ranks in the importance for groundwater conservation (computed with XL-Stat, correcting significance for multiple comparisons).

Concerning the question, as to what institution should play an active role in groundwater conservation, Figure 5 defines a partial ranking as follows: Least responsibility rests with 'other institutions' (also for 89% respondents at the last rank) and all institutions had a stochastically higher priority than 'others'. More importance rests with the Union Government (for 35% fifth) and civil society organizations (for 50% fourth), but the State Government has stochastically higher priority and also municipal governments have stochastically higher priority than civil society organizations. Most responsibility rests with the State Government (for 48% first), municipal governments (for 48% second) and farmers (for 33% third).

With respect to the question, who governments drafting and implementing water policies should hear, Figure 6 defines a partial ranking as follows: Farmers (for 68% of respondents at rank one) had a stochastically higher priority than all other groups, except civil society. Civil society (for 44% rank two in priority) had a stochastically higher priority than courts or 'other groups'. Academia (for 37% rank three) and industry (for 30% rank four) had a stochastically higher priority than 'other groups'. Courts (for 52% rank five) and 'other groups' (for 93% at rank six) were not so important to be heard.

Figure 6 Pair-wise Tests for Differences in Need to be Heard by Policy Makers



Explanation: Based on 27 responses, nodes represent stakeholder groups and links indicate, that 'there is no 99.7% significant difference by Friedman's test' for the rank of importance to be heard (computed with XL-Stat, orrecting significance for multiple comparisons).

As the above questions to identify needs for legal and policy changes were more specialized, respondents skipped certain questions depending on the expertise. (For this set of questions, 7% of 667 entries, i.e. 29 responses to 23 questions, were not answered). The above percentages refer to those respondents that answered the respective questions; for the data set see Table 14.

3.2.2 Discussion

Both workshops confirmed that a substantial fraction of stakeholder representatives is skeptical about desalination plants, which are amongst the most costly options to secure drinking water supply. In India cultural issues (also for educated populations, only spring water may be perceived as clean and healthy) aggravate this acceptance problem. Also a low acceptance of non-structural policies was observed at both workshops. This is explained by the critical discussion of water pricing and privatization of water services, which are perceived critically also in other countries, e.g. South Africa (*Flynn & Chirwa,* 2005), as there are concerns that such instruments may deprive the poor from access to water.

The high acceptance for RWH was observed at both workshops, more strongly even at the policy workshop, as RWH is a traditional water supply option. However, despite the high acceptance of RWH, some criticize the mandatory implementation of RWH in every building without taking note of the different local situation, as explained in the discussion of the first workshop. Stakeholder representatives of the policy workshop therefore asked for regulations that allow considering the local situation; more than 80% of approved of such legal approaches.

The traditional approach to secure water supply, increasing of the capacity of existing reservoirs, was the most economical of the considered solution and generally accepted at both workshops. However, also for reservoirs there is a need for regulations that consider the local situations, as for vulnerable water bodies a higher protection would be needed than guaranteed by the national standards. A notorious example was the Orathupalayam dam project to use water from Noyyal River for irrigation, where five years after its completion in 1992, heavy water pollution from textile industry forced farmers to give up irrigation.

Although groundwater recharge by check dams was the second most expensive option, it was nevertheless accepted at both workshops. However, as discussed for the first workshop, farmers fearing to receive only insufficient compensation for arable land may oppose such projects. Also the survey of the policy workshop confirmed that stakeholders were aware of the need to hear farmers, when formulating water policies.

In terms of unit costs, infiltration ponds were second best option. While the acceptance was not as clear as for the other options, stakeholder representatives at the policy workshop about infiltration ponds supported the idea to construct thousands of infiltration ponds in the rural areas surrounding Chennai. Farmers may at first not understand why they should give up arable land and spend money to build such ponds (just to secure the water supply of Chennai). Stakeholder representatives were aware of this problem and they approved the idea that the government should support the farmers in building infiltration ponds. Later on the farmers should maintain them without public support.

A concern for the project team at the workshop discussions was the ineffectiveness of existing laws, such as the national Easement Act of 1882 vesting owners of land with ownership of groundwater, irrespective of the rights of neighbors or public interests in groundwater preservation. Thus, the interests of neighbors in water de facto have not been framed as legal entitlements or obligations. However, only 59% of stakeholder representatives at the second workshop shared such critical views about inadequacy of current groundwater laws and regulations. Overall, the majority considered existing policies and laws as sufficient. Further, the national agencies in charge of the implementation of national policies may not really influence actual decision making, as they tend to approve projects, which receive a 'no objection certificate' from state agencies (*Koonan*, 2010). Yet, the stakeholder representatives considered that the national government should indeed have only a minor role for groundwater conservation, in importance below state and local governments.

For the specific problem of groundwater extraction, more than 75% of stakeholder representatives could be convinced about the need to better regulate it and they supported the idea that a state authority should be in charge of MAR. Currently different agencies of the government appear to act in an uncoordinated manner and without an integrated perspective about MAR.

The survey identified also a coordination and communication problem, illustrated for the first workshop by the lack of a common understanding of key criteria, such as health. A cluster analysis confirmed this lack of a common vision: While amongst 50 stakeholder representatives, 22 with similar preferences could be identified, the other 56% were almost idiosyncratic and basically unfavorable to MAR (e.g. most of them were indifferent or negative with respect to check dams).

3.2.3 Policy recommendations

Groundwater is an important source of domestic water supply in Chennai during the regular droughts and the peri-urban villages depend completely on groundwater. As agriculture and industry have been overexploiting groundwater, which is evident from the lowering of the water table and the intrusion of sea water, more effective instruments would be needed to control the extraction of groundwater and the use of water.

Amongst options to secure future water supply, two MAR approaches were considered, namely building large check dams or building many small infiltration ponds. However, check dams for groundwater recharge are costly and conflicts about land acquisition have caused substantial delays. For the same reason, infiltration ponds could meet resistance, as thousands of ponds would be needed, but there is no legislation that would make them mandatory. Amongst other feasible options is RWH on roofs: It is already mandatory, but it can be made more effective by continuous enforcement (monitoring). Desalination plants and reverse osmosis of brackish water are too costly solutions to cover the basic demand, and consumers may not accept them. Building new reservoirs as additional water sources is costly and was not considered, as Tamil Nadu state already operates reservoirs outside the state. Instead the enlargement of existing reservoirs was considered; it was the most cost effective of the considered options.

Thus, in the short term the most economical and least conflict-ridden solution appears to be the enlargement of existing reservoirs. In the long term, infiltration ponds, which are the second most economic solution, are an alternative that most stakeholder representatives would accept. However, there is a coordination problem, as it would have not much effect, if only a few hundred farmers would build infiltration ponds: They would face costs, but the groundwater table would barely rise. To solve this problem, stakeholder representatives would support the legal amendments needed to implement MAR structures, such as the establishment of a state authority responsible for MAR. It was foreseen by the Tamil Nadu Groundwater Development & Management Act of 2003, which was repealed in 2013. Only certain aspects were preserved in the form of Government Orders. Most stakeholder representatives would favor regulations similar to this law.

4 Case Study Haridwar (River Bank Filtration)

4.1 Summary of policy recommendations

The results of the various investigations conducted on bank filtration (BF) within the Saph Pani project have shown that BF can potentially improve the drinking water supply in India. Furthermore in conclusion to the "International Conference on Natural Treatment Systems for Safe and Sustainable Water Supply in India" (Saph Pani, 2014), certain aspects were highlighted that are relevant for policy recommendations, as follows:

- Bank filtration should be further developed and applied in India wherever technically feasible, e.g. where suitable hydrogeological conditions exist and in combination with appropriate post-treatment systems (Saph Pani, 2014).
- For the effective nation-wide propagation of BF in areas where suitable hydrogeological conditions exist, the development of a master plan based upon the integration of scientific results of the Saph Pani project, but also other DST-WTI funded and previous projects on BF, is essential (HTWD and NIH, 2014).
- For the effective implementation of BF in the various states in India, the Central Government should issue a directive to state governments. The directive should emphasize the consideration and eventual application of BF as an alternative and/or supplement to existing or planned direct surface water abstraction systems. As an example, the Department of Drinking Water of the Government of Uttarakhand, issued a government order on 25.03.2006 wherein specific technologies for drinking water supply such as BF and the use of indigenous "Koop" wells should be encouraged by water supply companies working in Uttarakhand.
- As many rural and urban areas in India are facing drinking water problems in terms of quantity and quality, the implementation of BF projects can be financed through specific programmes of the Government of India like the National Rural Drinking Water Programme and the Urban Development Programme.
- For the faster implementation of BF projects, a database of industrial firms, including small and medium enterprises having the required skills, should be made and published via internet.
- For greater visibility of BF and improved technology transfer, at least one BF demonstration site should be developed in the state where it can be applied.

- The investigations on the construction and operation of BF systems should also include economic comparison with existing drinking water production plants using surface water directly as source water.
- Safety issues should be highlighted by preparing a fact-sheet on main advantages of BF, such as a high buffering capacity to cope with extreme events, accidental spills and terrorism.
- A guideline for implementation of BF in India should be prepared and distributed to the various states.
- Assistance to determine the feasibility of BF and subsequent hydrogeological investigations to select an appropriate BF site, design the BF system and manage and operate it, can be secured through the Indo-German Competence Centre for Riverbank Filtration (IGCCRBF) of which the National Institute of Hydrology Roorkee is the coordinator in India and is supported for scientific and technical aspects by the Indian Institute of Technology Roorkee and for aspects related to implementation by the Uttarakhand State Drinking Water Supply and Sanitation Organisation - Uttarakhand Jal Sansthan (UJS).

5 Technical recommendations

Technical recommendations for use of BF, MAR and NTSs for wastewater treatment are provided by the respective work package leaders in the following paragraphs.

5.1 Summary of technical recommendations for river bank filtration (WP1)

Bank filtration systems exist in India in diverse hydro-climattic and geological areas. Investigations on their hydrogeological parameters, system design, water quality and operation of some of these BF sites (Sandhu and Grischek, 2012), as well as specific aspects on the risk of floods and their mitigation to BF systems (Saph Pani D1.2, 2013) and risk-based assessment and management for BF sites in India (Bartak et al., 2014), have been used to derive technical recommendations as follows:

- A four stage approach can be used to assess the viability and risks related to using BF based on the example of the Haridwar BF system as described by Bartak et al. (2014). This includes an initial viability assessment, maximum and pre-commissioning risk assessment, operational risk management and refinement of risk management plans. In this context water safety plans, management of the BF system and communication of water quality monitoring data and emergency operation procedures can be formulated for a specific site to minimise and mitigate a risk related to the use of BF.
- For the scientific and technical investigation and subsequent development of potential bank filtration sites in India, a science-based methodological concept can be used as described in Sandhu et al. (2011, 2013). This is also a systematic four stage approach consisting of (1) an initial site assessment, (2) basic site-survey and establishing monitoring infrastructure, (3) monitoring water, quality, levels and production well discharges and determining aquifer parameters and (4) numerical groundwater modelling. Geophysical subsurface investigation techniques should also be used either in stage 1 or 2 as far as possible in case no site-specific subsurface lithological information exists from borehole records.
- The extreme flood of June 2013 in Uttarakhand underlined the importance of constructing flood proof wells. Consequently technical measures to protect BF wells and sites from floods and mitigate the effects of floods can be applied as described in the Saph Pani Deliverable D1.2 (2013).
- The contamination from land-side groundwater is usually a threat for BF sites downstream of habitations, the source of which can be traced by including analyses of organic micropollutants and through numerical groundwater flow modelling. Thus as far as possible BF sites should always be located upstream of habitations and sewage disposal.
- The presence of confining clay extending beneath the riverbed in the lower courses of the Ganga and its tributaries originating to the North from the Himalayas can be a limiting factor for BF (Sandhu et al., 2011). Consequently, along the banks of rivers

originating from the South (e.g. Sone, Koel, Falgu Rivers of the South Ganga Plain and Peninsular India) and at their confluence with the Ganga River, the coarse sand aquifers found at a shallow depth have a good hydraulic contact with the Ganga River, and thus these sites can serve as potential BF sites (Sandhu et al., 2011).

- Limitations of access for well drilling equipment in mountainous areas have to be taken into consideration as well as the availability of land that is a common issue at most river side areas in India. Furthermore the aquifer thickness in hills and in Peninsular India, East Coast, semi-arid western India (Gujarat) and parts of South Ganga Plain is limited, thus use of horizontal collector (drainage) pipes located within the riverbed can be an alternative to vertical wells.

5.2 Summary of technical recommendations for managed aquifer recharge (WP2)

Artificial recharge of groundwater is in practice for several centuries in India. Right from the ancient days, canals, ponds, anicuts and reservoirs have been dug and constructed in India to improve the water availability. There are numerous examples and stone inscriptions from as early as 600 A.D. citing that ancient kings and other benevolent persons considered construction of small ponds to collect rainwater which also assisted increasing groundwater recharge. Traditionally each village had a pond to store surface run off and to augment groundwater recharge. Most of the temples had a tank which also serves as a structure for groundwater recharge (Deliverable 2.1, Saph Pani). In the case of Chennai study site, seawater intrusion due to over pumping of the alluvial aquifers to meet about 5% of the city's water requirements as well as local irrigation needs. MAR by check dams and percolation ponds were constructed to mitigate the problem of sea water intrusion.

The main technical recommendations stemming from WP2 can be summarised as follows:

- Check dams resulted in an annual recharge of about 40- 50% of water harvested. To prevent clogging of the river beds cleaning of the river beds need to be done once a year (D2.3) (Parimalarenganayaki 2014)
- Check dams in future need to be planned with sluice gates so that it can be opened when the check dam overflows to facilitate removal of sediments at the bottom(Parimalarenganayaki 2014).
- With the completion of all the planned check dams will result in an approximate addition of groundwater recharge by 16 Mm^3, which will not be sufficient enough to mitigate seawater intrusion (D2.3) (Parimalarenganayaki and Elango 2013).
- A study carried out in the pilot percolation pond indicate about 40% of water stored will be recharged every year (Raicy and Elango 2014). Hence, if several such ponds need to be planned in this area (D2.3).
- If about 10,000 percolation ponds are constructed in this area, a volume of about 11 Mm^3 of water can be recharged every year. Hence, it is recommended policy options need to be looked into to motivate the construction of percolation ponds.

5.3 Summary of technical recommendations for natural wastewater treatment technologies (WP3)

In the light of shortages of water in several parts of the World (including in Asia), communities are searching for the alternatives which would augment their water resources. In that context, clearly, the engineered constructed wetlands (CWs) and other natural treatment systems (NTSs) have attracted attention of environmental engineers and scientists because these technologies are capable of treating sewages and wastewaters at phenomenally low operation and maintenance (O&M) costs as well as low power requirements. Consequently, they have been favourably looked up to in the countries, which have the natural advantages of tropical climate and warm weather.

One of the focus areas pursued in WP3 was the assessment of the prevailing practice of natural treatment technologies in general and constructed wetlands in particular across India and the learnings from the assessment were used to develop suitable method of engineered constructed wetland-based sewage treatment system to achieve enhancement of reduce of treated sewages. The other highlight of the activities in WP3 has been the research undertaken in the wastewater-impacted micro-watershed within the Musi River basin situated at the outskirts of Hyderabad Municipal Corporation. This research proposed potentially useful solutions for farmers surrounding the natural wetland through devising a system of small engineered constructed wetlands to augment the irrigation water supply. Such interventions will also improve the quality of irrigation water and thereby reduce the impact of contaminated Musi River on the surrounding agriculture.

5.3.1 Recommendations on engineered natural treatment systems for wastewater treatment

The engineered NTSs have been incorporated into sewage treatment plants (STPs) to treat sewages and sullages since early seventies – especially in the under-developed and developing countries in Asia and Africa. Several STPs employing a variety of NTSs have been studied and reported in literature (Arceivala and Asolekar, 2006 and 2012; Chaturvedi and Asolekar, 2009; Asolekar et al., 2013; Chaturvedi et al., 2014). There are 108 sites across India where publicly operated NTSs are used for treating mixtures of sewages and sullages and in some cases biodegradable industrial effluents. Among those, the 41 STPs were studied in-depth by the authors during December 2011 to June 2014. The details of these 41 sites have been presented in the Report No. D3.1 of Saph Pani Project (Asolekar, 2013).

At the outset, the exercise of assessment of potential of these 108 systems was undertaken focusing constructed wetlands and other natural treatment technologies currently practiced for treatment of municipal and industrial effluents across India. Based on this compressive study, gaps in understanding of the current state of art as well as strategies for achieving improved performance of constructed wetlands and other natural treatment systems were articulated – especially focusing the potential for recycling and reusing of treated effluent.

With the help of several batch and continuous laboratory-scale constructed wetland reactors, a variety of experiments were conducted for investigating the efficiency of plant species, media in constructed wetlands as well as operation routines for enhancement of the performance.

As a part of technology development efforts, the sub-surface flow constructed wetland based pilot-plant was designed, constructed and commissioned on the campus of IIT Bombay. The experiments were conducted for improving operational stability, minimising the clogging propensity as well as for determining best practices for operation and maintenance of constructed wetlands.

The lessons learnt in this research have been disseminated with help of newsletters and national and international training programmes aimed at building capacity of researchers, practitioners, designers and regulators hoping to generate the reusable treated effluents at lower costs. Some of the salient recommendations were:

1. Poor treatment and disposal of sewages as well as non-point source load of nutrient emerging from farm runoff and unsewered urban and rural drainages has posed a severe challenge of contamination of surface and groundwater in India.
2. The soil aquifer treatment, especially the engineered constructed wetland as well as managed aquifer recharge and riverbank filtration have been concluded to be useful and relevant candidate technologies having the eco-centric character and potential for addressing some of the critical problem of water contamination in India.
3. Engineered constructed and natural wetlands and the other natural treatment systems described above appear to be the likely solution for a country like India, owing to their virtues listed below:
    - Capable of achieving excellent removal of carbonaceous and nitrogenous BOD, phosphate and pathogen loads,
    - Relatively inexpensive O&M as well as capital costs,
    - Less mechanized,
    - Do not need electrical power,
    - Can be operated with the help of the skills of rural folks and
    - Blend well with the rural and peri-urban landscapes.
4. Reuse oriented technological options for treatment of sewages and up-gradation of contaminated ambient waters for the purposes of agriculture, process industry as well as uses in recreation and groundwater replenishment are favored for public investment in the recent times. Merely compliance-driven investments are being seen as ecosystem damaging and wasteful.
5. It is concluded in this research that the most appropriate sewage treatment system in India could incorporate an excellent primary treatment unit followed by secondary treatment unit based on NTS. Further, depending on the reuse option prescribed by the community; a high–class tertiary unit followed by disinfection should also be

combined with the NTS so that treated wastewater can be gainfully reused.

6 Abbreviations

AHP: Analytical Hierarchy Process

BF: Bank Filtration

CGWB: Central Ground W§ater Board

DST-WTI: Water Technology Initiative of Department of Science and Technology, Government of India

MAR: Managed Aquifer Recharge

NGO: Non Governmental Organisation

NWTS: Natural Wastewater Treatment System

POSAF: Planning Oriented Sustainability Assessment Framework

RWH: Rain Water Harvesting

UCOST: Uttarakhand State Council for Science andf Technology

UREDA: Uttarakhand Renewable Energy Development Agency

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8 Annex

Table 12 Acceptance of Stakeholders for Water Supply Options and Importance of Criteria

General				Potential						Rank						Acceptance						Importance				
No	Age	Gender	Role	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	Health	Environment	Costs	Social	Practical
S01	59	M	F	2	1	2	2	1	2	6	3	2	5	1	4	0	0	1	0	1	0	1	4	3	2	5
S02	33	F	G	3	2	1	3	2	4	5	2	1	4	3	6	-1	1	1	0	0	-1	3	1	4	2	5
S03	20	F	A	3	1	2	2	2	1	6	1	2	5	3	4	-1	1	1	0	0	0	1	2	5	3	4
0S4	28	F	G	3	2	1	2	1	3	6	4	1	3	2	5	-1	0	1	0	1	-1	1	3	2	5	4
S05	35	M	A	3	2	2	2	1	3	5	3	2	4	1	6	-1	0	1	0	1	-1	1	3	4	2	5
S06	50	M	G	3	1	1	2	1	2	6	1	4	3	2	5	-1	1	0	0	1	0	-	-	-	-	-
S07	-	-	-	3	1	3	2	2	1	6	1	3	4	2	5	-1	1	0	0	1	0	1	2	3	4	5
S08	64	M	F	3	2	2	4	2	4	4	6	4	3	2	1	0	0	0	0	1	0	1	3	2	4	5
S09	57	M	E	3	1	2	2	2	3	6	3	1	2	4	5	-1	0	1	1	0	-1	1	2	4	3	5
S10	54	M	G	3	2	2	2	2	2	5	2	1	3	4	6	-1	1	1	0	0	0	1	2	3	4	5
S11	71	M	F	3	1	2	3	2	3	5	4	1	3	2	6	-1	0	1	0	1	-1	1	3	5	3	4
S12	32	M	F	4	4	1	1	1	1	6	4	1	3	2	5	-1	0	1	0	1	0	4	5	3	1	2
S13	46	M	F	3	2	1	2	2	4	5	4	1	3	2	6	-1	0	1	0	1	-1	1	3	4	2	5
S14	36	M	G	2	2	2	3	3	2	4	1	4	4	1	1	0	1	0	0	0	1	2	1	2	2	2
S15	25	M	A	2	2	3	2	2	2	1	4	6	2	5	3	1	0	-1	1	0	0	2	1	3	5	4
S16	56	M	F	3	1	2	2	3	4	6	2	1	3	5	4	-1	1	1	0	-1	0	1	2	4	3	5
S17	54	M	G	2	1	1	3	1	4	3	1	5	4	2	6	0	1	0	0	1	-1	2	4	1	3	5
S18	57	M	F	3	3	1	3	2	2	5	4	1	3	2	6	-1	0	1	0	1	0	2	1	5	3	4

Table continued (more respondents)

Table 12 Acceptance of Stakeholders for Water Supply Options and Importance of Criteria continued

General				Potential						Rank						Acceptance						Importance				
No	Age	Gender	Role	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	Health	Environment	Costs	Social	Practical
S19	38	M	F	1	1	1	1	1	3	5	2	1	3	4	6	0	1	1	0	0	-1	1	4	2	3	5
S20	27	F	E	3	1	3	2	1	2	6	2	5	4	1	3	-1	1	-1	0	1	0	1	2	4	3	5
S21	71	M	E	3	2	2	3	3	2	6	2	1	3	4	5	-1	1	1	0	0	0	1	2	5	3	4
S22	50	M	G	3	3	2	3	1	3	2	4	3	6	1	5	0	0	0	-1	1	-1	1	3	2	4	5
S23	53	M	G	1	1	1	1	3	4	1	6	3	4	2	5	1	0	0	0	0	-1	4	5	1	2	3
S24	25	M	A	1	1	1	1	2	2	3	1	2	4	5	6	0	1	1	0	0	0	2	1	3	4	5
S25	56	M	F	3	1	2	3	2	3	5	5	2	3	1	4	-1	0	1	0	1	0	1	2	4	2	5
T01	52	M	F	1	1	4	1	4	1	6	1	5	2	3	4	0	1	-1	1	0	0	1	3	5	2	4
T02	37	F	E	2	2	2	2	2	3	2	3	4	1	5	6	1	0	0	1	0	-1	2	5	4	3	1
T03	37	M	A	3	2	2	3	2	2	6	3	4	5	1	2	-1	0	0	-1	1	1	1	2	5	3	4
T04	41	M	F	3	4	1	1	1	4	5	4	1	2	3	6	-1	0	1	1	0	-1	1	3	4	2	5
T05	75	M	E	2	1	2	2	3	3	2	1	4	3	5	6	1	1	0	0	-1	-1	1	3	5	2	4
T06	53	M	G	2	1	1	2	1	1	5	2	2	5	2	1	0	1	1	0	1	1	1	2	5	4	2
T07	28	M	G	2	2	1	2	2	1	3	1	2	4	5	6	0	1	1	0	0	0	2	1	5	4	3
T08	66	M	F	2	1	1	1	3	1	6	3	1	4	2	5	0	0	1	0	0	0	4	1	2	5	2
T09	49	M	F	3	2	2	2	2	2	6	4	1	3	2	5	-1	0	1	0	1	0	2	1	3	4	5
T10	39	M	-	1	2	2	3	2	2	5	1	4	3	2	6	0	1	0	0	1	0	2	3	4	1	5
T11	59	M	F	4	3	3	2	1	4	6	3	4	2	1	5	-1	0	0	1	1	-1	3	1	5	2	4

Table continued (more respondents)

Table 12 Acceptance of Stakeholders for Water Supply Options and Importance of Criteria continued

General				Potential						Rank						Acceptance						Importance				
No	Age	Gender	Role	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	desalination	RWH	check dams	infiltration ponds	larger reservoirs	policies	Health	Environment	Costs	Social	Practical
T12	51	M	G	4	1	1	2	1	1	6	1	4	3	2	5	-1	1	0	0	1	0	1	2	4	3	5
T13	71	M	E	1	3	2	2	3	3	1	2	3	4	5	6	1	0	0	0	-1	-1	1	2	3	4	5
T14	29	F	G	3	1	2	2	2	3	5	2	3	1	4	6	-1	1	0	1	0	-1	1	3	2	4	5
T15	56	M	E	3	1	1	1	1	1	5	2	1	3	4	6	-1	1	1	0	0	0	2	1	4	3	5
T16	32	M	A	3	2	1	1	1	2	5	3	1	2	4	6	-1	0	1	1	0	0	1	2	5	3	4
T17	55	M	A	1	2	3	2	3	2	1	3	5	2	5	3	1	0	-1	1	-1	0	1	3	2	4	4
T18	49	M	E	1	1	1	3	2	3	2	1	5	3	4	6	1	1	0	0	0	-1	1	2	5	3	4
T19	29	M	A	2	2	1	2	1	1	5	1	1	1	1	5	0	1	1	1	1	0	1	1	3	3	5
T20	57	M	G	1	1	3	4	2	4	5	2	4	3	1	6	0	1	0	0	1	-1	1	3	4	2	5
T21	77	M	E	2	1	-	3	-	-	6	1	2	4	3	5	0	1	0	0	0	-1	1	2	3	4	5
T22	57	M	E	1	1	3	2	2	2	1	5	4	3	2	6	1	0	0	0	1	0	2	1	4	3	5
T23	57	M	G	3	2	1	2	1	3	5	2	3	4	1	6	-1	1	0	0	1	-1	1	2	5	3	4
T24	52	M	G	2	2	2	2	2	3	5	4	1	2	3	6	0	0	1	1	0	-1	1	2	5	3	4
T25	45	M	G	1	1	1	4	1	1	5	4	3	2	1	6	0	0	0	0	1	0	5	3	4	1	2
T26	39	M	G	1	2	2	1	2	2	1	2	4	5	3	6	1	1	0	0	0	0	1	5	3	2	4
T27	51	M	G	2	1	3	3	2	2	2	1	3	4	5	6	1	1	0	0	0	0	1	3	2	4	5
T28	56	M	G	1	2	3	2	1	2	1	5	6	3	1	3	1	0	-1	0	1	0	1	1	5	1	4
T29	35	M	G	2	3	2	1	1	2	2	1	6	3	4	5	1	0	0	0	0	0	1	2	3	5	4

Explanation: Numbers: Sxx stakeholder workshop, Txx policy workshop; Gender F female, M male; Role: A academia, E experts from NGOs or business; G government; ‘-‘ = no response

Table 13 Stakeholder views on infiltration ponds and policies to implement them

No	T01	T02	T03	T04	T05	T06	T07	T08	T09	T13	T14	T15
Cluster	NC	NC	C	C	NC	NC	NC	NC	C	NC	C	C
Water Supply: Improvements needed	1	0,5	0,5	0,5	0,5	0,5	0,5	1	1	0,5	0,5	0,5
Ponds: want them	0,5	1	0,5	1	0,5	1	1	1	1	0,5	1	0,5
Ponds are supported by and will comply with existing polices and laws	-1	0,5	0,5	1	1	1	-0,5	0,5	-0,5	-0,5	-0,5	0,5
Farmers should drive	1	1	1	1	1	-1	-1	1	1	1	-1	-1
Government should drive	-1	-1	1	-1	-1	1	-1	1	-1	-1	1	1
Taxpayer should drive	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Consumers should drive	-1	-1	1	-1	-1	-1	1	-1	-1	-1	-1	-1
Others should drive	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Farmers should pay construction	-1	-1	-1	-1	1	-1	-1	1	1	-1	-1	-1
Government should pay construction	1	1	-1	1	-1	1	1	-1	-1	1	1	1
Taxpayer should pay construction	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Consumers should pay construction	-1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Others should pay construction	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Farmers should pay O&M	1	1	1	1	1	-1	1	1	1	1	1	-1
Government should pay O&M	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Taxpayer should pay O&M	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1
Consumers should pay O&M	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1
Others should pay O&M	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1
Farmers should operate	1	1	1	1	1	1	1	-1	1	1	1	1
Government should operate	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1
Private Organization should operate	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Others should operate	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Table continued (more respondents)

Table 13 Stakeholder views on infiltration ponds and policies to implement them continued

No	T16	T17	T18	T19	T22	T23	T24	T25	T26	T27	T28	T29
Cluster	C	NC	NC	NC	NC	C	C	NC	NC	NC	NC	NC
Water Supply: Improvements needed	0,5	1	0,5	0,5	0,5	0,5	0,5	0,5	1	1	1	0,5
Infiltration Ponds: want them	1	1	1	0,5	1	0,5	0,5	-1	-0,5	-1	1	0,5
Ponds are supported by and will comply with existing polices and laws	0,5	0,5	0,5	-0,5	-1	1	0,5	0,5	0,5	0,5	1	0,5
Farmers should drive	1	1	-1	-1	-1	1	-1	-1	-1	1	-1	-1
Government should drive	-1	-1	1	-1	-1	-1	-1	-1	1	-1	1	1
Taxpayer should drive	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Consumers should drive	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1
Others should drive	-1	-1	-1	1	1	-1	1	-1	-1	-1	1	-1
Farmers should pay construction	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1
Government should pay construction	-1	1	1	-1	1	-1	-1	1	-1	-1	1	1
Taxpayer should pay construction	-1	-1	-1	-1	-1	1	1	-1	1	-1	-1	-1
Consumers should pay construction	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Others should pay construction	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	1	1
Farmers should pay O&M	1	1	-1	1	-1	1	-1	-1	-1	1	-1	-1
Government should pay O&M	-1	-1	1	-1	1	-1	-1	1	-1	-1	-1	-1
Taxpayer should pay O&M	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1	-1
Consumers should pay O&M	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Others should pay O&M	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1
Farmers should operate	1	1	-1	1	-1	1	1	-1	1	-1	1	1
Government should operate	-1	-1	1	-1	-1	-1	-1	1	-1	-1	-1	-1
Private Organization should operate	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1
Others should operate	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1

Table continued (more issues)

Table 13 Stakeholder views on infiltration ponds and policies to implement them continued

No	T01	T02	T03	T04	T05	T06	T07	T08	T09	T13	T14	T15
Cluster	NC	NC	C	C	NC	NC	NC	NC	C	NC	C	C
Mandatory ponds for >1acre farm	1	0,5	0,5	1	0,5	1	1	0,5	1	-0,5	1	0,5
Fine farmers without pond	1	0,5	-1	1	-0,5	1	0,5	-1	0,5	0,5	1	-0,5
Support ponds	1	1	0,5	1	1	0,5	1	1	1	1	1	1
inform about ponds	1	1	0,5	1	1	1	1	1	1	1	1	1
Rank mandatory ponds	1	3	3	3	3	1	1	3	1	5	1	3
Rank fines	4	4	5	4	4	3	1	5	4	4	4	5
Rank support	2	2	1	2	1	2	1	2	2	1	2	1
Rank information	3	1	2	1	2	1	5	4	3	2	3	2
Rank other	5	5	4	5	5	5	5	5	5	3	5	4
Accept mandatory ponds	1	0	0	0	0	1	1	0	1	0	1	0
Accept fines	0	0	-1	0	0	0	0	-1	0	0	0	0
Accept support	1	1	0	1	1	0	1	1	1	1	1	1
Accept information	0	1	0	1	1	1	0	0	0	1	0	1

Table continued (more respondents)

Table 13 Stakeholder views on infiltration ponds and policies to implement them continued

No	T16	T17	T18	T19	T22	T23	T24	T25	T26	T27	T28	T29
Cluster	C	NC	NC	NC	NC	C	C	NC	NC	NC	NC	NC
Mandatory ponds for >1acre farm	1	0,5	0,5	1	-1	1	1	-1	-0,5	-1	-1	1
Fine farmers without pond	0,5	-1	-1	-1	-1	0,5	0,5	-1	-1	-1	-1	1
Support ponds	0,5	0,5	1	-1	-1	0,5	-0,5	-1	0,5	0,5	1	1
inform about ponds	1	1	1	1	-1	1	1	0,5	0,5	-0,5	1	0,5
Rank mandatory ponds	1	2	3	1	4	1	1	5	3	5	3	3
Rank fines	4	4	5	3	5	2	5	4	5	4	5	4
Rank support	2	3	1	5	2	3	2	2	1	2	2	1
Rank information	3	1	2	1	1	4	3	1	2	1	2	2
Rank other	5	5	4	1	3	5	4	3	4	3	2	5
Accept mandatory ponds	1	0	0	1	-1	1	1	-1	0	-1	0	0
Accept fines	0	-1	-1	0	-1	0	0	-1	-1	-1	-1	0
Accept support	0	0	1	-1	0	0	0	0	0	0	1	1
Accept information	0	1	1	1	0	0	0	0	0	0	1	0

Explanation: Cluster: C = cluster, NC = non-cluster, ±1 = yes/no, ±0.5 = yes/no with reservations, 0 = indifferent; Ranks: 1 = highest

Table 14 Stakeholder Views on Legal and Policy Issues

No	MAR adequate	Groundwater law adequate	Groundwater Act like repealed one needed	Groundwater Act like Planning Commission draft needed	State Water Allocation Authority neded	This authority should regulate groundwater extraction	This authority should compell MAR structures	Rank Union government for GW	Rank State government for GW	Rank Local government for GW	Rank Farmers for GW	Rank Civil Society organisations for GW	Rank others for role in GW	removal of encroachments to protect groundwater	region specific laws/policy in relation to MAR	region specific laws/policy in relation to water pollution	land utilization policy based on water availability	Priority Farmers to hear	Priority Civil society to hear	Priority Industry to hear	Priority Academia to hear	Priority Courts to hear	Priority Others, which government should hear
T01	1	-0,5	1	-	1	1	1	5	4	3	1	2	6	1	1	1	1	1	3	6	4	2	5
T02	0,5	-0,5	1	0,5	0,5	0,5	1	5	3	1	2	4	6	0,5	0,5	1	0,5	1	3	4	5	2	6
T03	0,5	-0,5	1	1	0,5	0,5	0,5	5	4	2	1	3	6	1	1	1	0,5	1	2	5	3	4	6
T04	-1	0,5	0,5	1	-0,5	0,5	0,5	3	1	2	5	4	6	1	1	1	1	1	3	5	2	4	6
T05	-0,5	-	1	-0,5	1	1	-	5	2	3	1	4	6	1	1	1	1	1	4	2	3	5	6
T06	1	0,5	0,5	-0,5	0,5	1	1	3	1	1	3	4	6	1	1	1	1	1	2	4	2	4	6
T07	0,5	0,5	-0,5	1	1	1	1	3	1	1	3	4	6	1	1	1	0,5	1	5	2	4	3	6
T08	-	1	-1	-0,5	-1	-	-	-	1	2	1	3	4	1	1	1	-1	1	2	5	4	6	3
T09	0,5	-	0,5	1	0,5	1	1	4	3	1	2	5	6	1	1	1	-0,5	1	2	3	4	5	6
T10	-1	-1	1	1	1	-1	1	2	1	4	3	5	6	1	1	1	1	1	4	3	2	5	6
T11	-0,5	1	-1	-1	-1	-1	-	2	1	3	5	4	6	1	-1	-1	-1	-	-	-	-	-	-
T12	-0,5	-1	1	1	1	1	1	1	2	3	5	4	6	1	1	1	1	1	2	3	4	5	6
T13	0,5	0,5	1	1	1	1	1	5	1	2	4	3	6	1	1	1	1	1	2	5	3	4	6
T14	0,5	-0,5	1	0,5	1	1	0,5	3	4	-	-	-	6	1	0,5	0,5	0,5	6	-	-	-	-	-
T15	0,5	-1	0,5	1	1	1	1	4	1	2	3	5	6	1	1	1	1	2	1	3	4	5	6

Table continued (more respondents)

Table 14 Stakeholder Views on Legal and Policy Issues continued

No	MAR adequate	Groundwater law adequate	Groundwater Act like repealed one needed	Groundwater Act like Planning Commission draft needed	State Water Allocation Authority neded	This authority should regulate groundwater extraction	This authority should compell MAR structures	Rank Union government for GW	Rank State government for GW	Rank Local government for GW	Rank Farmers for GW	Rank Civil Society organisations for GW	Rank others for role in GW	removal of encroachments to protect groundwater	region specific laws/policy in relation to MAR	region specific laws/policy in relation to water pollution	land utilization policy based on water availability	Priority Farmers to hear	Priority Civil society to hear	Priority Industry to hear	Priority Academia to hear	Priority Courts to hear	Priority Others, which government should hear
T16	-0,5	-1	0,5	-	-	-	-	-	-	-	-	-	-	1	-	-1	-	1	3	4	2	5	6
T17	1	-1	0,5	0,5	0,5	1	0,5	5	3	2	1	4	6	-0,5	0,5	1	1	2	1	3	5	4	6
T18	0,5	1	1	1	1	1	1	3	1	2	5	4	6	1	1	1	1	1	2	3	4	5	6
T19	-0,5	-0,5	-0,5	-1	-0,5	-0,5	-0,5	-	-	2	3	-	1	1	1	-0,5	-0,5	2	1	5	3	4	6
T20	-1	-1	1	-0,5	-1	-1	-1	2	1	5	3	4	6	1	-1	1	0,5	3	2	1	4	5	6
T21	-1	-1	-	-	-	-	-	5	1	2	4	3	6	1	1	1	0,5	2	1	4	3	5	6
T22	-1	1	-1	-1	0,5	0,5	-0,5	5	2	1	3	4	6	-1	-1	1	1	1	2	4	3	5	6
T23	-0,5	-1	1	0,5	1	0,5	1	2	1	4	3	5	6	1	1	0,5	1	2	1	4	5	3	6
T24	0,5	-0,5	0,5	0,5	0,5	0,5	0,5	5	3	2	1	4	6	0,5	0,5	0,5	0,5	1	2	4	3	5	6
T25	-1	-1	1	1	1	1	-1	1	2	3	5	4	6	1	1	1	1	1	2	4	3	5	6
T26	-0,5	-0,5	0,5	-0,5	0,5	0,5	0,5	4	3	2	1	5	6	0,5	0,5	0,5	-0,5	1	5	2	3	4	6
T27	0,5	1	-1	1	-0,5	-	-1	4	1	2	3	5	6	1	-0,5	1	1	2	1	3	4	5	6
T28	0,5	0,5	0,5	1	0,5	1	0,5	6	2	1	4	2	5	1	1	1	1	3	1	1	3	3	6
T29	-0,5	0,5	0,5	0,5	1	1	0,5	4	3	2	1	5	6	1	0,5	1	1	1	2	3	4	5	6

Explanation: ±1 = yes/no, ±0.5 = yes/no with reservations, 0 = indifferent; - = missing; Ranks: 1 = highest