# Analysis of Community Based Nature Oriented Surface Water Treatment

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# ANALYSIS OF COMMUNITY BASED NATURE ORIENTED SURFACE WATER TREATMENT

**PHD THESIS**

ELABORATING A FULL SCALE PILOT PLANT FOR
A RAINWATER AND SOLAR BASED DRINKING WATER SUPPLY

FOR AN AREA WITH ARSENIC CONTAMINATED GROUNDWATER
IN THE GANGETIC DELTA, RURAL WEST BENGAL, INDIA.

WITH FOCUS ON THE EVALUATION OF ITS
TECHNICAL, SOCIAL, ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY

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## SUMMARY

In this thesis the development, implementation and analysis of a full scale pilot for drinking water supply is elaborated. The intention of the study lies in identifying and verifying methodologies, technologies and approaches which lead to the sustainable setup of water resource protection, water purification and distribution, with the aim of providing safe drinking water to all people in an area where the majority of the population currently does not have access to a safe drinking water source.

The reasons for the lack of safe water provision are identified in the introductory chapter and are grouped into technical, social, environmental and economic challenges. Based on the identified problem, the objective of the study and the questions for which answers are to be elaborated are drafted in the second chapter.

The third chapter outlines the research approach and methodologies for producing results. Accordingly the next chapter gives an overview of some water treatment technologies which are suitable for a community based water supply based on surface water, with the aim to identify a technology which ensures safe water reliably and can be set up and operated by members of a rural community. It should further make use of local resources and require as little chemicals and energy as possible so that O&M expenses are kept low.

The situation in the identified pilot region is assessed in regards to the demography, geography, existing infrastructure, current water supply and future demand, as well as potential water resources and options for usage of renewable energy. The assurance of the attitude of the local population, their interests and expectations as well as contributions in regards to the development of a suitable water supply project is the next step in the baseline assessment.

In the second part of the thesis a rainwater harvesting system feeding into a village pond and a near-natural treatment system consisting of sedimentation, roughing filtration, slow sand filtration and activated carbon filtration followed by disinfection is designed. The design includes the solar photovoltaic based energy provision for the pumps for water extraction and supply, the catchment area management for the water source as well as a setup for the online and offline monitoring of the performance of the treatment plant. The design reflects the actual implementation in the field.

In the final part of the study the monitoring results on performance of the treatment system are analysed and conclusions for optimization of operation processes are elaborated in chapters 7 and 8.

Chapter 9 evaluates the implemented solution in a comparison with the current situation, a conventional technology and a technologically advanced solution which is also set up at the pilot site. The comparison consists of the technical performance, socio-economic and environmental impacts as well as financial viability and views of stakeholders on these sustainability criteria.

As a result it can be stated that a reliably working water treatment has been developed which is analysed to be more sustainable than conventional solutions in regards to performance and socio-economic and environmental aspects. It is more viable than advanced technologies from an economic point of view and generates more public benefits than all the compared solutions. It is however further concluded that none of the technological solutions will be implemented by pure market forces and that a political will and public intervention are required even for the most efficient and most affordable solution.

Finally a brief outlook is given for further components of a sustainable water supply including distribution network, sanitation infrastructure, sewerage system, waste water treatment and energy recovery with a biogas plant. Details of the assessment methodologies, the monitoring data, design drawings and evaluation calculations are given in the appendices.

## CONTENTS

# PART I
# APPROACH

## 1 INTRODUCTION TO THE SITUATION OF ARSENIC MITIGATION IN THE WATER SUPPLY IN WEST BENGAL

Safe drinking water is seen as a basic human right by the majority of governments worldwide, and the goal is to provide universal and equitable access to safe and affordable drinking water to all [2]. Still billions lack access to safe water which is reliably and continuously delivered in sufficient quantities [3]. Reasons for the denial of this right are multifold, so are solutions to ensure it. According to the technical and economic options as well as the social and cultural circumstances, the provision of this basic human right is approached in a variety of ways. Depending on the regional geo-hydrological conditions, the available sources are either surface- or groundwater in their diverse occurrences. In India, nowadays almost 85% of the rural population is dependent on groundwater to meet their domestic needs, including drinking water. But in many areas groundwater quality is not suitable for drinking due to geogenic occurring contaminants [4]. Arsenic, one such contaminant, was detected in the Indian state of West Bengal since the early 1980s [5,6]. By now the extent of arsenic contamination has grown and the entire Ganga, Meghna and Brahmaputra plain in India and Bangladesh, home to 500 million humans, is potentially affected by the growing groundwater contamination [7,8]. The source of arsenic in the groundwater is discussed with various explanations. Basically it is agreed upon that arsenic is mobilised from the alluvial sediments of the Ganga Meghna and Brahmaputra rivers originating in the Himalayas and can be found in aquifers in the entire Bengal Basin in India and Bangladesh[9]. Its health impacts have been observed since 1984 in West Bengal, and since then people became aware of its toxic properties [6]. The symptoms of chronic arsenic poisoning include various types of dermatological lesions, muscular weakness, liver disorder, nervous disorder etc. Arsenic is a potential carcinogen, therefore cancer can occur after prolonged exposure [10,11]. The health problems are also related to socio-economic consequences, leading to poverty, exclusion and marginalisation, especially of girls and young women [8]. In the last decades many arsenic removal units have been built to remove arsenic from tube well water, though in most cases these units were not successful [12,13].

This thesis addresses these problems by elaborating sustainable solutions for the provision of safe water from an arsenic-free source. Surface waters are generally free from arsenic and are thus a potential source for an arsenic-free water supply. In the arsenic prone remote rural areas in West Bengal, village ponds are generally available in great numbers making it a promising option to study on. Although a few pilot projects in this regard have been made, documentation of these are rare and very brief; existing monitoring and evaluation reports are based on little data.

### 1.1 BACKGROUND TO EXISTING APPROACHES TO PROVIDE SAFE WATER

#### 1.1.1 GOVERNMENT AND NGO INITIATIVES

Provision of drinking water is the task of the Public Health Engineering Directorate (PHED) in West Bengal. In 2006 PHED, guided by the Arsenic Task Force since 1995, has set up a 21 billion INR Master Plan for Arsenic Mitigation for West Bengal with the aim of providing clean water. From the technological point of view two main approaches were chosen. The most widely implemented technique for a design population of 6.9 million people and a budget of 7.5 billion INR is a mid-term solution of constructing new groundwater based schemes with arsenic removal plants attached to them. Most of the estimated expenses are allotted for the long-term solution, which is more expensive per capita and thus reaches only 5.9 million people with a budget of 12.5 billion INR. An additional medium term solution for a design population of 0.14 million with a budget of 138 million INR is envisaged with new groundwater schemes. As a short term solution another 3.6 million people are intended to be provided with water from existing plants which are fitted with new arsenic removal units. For this purpose 827 million INR is allocated [14].

In the master plan, only for 35% of the 16.6 million identified affected people is a long-term solution being planned. The long-term solutions are based on using surface water resources treated by conventional surface water treatment processes. The surface water sources are generally free from arsenic contamination, thus no further removal of arsenic is necessary. A reason for the rather low proportion of people having a long-term solution could be the assumed higher per capita expenses of approximately 2130 INR per head against 1090 INR for the medium term solution[14]. As per official communication the yearly investments in rural drinking water supply have gone up around 10 billion INR in 2000 and 25 billion in 2006 to around 80 billion yearly between 2007 and 2015 which shows the enormous public efforts in this sector. Till January 2015 almost 15 million people (89%) of the identified arsenic affected population could thus be provided with safe drinking water[15]. Although more critical sources speak of 50 million people in West Bengal being exposed to drinking water with arsenic levels exceeding the drinking water quality standards[16], and the official statistics of provision of safe drinking water might not always correlate with the population actually being able to drink safe water [17], it seems that the governmental institutions are finally taking the problem seriously[18] around 20 years after its discovery in 1983/84[19].

Apart from the government approach according the master plan, prior efforts had also been conducted by the PHED, other governmental institutions and also NGOs towards arsenic mitigation in drinking water supply. Big diameter deep tube wells had been set up, tapping arsenic free aquifers. As the deeper aquifers are still partly free from arsenic contamination, clean water can be extracted from these as a midterm solution[20]. In many cases though, even the deeper aquifers are contaminated and the explored groundwater has to be treated with arsenic removal plants [9]. On the other hand, many different technologies had been tested to remove arsenic [21]. In short term solution approaches Arsenic Removal Plants or Units (ARP/ARU) are attached to existing tube wells. These solutions have been tried with various filter media and removal processes which work on a laboratory level, but have mostly (82%) miserably failed in the field [7,13]. Still, for a long time one of the main interventions was to set up ARUs funded by the government (till 2006 around 1900 such units were funded by the government for approx. 135 million INR) [7]. Another community based approach is the usage of dug well which are also generally arsenic free, but often have to face challenges with other shallow aquifer percolations [22]. House level individual arsenic removal units also achieved good results in pilot studies, but are difficult to monitor in the long run as they also depend on proper maintenance and exchange of filter material[23]. The focus on pilots for long-term solutions based on surface water sources remained rather the exception (compare chapter 4.2).

### 1.1.2 CHALLENGES OF CURRENT SOLUTIONS

The currently implemented long-term approach in arsenic mitigation of the WB government is to focus on surface water supply schemes with large scale projects for big supply areas [15]. There is only limited direct involvement of the local population and therefore installations are not respected or maintained, and in worst cases are even destroyed due to the lacking sense of ownership. This results in the loss of precious treated water in huge quantities [24]. Costs for pumping the water over long distances make up a big share of the operation costs of the water supply. Thus areas with a high density of population close to bigger surface water resources are prioritised for installation of

surface water supply schemes. For smaller rather isolated villages the mid and short term solutions with deep tube wells and/or arsenic removal plants have been decided on. Many of these are not working, and the population still uses arsenic poisoned groundwater.
Poisoned water is not only directly consumed by humans but also used for all other purposes including irrigation and cattle feeding. Contaminated groundwater used for irrigation leads to toxic accumulation in crops and grazing cattle which reaches the human after some time.
It has been observed that intense extraction of groundwater leads to the poisoning of extensive groundwater aquifers[9], thus poisoning further tube wells which are used by a great majority of the villagers. Lack of sanitation infrastructure leads to contamination of surface water sources which are generally arsenic free[4].

*Figure 1 Broken piped water supply stand post*

*Figure 2 Defunct arsenic removal unit*

#### 1.1.2.1 TECHNICAL LIMITATIONS

Technical issues can be analysed at various stages: firstly in the selection of the water source. Water sources can have easily removable suspended contaminants, or more difficult to remove dissolved pollutants as in the case of arsenic occurring in many of the groundwater sources of the project area. Quantitatively, many surface water sources are not perennial, thus not able to supply water during the time when it is most needed. Catchment area conditions, infiltration, evapotranspiration as well as potential pollution sources have to be looked into when planning and dimensioning a supply based on a surface water source.
The second stage facing challenges is the treatment process. The technical aim of the treatment process should be to achieve the Indian Standard for Drinking Water Quality (IS10500)[25]. The quality has to be achieved reliably independently of varying raw water quality which can change due to various reasons such as seasonal effects or activities in the catchment area. Treatment processes depend not only on water quality but also on the regularity of water availability (flowrate in case of biological treatment) and resources like energy, chemicals and skilled labour for operation and maintenance. In remote regions with regular load shedding, unavailability of chemicals e.g. alum, chlorine and technicians staying a day journey away, shortages in these resources often lead to interruptions of operation. Systems depending on the exchange or regeneration of filter media are especially challenging, as often the local users do not have sufficient means of assessing the status of exhaustion of the media. In these cases, remobilisation of previously adsorbed contaminants often poison the consumer who believes the drinking water is safe. Another big challenge is the maintenance of the treatment system. Often systems are being neglected as maintenance funds are not available or not used for the designated purpose.
Finally, even if the treatment can be taken care of, one of the biggest challenges in the project area is the distribution and final appropriation of water by the actual consumer. Here challenges of post-

contamination of water are common as pipelines tend to have leaks, and sparse maintenance, if at all, concentrates on the visible issues rather than on pipelines which are dug below the ground. The common practice of intermittent provision of water leads to the ingress of contaminants into the pipeline. This happens in intermittent supplies when the pressure inside the pipeline drops, allowing outside water, in worst cases sewage, to enter the distribution line. Reasons for the intermittent supply are similarly the cause for its contamination, the poorly setup and maintained distribution network not allowing the supply to be continuous as large amounts of water would be lost. In this way often distribution points such as stand posts can be seen without even having a provision to be closed so that during water supply period water just pours out and gets wasted in case no one collects it. Thus technically source sustainability, reliable treatment and protected distribution all have to be looked into.

#### 1.1.2.2 SOCIAL PROBLEMS

Clean drinking water is a prerequisite for maintaining health. Social problems are manifold related to health problems, e.g. work disability days causing further poverty, or social exclusion due to visible disease. Safe drinking water can thus be seen as an investment which pays off, and those without means to invest get further stuck in the vicious circle of spoiling their productivity and future prosperity[17]. As publicly available water supply is only rarely of drinking water quality, the affluent part in society affords to buy individual domestic treatment systems to produce their own safe drinking water. On the other side, the poorer part of the society is doomed to suffer from water borne diseases. Availability of safe water for all parts of the society is thus a mode of poverty alleviation, helping the poor to help themselves.

On the other hand, social challenges for a community supply are the lack of sense of ownership for common goods. Not only in the water supply sphere, but also related to other common infrastructure, the mentality to contribute to benefit jointly seems to be a rare phenomenon, and trust in common ownership is missing: e.g. metered electricity supply, though it uses a social tariff system, is being bypassed by hooking up to public electric lines leading to voltage drops, damage of the grid and finally load shedding. Even in cities, common areas with recreation potential for the adjacent inhabitants are used as dumpsites, although municipal waste collection is available on a daily basis. Reasons for this attitude might be found in the hierarchal organised society with a wide gap between the better off and the poor. While the poor part of the population are concerned about day to day survival, lacking basic human needs, and thus cannot afford to care about common assets, the richer part is used to the vast discrepancy of having commodities which they know cannot be shared with everyone. The better off thus prefer to ensure individual infrastructure than to bother about infrastructure for the public. Further trust is lost due to the perception of non-transparent public budgets and corruption in maintenance of rules and regulations, leading to even less willingness to pay for public services.

In the case of water supply, this leads to a situation where individuals are ready to pay manifold amount of money for their individual treatment system, rather than contributing to a public supply system which could provide them with the same or even better quality and quantity of water at a fraction of cost, at the same time enabling a system which could provide the needy with safe water and contribute to the overall development of the society. This awareness on the benefits of common goods, joint action and solidarity on the one side has to go hand in hand with the strengthening of public organisations and structures which are accountable and take responsibility in provision of services to the society.

#### 1.1.2.3 ENVIRONMENTAL POLLUTION

In the course of industrialisation, environmental pollution has increased and environment technologies for pollution mitigation have become necessary. In remote rural areas, waste management systems have not yet been set up and thus solid waste is either burned locally, buried or just left to itself to wither away by the impact of the weather and environment. In areas without piped water supply, it is needless to speak of sewerage systems and even pit toilets are not standard, although there has been a change in this regard in the last years during the study period itself. Still sewage is openly discharged at the point of usage and either infiltrates into the ground or flows into the adjoining surface water body, making it unsuitable for any further qualitative usage. Open defecation being washed away by the next rain runs off into the next surface water body, so do the abundantly applied pesticides and fertilizers in agricultural catchments. Surface water sources are thus prone to be contaminated with pathogens as well as toxics, and to be rather eutrophic than oligotrophic, limiting their self-cleaning capacities.

Infiltration of contaminant near groundwater extractions also lead to similar contamination for shallow tube wells, whereas geogenic dissolved toxic contaminants like arsenic and exceeding levels of other chemicals like iron, constitute the composition of most groundwater sources in the project area.

Regarding emissions from water supply systems, greenhouse gas emissions related to energy production depend on the energy intensity of the supply technology, mainly application of pumps among other electrical equipment. Large central systems are efficient in their treatment process but require proportionally higher overall energy due to the long distribution paths by booster pumps. Pressure treatment systems require more energy than gravity based biological systems.

Discharge of effluents from drinking water treatment systems are rather negligible apart from filter backwashes, sludge from precipitation processes and brine discharge from membrane systems. Of special concern are arsenic removal units producing highly enriched arsenic sludge which has to be taken care of as hazardous waste.

Environmental impacts at the level of resource consumption for construction and production of the treatment equipment and emissions generated by its possible transportation in case of imported ready-made parts. Advanced technologies, often produced overseas using specific materials imported from various countries, have higher carbon footprints than locally assembled systems built with locally available materials.

Finally the level of treatment of the sewage generated by a water supply system determines the impacts of the discharged waste water. A common concern is therefore the collection of sewage and proper conveyance to the treatment plant, whereas the functionality of waste water treatment plants is a second issue to be looked into.

#### 1.1.2.4 UNVIABLE ECONOMY

Production and distribution of safe drinking water costs money. In case of municipal water supplies, the user fees, if collected at all, do not cover the expenses and water supply is highly subsidised. A good reason for this is also that a majority of the population does not have means to pay them, and a social tariff similar to the electricity tariffs has the prerequisite of measuring the consumption, which in most cases is not being done. General practice is thus to just supply a certain amount of water to every consumer or joint consumption point independent of the actual requirement at that point leading to a wastage of resources on the one hand side and a shortage of resources on the other hand side.

Now looking at the remote rural areas where public water supply has not (yet) been set up, subsidised water provision is criticized and it is often spoken of user fees covering operation and maintenance. Although some water supply companies have been able to market their water in bottles and cover their expenses, a public piped water supply requiring water treatment in rural areas covering their expenses only by user fees is yet to be piloted. Thus there is no scope for a private investor solely depending on user fees. Several government schemes addressing this issue can be found when researching, e.g. the national rural drinking water programme stating 50% central or state contribution to the Operation and Maintenance (O&M) expenses adding up to the user fees[26]. Experiences with these schemes though could not be found in the project area. On the other side there is willingness to contribute by user fees, but the willingness to pay is few in number and low in amount. The collected money thus generally does not suffice to cover the remaining 50% of the expenses. Cost benefit studies as also conducted in the analysed project show manifold societal benefits in comparison to the costs, thus justifying increased public expenditure, which should be openly requested from the authorities. In practice modes of further reducing the costs on the one hand side and increasing the willingness to pay on the other hand side have to go hand in hand to make water supply systems economically viable under the current public funding conditions.

## 1.2 GEOGRAPHICAL AREA RELEVANT FOR THE RESEARCH

### 1.2.1 EXTEND OF GROUNDWATER CONTAMINATION

As per the scope of the study a suitable drinking water supply system is to be developed for a remote rural area in West Bengal which suffers from arsenic contaminated groundwater. Although the conditions in this area are very specific as described in the prior paragraphs, generally the developed solution could be suitable for many regions worldwide. Generally, areas where groundwater is not suitable for drinking and rainwater is available could be potential application sites. Groundwater contaminations of importance, apart from arsenic, are fluoride and salinity[27]. Worldwide 13% of groundwater sources under land masses are saline or brackish, of which 8% are due to human activities[28]. Elevated fluoride concentrations occur on all continents and are more common than arsenic with hotspots in Argentinean Pampas, Chile, Mexico, India, Pakistan, East African Rift and some volcanic islands (e.g. Tenerife)[29].
Regarding arsenic contamination also, various parts worldwide are affected. 38 Countries have regions where the level of arsenic in the groundwater is unhealthy according to the water quality standards[30]. One of the worlds' hotspots is the Ganga-Meghna-Brahmaputra plain, which is home to more than half a billion people. Here Bangladesh, Nepal, China, Myanmar and India are affected (compare Appendix D). Other hotspots are in Argentina and Mexico[31].
In India alone currently 70 million people are drinking arsenic contaminated water[4]. Critically impacted states are Uttar Pradesh, Chattisgarh, Jharkand, Manipur, Assam and most affected West Bengal[30]. Recent studies state that in West Bengal 15 and 50 million people are exposed to arsenic in drinking water exceeding 50 and 10µg/L respectively[32]. The arsenic situation in rural West Bengal has been studied by various organisations, and maps of contaminated regions and even individually affected tube wells are available[5,33–35].

### 1.2.2 PROJECT AREA FOR THE FULL SCALE PILOT PLANT

The most severely affected districts in West Bengal districts, where concentrations above 300µg/L have been found comprise of Malda, Bardhaman, Howrah, Hooghly, Kolkata, North 24 Parganas, South 24 Parganas, Nadia and Murshidabad. Of these the latter four are the worst affected, for which a screening for the research activities has been conducted. Criteria for the selection of the study area are:

- Non-existence of public piped water supply scheme and no near future plans for setting up a scheme
- Arsenic contamination of groundwater sources
- Remote location with poor infrastructure, still accessible from Kolkata in a one day journey
- Poor population with high ratio of people below poverty line or social minorities
- General interest of the population to improve water supply situation and contribute to the development of a solution
- Availability or scope for the development of a surface water source

While various arsenic mitigation activities have been taken up in North 24 Parganas and South 24 Parganas due to the proximity of the states' capital Kolkata, initiatives in Murshidabad and Nadia are rather sparse and existing attempts rather unsuccessful. Thus several village clusters were shortlisted and assessment visits conducted. The finally identified and selected village cluster for the pilot project is thus situated in one of the least economically developed blocks having the highest percentage of poisoned wells, unmanaged and unused surface water bodies and in near future no intervention regarding the setup of a water supply is planned according to the government master plan and interviews with PHED representatives at block and state level[36]. The village cluster Jyot Sujan and adjoining Malpara villages located in the Murshidabad district in the state West Bengal are finally selected for the project site [37]. More information on the area are given in chapters 0 and 6.2.1.2

# 2 OVERALL OBJECTIVE OF THE RESEARCH

Presented research activity aims at elaborating a viable solution for the provision of safe drinking water to communities not having access to safe water sources. This objective is being approached by setting up a real life full scale pilot scheme considering the specific local capacities regarding technical know-how, socio-economic background and ecological environment of the region.
The developed solution is thus based on the traditional, well accepted and environmentally sound way of using widely available surface water bodies on a community level. Local affected population, especially women and the poor, are involved in planning and implementation of the technological, logistical and financial management of the water resources and infrastructure, using a robust technology based on local available resources. This leads to sovereign decisions on the most appropriate model of water management. The research activity sets up capacity and infrastructure assuring safe drinking water and an integrated management of water sources (IWRM) which is needs driven. The IWRM approach involves all stakeholders and thus finds compromises for taking the most beneficial decisions for everyone by considering the widest possible range of aspects. The developed solution has the potential to be duplicated for many areas which have similar conditions regarding the environmental and socio-economic circumstances. In the specific case of arsenic affected areas, reintroduction of traditional surface water usage mitigates further poisoning of groundwater with arsenic, making it a sustainable long-term solution. This enables the continuation of existing smaller extractions of groundwater for drinking purposes as midterm solutions in exceptional cases. Minimisation of energy demand for the installations is approached with an energy efficient overall setup which goes hand in hand with the usage of renewable energy sources and thus contributes to Climate Change Mitigation.

## 2.1 RESEARCH QUESTIONS

Considering the results of the solution finding process for the provision of safe water the following overall question is being dealt with:
*How can a community based surface water treatment plant be planned, designed, setup, operated, maintained, monitored and optimised in order to be a sustainable solution for a rural community in West Bengal suffering from arsenic groundwater contamination?*
This question is to be answered on various levels regarding technical, socio-economic and environmental aspects as well as various extents comprising the entire project process of conceptualisation, planning, development, implementation and operation of the full scale pilot setup.
Concerning the technical implementation aspect the overall question relates to:

- *What is the extent and design of catchment area and size of pond reservoir required for harvesting sufficient water with suitable quality as a source for a drinking water treatment plant catering to 140 families or 14 KLD (700 people with 20LPCD)?*
- *How does a robust solar energy based surface water treatment plant have to be designed taking into consideration the assessed raw water quality and having the intention to provide safe water according to the Indian Drinking Water Quality Standard IS 10500?*
- *How can the treated water be distributed to the consumer ensuring its quality?*
- *How can the domestic wastewater be collected and treated so that it can be discharged into the environment without creating any pollution?*

While elaborating solutions for the entire water cycle from collecting rainwater as the water source for the supply system to the discharge into the environment, a special focus is laid on the water treatment process by multi-stage filtration. Although elaborated in the course of the study, it can already be foreclosed that the treatment process consists of Horizontal Roughing Filter (HRF), Slow Sand Filter (SSF) and Activated Carbon Filter (ACF). For these components optimisation efforts are worked out focussing on finding answers to the core operating figures of the treatment system:

- *What is the loading capacity of the filtration system and what does it depend on?*
- *How can the loading capacity be increased by process regulations?*
- *How can the scraping and cross flushing periods be extended in order to reduce the maintenance expenditures?*
- *Which flowrate achieves the highest overall removal efficiency?*
- *Which level of pre-treatment achieves the highest removal efficiency of the slow sand filter and what dimensioning optimisation in relation to pre-treatment and main treatment could be looked into?*
- *How does the dissolved oxygen level in the ecological treatment process influence the removal efficiency?*
- *How does the flowrate influence the dissolved oxygen level in the slow sand filtration process?*
- *Does the turbidity removal correlate with the bacteria removal?*
- *What other parameters of the treatment process could be optimised in order to achieve higher removal efficiencies of turbidity and bacteria removal, longer intervals between two scraping events (more loading), higher flowrates?*

While the technical viability is one prerequisite for the functioning of the system, the actual impacts of the solution rather aim at socio-economic aspects, thus answers to the following questions are elaborated:

- *How can it be ensured that all parts of the community, especially children, women and the poor benefit from the project?*
- *How can the benefits of the water supply system on the society, the community and the direct consumers be maximised and what components of the system and processes in their development are relevant in this regard?*
- *How can the system be designed so that costs, resources and skills that are required for the implementation as well as the operation and maintenance of the system components are reduced?*
- *How can the sense of ownership by the community be enhanced so that the willingness to contribute to the maintenance of the system is increased?*
- *What are sources for funding the operation and maintenance of the system?*

Overall sustainability has to look into the long-term assurance of the resources required for the system processes. Thus questions regarding environmental aspects are dealt with mainly looking into the protection of the water source, as well as minimisation of polluting impacts:

- *What are the pollutants (specifically pesticides, fertilizer, nutrients, open defecation) in the catchment area and how can they be minimized?*
- *How can the non-renewable resources for the construction of the system be minimized?*

- *How can the energy consumption and thus GHG emissions of system be minimized?*
- *How can the requirement of usage of chemicals be minimised or substituted?*
- *How can polluting effluent discharge of system be minimized in quality and quantity?*
- *How can water borne diseases be reduced in the supply area?*

Finally the developed solution named as an alternative technology has to compete with the currently existing, a conventional and an upcoming advanced solution; thus a comparison of the above mentioned aspects is being made with a selected well known system and an advanced system which has also been set up in the study area.

## 2.2 OUTPUTS AND EXPECTED RESULTS

The elaborated results focus on demand-driven solutions that meet the geo-hydrological preconditions and socio-economic circumstances. Solutions are technological feasible and based on the locally available resources. The approach aims at setting the frame for large scale implementation of this technology by designing and constructing one full scale pilot scheme and backing the whole process by analysis of the technical as well as social and economic aspects of the overall process. This study may serve as a guide for further replications. Apart from providing safe drinking water in a sustainable way, the expected results of the study project further cover the following aspects on a more general level:

### 2.2.1 INNOVATIVE TECHNOLOGY FOR WATER QUALITY CONTROL

The studied technology is especially suitable for remote areas which are not yet connected to piped water supply schemes and have not been connected to electricity. Special focus is thus laid on independence from existing infrastructure and fully locally maintainable solution. No compromise is made on the quality of the water. The elaborated surface water treatment process leads to impeccable drinking water quality. Safe water provision will be made accessible for every household covered in the project area by ensuring point of use water quality. Solutions are innovative in the smart combination of various well-proven technologies and processes. Ecological processes and cycles are made use of, thus requiring less external energy and resources. System processes are designed to be intuitive for the operator. The selection of consumables and spare parts is based on their local availability and affordability. For technological installations, a strong focus is laid on awareness and capacity development assuring the acceptance and operability of the system for sustainable long-term maintenance of the utilities.

### 2.2.2 POSITIVE SOCIAL, ECONOMIC AND HEALTH IMPACTS

By involving local skills and knowledge in the planning, construction and operation of the treatment plant and the water supply, positive implications will occur for the local economy. Small scale plants have the advantage of being operated by local staff and owned by the local communities, thus empowering them to take decisions on their own requirements. Increase of households' income is expected by decreasing the disability/disease-adjusted life years (DALYs) due to healthier status and less suffering from water borne diseases and thus more productive time availability. In addition to the safe water source, the overall increased awareness of the involved communities with regard to the importance of safe sources of potable water and water handling will contribute to a healthier life. Women will be strengthened and involved in the social, political and economic spheres through essential participation in all project activities. In all activities at least 33% quota for woman as well as 33% quota for low income group (BPL) and minorities will be taken care of, stimulating and enhancing the competency of the most affected population groups.

### 2.2.3 RESOURCE CONSERVATION, CLIMATE CHANGE ADAPTATION AND MITIGATION

Resource sensitive construction and selection of local materials contributes to emission reduction in comparison to imported readymade systems. Environmental quality of catchment area and water bodies is improved by catchment area management, improved sanitation and waste water collection and treatment. As the surface water usage interferes less with the groundwater aquifers, the impact on further poisoning of groundwater sources with arsenic will be reduced and a sustainable environmental sound water cycle reintroduced. Coping with the changed irregular rainfall pattern, which becomes less predictable, the enhanced management of the available water sources is a major step in adapting to climate change. The usage and maintenance of surface water bodies further leads to conserving and possibly even recharging the groundwater sources thus approaching climate change impacts like water scarcity and water quality deterioration. Usage of renewable energies for the operation of the equipment leads to emission reductions and thus climate change mitigation.

# 3 STUDY APPROACH AND RESEARCH METHODOLOGY

The basis for this thesis is applied research which depends on scientific knowledge and methods but focuses on the solution of a real life problem with its economic, social and political components [38]. Real life has not only to do with principles of nature but also with human will and motivation. Success of the research and achievement of the aim of sustainability thus depend on the momentum created with the stakeholders of the technological solution during the conduct of the study, as well as the correct application of scientific methodologies for the development and optimisation of the technological components. Following the chronological order of a real life project the scientific elaboration of the study is approached in a 3 phased manner. First phase is literature research and needs assessment. This is followed by design and implementation of treatment and supply scheme. The last but most important phase comprises of operation, evaluation and maintenance of the utility including the exit strategy of the research and project activities.

## 3.1 KNOWING STATE-OF-THE-ART TECHNOLOGY AND DEVELOPING COMMUNITY BASED ORGANISATION STRUCTURES

Setting up a surface water community based water supply scheme and the concept of involving the stakeholders is not new, and various projects and programmes exist. These are studied and conclusions drawn from the lessons learned by prior initiatives. Not all information, especially grassroots experiences, are well documented, thus field surveys and interviews are conducted to complement secondary information with first-hand information.

### 3.1.1 LITERATURE RESEARCH

The study builds upon the prior thesis dealing with arsenic groundwater contamination, its regional extent and health impacts, as well as the evaluation of existing mitigation approaches and the conceptualisation of possible alternative solutions[39], thus the literature research only needs to update these aspects. New research starts on standard literature for treatment technologies on conventional small scale surface water treatment plants and their design criteria. This is studied in order to be able to judge the suitability of alternative and advanced systems. Specific project documentations of alternative technological implementations are then studied, and an overview of design criteria for the specific treatment process is generated. Experiences of NGO programmes in participatory approaches and the conduct of needs assessment is further collected for development of site-specific tools and workshop methodologies. Technical literature is compiled on water quality monitoring equipment and procedures for field test kits and field laboratories, as well as online sensors. Research is conducted on their availability, installation options and modes of operation. Operation and Maintenance manuals for water supply schemes are compared and appropriate processes extracted. Evaluation approaches including technology verification, social and environmental life cycle assessment and cost benefit analysis are studied and methodologies suitable for the context of the study derived. Government programmes are screened for schemes which offer support in the form of technical advice and funds for operation and maintenance.

### 3.1.2 STAKEHOLDER AND NEEDS ASSESSMENT

In the IWRM process not only the direct beneficiaries but also the regional knowledge providers and decision makers as well as technology providers and implementers have their specific stakes. The participatory approach thus deals with the inclusion of local stakeholders, universities and consultants, governmental bodies, NGOs and companies at specific implementation periods. The most important task for the development of the project implementation mode is to assess the needs of each stakeholder and to address these during implementation. In-depth interviews with community representatives of the involved Gram Panchayats (village administration), Zilla-Parishads (district administration) as well as with the Public Health Engineering Department (PHED) are conducted.

#### 3.1.2.1 COOPERATION PARTNERS, ASSOCIATES AND ADVISORS

Universities, research organisations, companies and government institutions play important roles in acquiring information, knowledge and experiences for the development of the model pilot. Knowledge and technology providers to the study are the partners of the ECO-India project: The author working for the research organisation adelphi research manages the collaboration of the Indian and European scientists. He develops the concepts, designs, monitors and evaluates the water supply scheme, while supporting the School of Water Resource Engineering at Jadavpur University in Kolkata in the technical implementation. He receives advice from the Department of Water Quality Control of the Technical University Berlin on the technological design and its monitoring and optimization. Support is received from the SMEs Dryden Aqua and AGM, who provide equipment and sensors for monitoring the performance, while Super Technicians supports in the site installation. Denmark Technical University contributes with the elaboration of the feasibility of usage of waste water sludge for biogas production, while Tyndall National Institute from the University of Cork researches on advanced monitoring and water treatment equipment and coordinates all European partners.
Further advice is sought from School of Environmental Studies from Jadavpur University, being the first organisation to focus on arsenic contamination in West Bengal, the Arsenic Task Force at the PHED and All India Institute for Hygiene and Public Health as well as the local UNICEF office among others.

#### 3.1.2.2 FORMING OF A VILLAGE WATER AND SANITATION COMMITTEE

A village water and sanitation committee (VWSC) is appointed in cooperation with the Gram Panchayat (GP). The VWSC members consist of members of the GP, fifty per cent women and representatives of minorities and poorer sections of the village[40]. Further members and advisors in our specific case are owners of the pond, land and tube wells involved in the water scheme, farmers of the catchment area, school teachers, Self Help Groups (SHGs) and local/Rural Medical Practitioners (RMPs), as well as the ECO-India project partners as temporary members. The VWSC is organised in various working groups with specific responsibilities and tasks:

1. Documentation and taking of minutes of all meetings and decisions of VWSC
2. Assessment and information collection
3. Working out consents and approvals for the usage of land
4. Regular communication between local stakeholders and project team
5. Sample Collection / Water Quality monitoring
6. Working out VWSC budget, fee structure and collection of fees
7. Book keeping, opening and managing bank account
8. Catchment area protection, management and monitoring
9. Technical operators in charge of technical planning, implementation and maintenance

Three important posts are elected in addition: a president, a secretary and a treasurer. The president and communication group represents the VWSC and communicates with the governmental authorities like Gram Panchayats, Block Development Officer (BDO), medical officers attached to Block Primary Health Centres (PHCs), Public Health Engineering Department (PHED) at Block and District level. In this way the VWSC represents the interest of the users of the water supply and requests for the contributions of the government authorities.

#### 3.1.2.3 SURVEYS AND TRUST BUILDING ACTIVITIES

Literature findings and initial concepts are verified in interviews with stakeholders and advisers as well as in prolonged site visits on which assessment meetings and focus group discussions are conducted. Five basic aspects of the community are assessed: namely demography, geography, infrastructure, situation of water supply and community involvement in project activities. Transect walks lead to the development of a village map which is then further detailed using the Resource, infrastructure, demand and access (RIDA) analytical framework [41].
Awareness campaigns and needs assessments are jointly developed and conducted with the VWSC[37]. Methodologies applied are based on Participatory Rural Appraisal (PRA) tools, quantitative and qualitative questionnaires, workshops and field surveys. Past and current approaches to community based drinking water supply [42,43] are compared and analysed regarding their suitability for areas in West Bengal, India with arsenic contaminated groundwater aquifers [44] or areas similarly suffering from non-potable groundwater sources. Issues regarding water pollution [45], common global challenges related to policies, planning and coordination as well as financing and human capacities[46] have been considered while developing the assessment approach [47,48].
The specific regional circumstances of the project communities are assessed with surveys on demography, geography, infrastructure, situation of water supply and potential community involvement in the project activities [41,49].
During site visits a pilot needs assessment is conducted together with the VWSC, which then conducts the full scale needs assessment with 250 households. The prime needs related to provision of safe drinking water, improvement of sanitation facilities and hygienic awareness are quantified. Water demand for the community is assessed including water for drinking, cooking, cleaning, washing clothes, sanitation etc. Availability of supporting infrastructure, the quality and quantity of environmental services and its implication to the community’s living conditions and potential contribution from the community to support the realization of the project is further surveyed. Trust is generated in considering options of every household on the perceived problems and challenges as well as on solution approaches.

## 3.2 PLANNING AND DESIGN OF SUITABLE TECHNOLOGY

Peoples direct involvement in participatory needs assessment workshops, focussing on the recent requirements regarding water demand as well as technical and organisational setup for the implementation phase details out the prior collected information and shows up the roadmap for the upcoming project activities [50].

### 3.2.1 PARTICIPATORY PROJECT DEVELOPMENT

Existing plans which had been developed for the thesis concept and the project proposal are revised, updated and detailed out on the basis of the results of key informant interviews with representatives of the community in the envisaged project area. The pre-selection of the village cluster Jyot Sujan and Malpara is decided in agreement with the local Panchayat, block development officer, PHED engineers at block and state level and the partners of the ECO-India project. Final decision is then taken after conducting a pre-assessment [37] and local surveys in which the commitment of the local population is ensured.
The needs assessment is then conducted together with the VWSC group for quantitative information collection. Results are summarised in multi-criteria decision matrices which serve as an initial basis for the development of the draft design documents. Developed options are discussed with core stakeholders as well as all members of the VWSC during the initial phase of the project. All discussions and decisions of the VWSC are documented by the VWSC group for documentation and minute taking.
Joint planning workshops with the VWSC group for working out consents and approvals for land usage, land owners and local government authorities ensure that the setup of water schemes is in line with their interests and support in form of the pilot project is openly welcome. Agreements are finalised with the concerned owners, government bodies and the VWSC for the identified suitable locations for the setup of project constructions.
Upon having agreed on the specifications within the VWSC and with relevant stakeholders, a detailed project report is developed to detail out the technical specifications and construction drawings [51]. In parallel, a feasibility study compares the current situation with the planned intervention and a conventional and advanced setup. The feasibility study evaluates technical performance, socioeconomic and environmental impacts, costs and benefits and concludes with a Multi-criteria Analysis considering all prior elaborated results [52]. Prior to commencing with the actual construction activities at the site, the feasibility study results are discussed in the VWSC and the final decision for the technology option confirmed on the basis of the detailed project report.

### 3.2.2 EMPOWERMENT OF THE COMMUNITY

As a general approach of the capacity development the Training of Trainers (ToT) model is followed so that local multipliers can continuously keep up the competency level of the population and reach out to a larger population [53]. Awareness workshops for direct beneficiaries to facilitate involvement in all project steps are held in cooperation with the locally educated trainers. Topics, among others, include health care, organisation setup for water resource management on the community level and organisational development for the VWSC. In order to further support the VWSC, these are followed with specific planning, implementation, operation and maintenance as well as monitoring, evaluation and business management workshops. The technical groups of the VWSC are trained in their tasks. Treasurer and secretary together with the group for working out the VWSC budget, fee structure and collection of user fees, the group for book keeping and accounting of the VWSC are guided to conduct their tasks related to financial and organisational management, so that the scheme can later be run by the VWSC preferably autonomously. Each training and workshop is evaluated and the results incorporated in the development of the upcoming session [54].

## 3.3 REFLECTIONS DURING SETUP OF WATER SUPPLY AND MONITORING EQUIPMENT

The technical implementation is taken up in phases; each phase is monitored and evaluated in order to fine -tune the next phase. The first phase is setting up catchment area management and the water reservoir. Secondly the water treatment plant is constructed. Then, supply by distribution network, house connections and the entire holistic solution including sanitation, sewerage, waste water treatment and irrigation are looked into.

### 3.3.1 DEVELOPING IMPLEMENTATION PLANS

Together with the local VWSC members detailed action plans on the basis of the jointly defined objectives and aims are developed. The local VWSC members coordinate the future participation process of the population in the setup of the water supply. An agreement between the local (permanent) and the temporary (ECO-India project partners) VWSC members is made mentioning that the temporary members will support the installation and commissioning of the constructions but the permanent members have to organise the operation and maintenance in the long run (Appendix I). Further agreements are signed between owners of the land and pond on which the treatment plant is set up.

The Terms of Reference (TOR) for each of the individual tasks for the construction activities are jointly developed considering the local available capacities and possible external technical support requirements. Technical details for the tender documents are developed in cooperation with the partner universities. For the catchment area topography assessment SRTM data [55] is complemented with level pipe measurements and total station alignments and Qgis[a] is used for delineation and as a mapping software. Constructional calculations are partly done with STAAD.pro[b] whereas Draftsight[c], Autocad[d] and 3Dmax[e] are used for the technical drawings. Hydraulic calculations for the distribution network are made with EPAnet[f] and WaterGems[g].

Potential local contractors expressing interest in execution of tasks are invited by the VWSC and their views on the TORs considered. Tasks which can be taken up by local contractors are tendered directly by the local VWSC members. External technical support is sought by the temporary members from towns and cities as close as possible.

The tenders are evaluated considering technical and financial aspects. Given the limited project budget the financial aspect acts as a criterion for exclusion.

### 3.3.2 ORGANISING CONSTRUCTION WORKS

Construction work monitoring at a remote site is very challenging for a project team which has its offices in a distance of half a day travel. Especially external contractors taking up activities with which the local members of the VWSC are not familiar have to be monitored closely by the project team. For this purpose very frequent communication and proper understanding is necessary during the periods when project team members have office work lined up. A VWSC group specifically formed for regular communication between permanent and temporary members is set up, all technical drawings and plans are explained to the VWSC group members and formats for monitoring the appropriate construction are developed. Timelines and deliverables of each contractor are clarified according to the TORs and contract agreements. All contractors are to report to the VWSC representatives first and only secondly to the contracting project partner of the ECO-India project. For all materials local suppliers are organised and manual labour is sourced from the villages as much as possible.

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***a www.qgis.org***

***b www.bentley.com/en/products/product-line/structural-analysis-software/staadpro***

***c http://www.3ds.com/products-services/draftsight-cad-software/***

***d http://www.autodesk.de/products/autocad/overview***

***e http://www.autodesk.de/products/3ds-max/overview***

***f https://www.epa.gov/water-research/epanet***

***g www.bentley.com/en/products/product-line/hydraulics-and-hydrology-software/watergems***

The technical implementation follows the planning documents in a phased manner as developed jointly in participatory workshops headed by the water commission. Firstly improvement of the capacity and quality of existing surface water sources is looked into. The selected pond needs to be deepened, embankments heightened, the surrounding land of the water body marked and fenced. Secondly canal flows and surface water runoffs are to be adjusted so that maximum rainwater can be harvested and captured in the pond acting as a raw water reservoir. Thirdly the construction of treatment plant including required tanks, filtration units, pump house and laboratory as well as installations for the power supply is organised. Finally the construction of a supply network, stand posts and house connections as well as sanitation, canalisation and the waste water treatment plant is envisaged.

### 3.3.3 STRENTHENING CAPACITIES FOR OPERATION AND MAINTENANCE

Operation and Maintenance (O&M) is intended to be done by members VWSC. O&M is required at all stages of the scheme. It starts with the water source. For this the catchment area protection, management and monitoring group sets up the catchment area management plan and participates in the workshops with the catchment land users discussing on pollution prevention and agreements for restriction on activities in protection zones. In the future this group is in charge of providing high quality raw water. To ensure water quality of the treated water the group for sample collection and water quality monitoring participates in each monitoring activity during the study period and conducts all sampling and measurements after being trained in the processes.
The technical aspects at the treatment plant are to be looked into by the technical operator in charge of technical planning, implementation and maintenance. The three members are involved in the technical planning and implementation from the beginning of the project, they are also responsible for the O&M of the treatment plant and supply network in the further lifetime of the scheme. As most community water treatment projects fail at this point, it is especially important to ensure that enough capacities for the future O&M are developed. A multifold parallel approach is important here. The members of the VWSC could change, move away or just not be interested to take care of the plant at a later point of time, thus the knowledge and capacities are trained to further stakeholders and interested people from the local population. O&M procedures are documented in a manner which is easy to understand and absolutely clear. Labels on all valves, switches and equipment which are required for O&M are placed which make a remote communication more effective when discussing on a possible unforeseen condition which needs to be solved via telephone or internet messaging. Further possible involved institutions and departments are given guided explanatory tours through the treatment plant in order to also develop an understanding for the plants processes.

### 3.3.4 CONDUCT AND MEANS OF MONITORING

Prior to handing over the treatment plant to the permanent VWSC members it has to be ensured that the plant provides safe water on a reliable basis and under various conditions.
One year operation and monitoring period is attended in which organisational and technical operation of the overall water supply scheme is monitored continuously, all observations are documented and any problems or unforeseen events are followed up for solutions.
For a rainwater based scheme the performance has to be monitored at various treatment steps ranging from maintenance of the catchment area for the water resource to the final distribution of treated water. In order to ensure reliable performance, the entire treatment system has to be operated and maintained taking into account the treatment aim of each of the steps, and following its specific procedures.
Upon completion of construction and media filling of the HRF/SSF system, the system should run at the regular flowrate of around 5LPM for each line for at least two months, and the turbidity of the

individual steps should be monitored. After two months the biofilm layer should have developed and the turbidity values should have reached acceptable limits. Now the activated carbon can be filled, and after one week of running the system with ACF, the CWT and OHT can be cleaned for final water quality provision. Now the intensive monitoring period for the filter unit can start. The WQ monitoring program consists of various means of monitoring: online monitoring, testing with field test kits and laboratory tests. The parameters selected for the performance monitoring programme mainly consist of turbidity, bacteria, free available chlorine, DO and temperature. Additional parameters are selected for monitoring nutrients (Nitrate, Phosphate) as well as other basic water parameters like pH and TDS (compare 6.5). Specific test runs are conducted for optimisation purposes varying flowrate and chlorine dosage and for the comparison of gravel and stone chips.
As a result of the monitoring period the critical parameters are identified which have to be monitored for ensuring safe water production. If a parameter exceeds 80% of desirable limit of the IS10500[25] the parameter will be taken up in the list of critical parameters and monitored regularly for this sample spot.

## 3.4 DISCUSSING AND EVALUATING RESULTS, ELABORATING OPTIMIZATIONS AND CONCLUDING ON SUSTAINABILITY

The finally elaborated project results are evaluated considering the three expected outputs and results set in the objectives of the study [56]:

1. Innovative technology for water quality control: Technological evaluation compromises mainly of hydrological observations and water sampling of the treatment stages and their analysis. Innovative optimization for the technology is derived with modifications in its design and fine tuning of its processes.
2. Positive social, economic and health impacts: The socio-economic impacts are assessed with the help of a modified socio-economic and environmental life cycle assessment (SELCA). In addition a cost benefit analysis (CBA) indicates the investment and O&M expenses as well as the micro- and macro-economic benefits.
3. Resource conservation, climate change adaptation and mitigation: Environmental aspects are covered in the SELCA.

Although all three aspects are looked into, the focus of the study lies on the technological performance evaluation and conclusion on process optimisations for the developed alternative technology. Nevertheless the actual aim of the technology is to cater to positive socio-economic and environmental impacts in the most effective way which makes it innovative. For this purpose the elaborated solution is compared to existing current solution, a conventional solution and an advanced solution. The comparison of the sustainability of these technologies are summarised in a Multi Criteria Matrix (MCA) and weighted with the views of various stakeholders. While SELCA and CBA are applied to all the solution options, the in-depth technical treatment performance evaluation is only conducted for the alternative solution.

### 3.4.1 TECHNICAL TREATMENT PERFORMANCE AND ITS OPTIMIZATION

Online and offline monitoring data is analysed and dependencies between process variations, input parameters and achieved results elaborated. Water resource management is evaluated by the constant quantification of the availability of the water source and monitoring of maintenance of the catchment management regime. Water quality and quantity is observed at various treatment steps according to the monitoring programme (chapter 3.3.4). Treated water is compared to the IS10500. Supplementary WHO standards are used for additional parameters [57]. Specific plant operating characteristics are worked out to make it comparable with existing solutions. These comprise of loading patterns of the SSFs and their impacts on water quality, removal efficiencies and filtration velocity. Operation characteristics are also concluded for the scraping intervals and following process diversion periods. Optimisations are worked out for pre-treatment process considering achieved water quality, removal efficiency, cross-flushing intervals and diversion time. Bacteria removal optimisation is derived from the dependency of water quality, removal efficiency and FAC level. Optimal flowrate is elaborated in regards to water quality and removal efficiency. The impact of aeration during the filtration process is analysed for water quality, removal efficiency and flowrate. The analyses are made by spread sheet calculations and graphs with the help of Excel. Integration, interpolation, identification of fitting curves and plotting is done with Matlab[h]. In some observations interpolated fitting curves are included to show up correlation tendencies. The interpolation method used is decided on the best fit, sometimes linear, sometime polynomial. These fits and interpolations in most cases have very low grades of determination and should only provide an idea of approximate tendencies, thus formula and coefficient of determination are not given. As many of the observations are multi-parameter dependent, strong fluctuations in 2 dimensional relations are very common. The approach followed here thus does not comply with strict statistical data evaluation but rather with a pragmatic explanation of real field data from a full scale pilot which is set up with the aim of providing safe drinking water and only secondly with the aim of conducting research experiments.

### 3.4.2 SOCIO-ECONOMIC AND ENVIRONMENTAL LIFE CYCLE ASSESSMENT (SELCA)

Life Cycle Assessment (LCA) is a modelling method for assessing impacts of products or services, and their sustainability. It originally focused on mitigating environmental pollution and their impacts and has also been applied to water treatment plants [58–62]. This study assesses both environmental as well as socio-economic impacts in an integrated approach and along the entire life cycle of the water purification and supply system, from construction (“cradle”) over operation to disposal (“grave”). In addition to the life cycle of the treatment plant the life cycle of the water is also considered, thus the process from the extraction of water from the environment, treatment and usage of water and the discharge of water back to the environment is looked into.
LCAs have different applications and on this basis make use of different methodologies. For the purpose of this study, a simplified methodology is compiled. It is based on the concept of the Environmental (E-) LCA (ISO 14040) and of a Social (S-) LCA developed by UNEP [63]. Accordingly the SELCA complements the E-LCA by an assessment of the sustainability of goods and services by including social and socio-economic pillars in addition to the environmental aspects. The SELCA is conducted in setting the goal and scoping, conducting an inventory analysis followed by assessing and interpreting their impacts [64].

### 3.4.3 COST BENEFIT ANALYSIS (CBA)

The Cost Benefit Analysis (CBA) is used to recommend the most appropriate solution in terms of profitability. In the process of a CBA, all expected costs and benefits are calculated and compared. In this way, it can support in decision making on the economically most viable option [65]. In this study, the CBA consists of the following steps:

1. Define the objective of the solution and the considered alternatives.
2. Establish a baseline to assess to what extent the previously defined objectives are achieved
3. Quantify and aggregate the costs and benefits over specific time periods
4. Compare the aggregated costs and benefits
5. Calculate the Benefit-Cost Ratio

***h www.mathworks.com/products/matlab***

The CBA is conducted on two levels (Table 1): The micro-economic analysis considers items that reflect direct costs or revenues ("internal") to the owner of the system. Those items that create a monetary benefit to the consumer or community – yet not necessarily to the system owner – are viewed as "external" costs or benefits. This macro-economic analyses allows for providing a broader perspective on both positive and negative impacts that are often excluded when only considering the usual private investment oriented micro-economic analysis.

***Table 1 Definition of Micro and Macro-Analysis***

| Level of Effects | Costs | Benefits | Type of CBA |
|---|---|---|---|
| Internal, private | Expenses occurring to the operator to provide the service of potable water | Revenues that can directly be collected by the operator for the provision of the service | Micro-Economic Analysis |
| External, public | Externalities that are caused to a third party during operation of the treatment plant (also social costs) | Benefits that accrue to the consumers, the village community or society due to provision of potable water | Macro-Economic Analysis |

The methodology of monetisation of costs and benefits and calculation of water price is given in the Appendix S.

### 3.4.4 SUSTAINABILITY CRITERIA AND SCOPE OF CONCLUSIONS

Based on the development objectives of the study, the overall sustainability of the pilot plant concept is assessed in comparison to the current existing situation, a conventional setup and an advanced solution described in the literature research (chapter 4). Criteria for the MCA to assess the sustainability of the technical solutions consist of the prior analysed aspects of technical performance, socio-economic and environmental impacts and financial viability and are comprised to the following points:

1. Water Quality compliance with permissible and acceptable limits of IS105000
2. Reliability of working status and provision of safe water
3. Availability of construction and installation material
4. Labour efforts for the setup of the plant
5. Energy and consumable requirements for operation
6. Skills and qualification requirements for operators
7. Level of socio-economic impacts
8. Level of environmental impacts
9. Adequacy of water price for O&M
10. Adequacy of water price for investment and O&M
11. Private Benefit to Cost Ratio
12. Public Benefit to Cost Ratio

The evaluation matrix consisting of options and criteria is then analysed by weighted summation [66]. The criteria are given a rating between 1 and 10 which is translated from achievement of the objective in percentage of the best option wherever feasible. Conclusions are drawn by weightage of these criteria in the view of stakeholder groups comprising of public society, government, community, consumers, private operator and private investor. Each criterion is weighted between 1 to 3 whereby a total of 20 weightage points are distributed [67].

The derivation of the scores for alternative setup and advanced setup is detailed out and based on actual measurements and experiences in the field, for which more data is available for the alternative system. Comparisons with the current system are drawn from survey information collected during the baseline assessment whereas the basis of data for the conventional system is concluded from the literature survey.

### 3.4.5 EXIT STRATEGY

After the conduct of the study the community should be in a situation of having a safe and reliable water supply which their own VWSC is able to operate and maintain. This should be the case if all sustainability criteria are met. Technical, financial and organisational capacities have to be in place. Procedures for achieving these are documented and available to the local members of the VWSC.
As further support and hand holding will still be needed, promotion events are organised for raising awareness with potential supporting institutions and for ensuring their support. The activities are especially focussed on the Panchayat, PHED, BDO as well as NGOs. Agreements with the Gram Panchayat are made to source O&M funds.
Further dissemination for up-scaling and replication of the solution is aimed at. Publications are prepared and conference presentations given in order to reach out to potential partners for the further implementation and up scaling of the pilot initiatives. This thesis is one of the efforts in this direction.

### 3.4.6 ASSUMPTIONS AND RISK MITIGATION

All necessary assumptions for a successful study project progress have been assessed prior to the formulation and submission of the thesis exposé [68]. Of course, risks still remain and assumptions have to be made and risk mitigation approaches developed. The sustainability and future usage of the results produced by the applied research activities during the elaboration of the thesis is envisaged on various levels.
The overall success for the sustainability of the project depends on meeting the actual needs of the local population and creating awareness, capacities and willingness for taking up the operation and maintenance of their water supply scheme. This is aimed at with the in-depth needs assessment and initial involvement of representatives of the local communities in the formulation of the project activities, thus creating a project ownership from the beginning. The agreement of community representatives towards participating in capacity development, forming of VWSC and agreeing to proposed PPP models addresses related risks. Still human behaviour can never be predicted with 100% certainty.
Technologically the selected treatment systems are generally robust and reliable, whereby their long-term performance in their combination and application in the specific circumstances is to be elaborated and will be one of the outcomes of the study. The successful setup of the technology depends on assessment of reliable information, regarding water resources, water and infrastructure demand as well as availability of resources and capacities, in this regard all data collected for the elaboration of the study proposal is to be verified through in-depth field studies.
Legal risks might be related to the usage of water bodies or compliance with building codes, possible accidents or health impacts due to malfunctioning of the treatment system or distribution scheme. Thus the legal requirements for access to the water resources and construction of the infrastructure are to be ensured.
Unfavourable political agitation is not assumed, government support is likely as project activities are in-line with the Millennium Development Goals in terms of reducing poverty and hunger, empowering women, improving health, ensuring environmental sustainability and developing international partnerships. Water conservation and increase of water efficiency is in-line with India's

National Water Mission. Mainstreaming the PHED master plan for arsenic mitigation makes backing by the state government possible.

Unforeseen risks for the study have occurred with funding and cooperation on the project level. While funds for approved project activities were disbursed in an asymmetric manner by the collaborating institutions and partly delayed and not disbursed till the end of the project period by the Department for Science of Technology of Government of India, only parts of the implementation activities could be taken up. Further partners in the project did not produce deliverables and even left the consortia. These issues led to delays in project implementation and less qualitative solutions due to unpredictable planning periods and urgent sourcing of equipment on the other hand when funds became available.

The main risks remain with the post project funding for the operation and maintenance of the water supply scheme. Although consumables and spare parts are locally available and comparatively inexpensive, labour salaries for O&M activities still need to be paid. The initial willingness to pay study has shown that not even one fourth of the required O&M expenses can be sourced by user fees, thus the scheme depends to a large degree on public funding or marketing. While both options are being followed and agreements with a private water distributer as well as the Panchayat for the sourcing of government funds are made, only the future development will show how dependable these agreements are.

# 4 COMMUNITY BASED SURFACE WATER TREATMENT SYSTEMS

When conducting research on the field situation related to public water supply in Indian rural areas, results can be called sad. In many places the government has set up piped water supplies, but the infrastructure is not maintained, taps are broken off and precious treated drinking water is just flowing into a puddle next to the stand post. Up to 40-70% of the water produced and supplied in India is lost unused due to leakage [69].

A possible explanation is that these centrally organised schemes do not create a sense of ownership in the population and thus there is no respect for the infrastructure; contrarily the demand and expectations are pointed towards the government which is perceived to be responsible for providing regular maintenance and guarantee uninterrupted supply of drinking water [70].

On the other side many households take own initiative and install a domestic water filter in their house in order to at least have safe drinking water at their own place. Many development cooperation projects have focussed on this opportunity and developed ecological filters based on slow sand filtration [71]. However, these numerous domestic filters are difficult to monitor as many individual samples have to be taken and it can thus not be ensured that these provide safe drinking water for everyone, as users might not operate and maintain them as per their requirements.

As a compromise between these two solutions - the one being a central large scale approach and the other one an individual approach - a community based solution could come up with the benefit of both sides, able to guarantee a safe water quality and mobilising stakeholder initiative in taking care of one’s own fate.

Various development cooperation projects have tried the community-based approach more or less successfully. Since the 70s the focus lay on participatory approaches. The Dutch IRC (Water and Sanitation) [72], or the SWISS EAWAG SANDEC (Water & Sanitation in Developing Countries) [73] published documentations on experiences with community-based approaches stressing both the technical as well as the socioeconomic aspects. Especially the latter aspects were given more importance when judging on the sustainability of the project. [74].

Regarding the technological approach, the most suitable solution depends on many factors, among which the size of the community, geohydrological conditions, existing infrastructure incl. availability, access and quality of surface water sources and financial and technical capacities of the community.

In the following some selected technological solutions are being described with the aim of meeting the above mentioned criteria. The solutions are grouped into 3 categories which will later also be compared in a sustainability evaluation:

- conventional systems, which are currently mostly being installed in India
- alternative approaches, which have been developed in the last decades by various development cooperation initiatives, of which one approach is being elaborated in this theses and setup at the project site
- advanced systems, which are currently commercially offered by innovative companies, of which one option is also set up at the project site

## 4.1 CONVENTIONAL SYSTEMS

In many rural areas in India bigger surface water treatment plants on conventional basis are setup and working well. Treated water quality complies with the standards and O&M procedures are well developed. The plants are often maintained by the skilled professionals from PHED. While the treatment works fine, issues are often faced with the current distribution mode and only rarely can the quality of water reach the consumer. This is mainly due to the poorly maintained distribution network and the intermittent supply which causes recontamination. This limitation of large scale distribution network could be overcome with smaller decentralized plants with the same technology. The main technologies applied in India for the treatment of surface water and described by the Central Public Health and Environmental Engineering Organisation (CPHEEO) are based on Slow Sand Filtration (SSF) and Rapid Sand Filtration (RSF), apart from direct chlorination and distribution [75].

### 4.1.1 RAPID SAND FILTRATION (RSF)

Nowadays RSF is the most common treatment method for surface water sources and referred to as conventional treatment. In comparison to SSF, the main advantage in the RSF technology is the reduction of required space as the filtration media is more porous and therefore water can pass with a filtration rate about 10 to 30 times higher than through SSF filter beds. To achieve removal of smaller particles a coagulant is dosed to the raw water which is rapidly mixed and then slowly stirred so that flocs form which can be mechanically filtered by the coarse sand (Figure 3). This process typically removes 30-70% of viruses, 30-90% of bacteria and 30-90% protozoa; thus disinfection is needed prior to supply. The removal efficiency depends on various factors including the coagulant dosage and type, the temperature but also water quality parameters such as alkalinity, pH as well as turbidity [76].

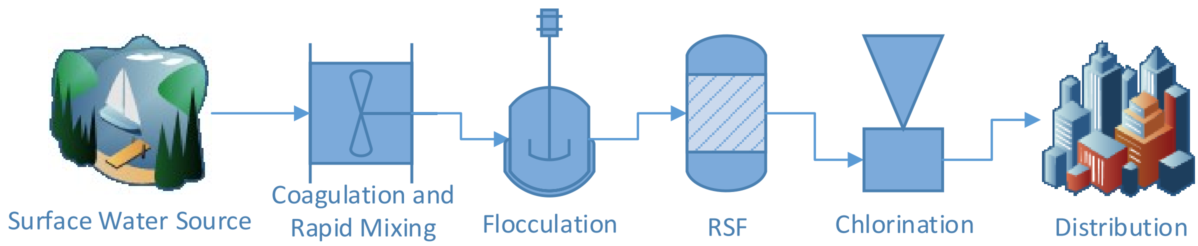


*Figure 3 Simple RSF process*

Depending on the quality of the inlet water further pre-treatment steps are added to remove dissolved solids, e.g. iron and manganese through oxidation with pre-chlorination and aeration. In order to decrease the load on the RSF, a sedimentation step can be included to separate the settling flocs generated in the flocculation process (Figure 4).

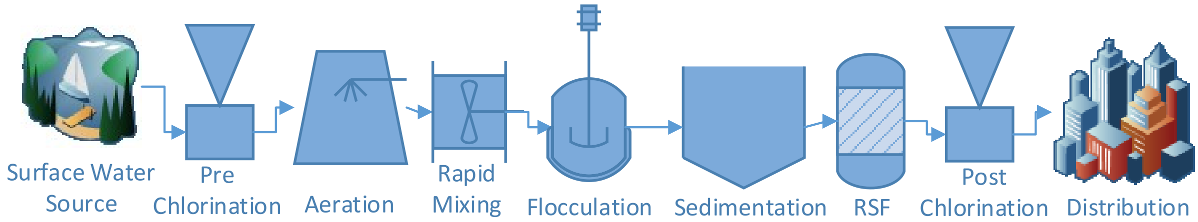


*Figure 4 Extended RSF process with oxidation and sedimentation*

Although the filtration step is usually gravity driven, the filter has to be backwashed frequently with high velocities and possibly with air scouring which requires energy. The O&M procedures for RSF are more complex as compared to SSF and require skilled operators as well as chemicals and energy, which make their application in remote rural areas challenging. Nonetheless, various attempts have recently been made to introduce this technology in rural communities in the project area:

### 4.1.2 EXAMPLE: SISSO RSF PLANTS IN MURSHIDABAD AND NORTH 24 PARGANAS

Small scale surface water treatment plants based on ponds or rivers as water source have been set up in West Bengal in the last years (2014-2015) by Sulabh Social Service Organisation (SISSO) together with various local NGOs. In Madhusudankati SISSO setup a treatment plant with assistance of the French NGO 1001 Fontaines which is now managed by the local village cooperative Madhusudankati Samabay Krishi Unnayan Samity [77]. The treatment is based on sedimentation in the pond, followed by coagulation and pre-chlorination which is facilitated by a motor in an elevated tank with first rapid mixing, then slow mixing and sedimentation. The pre-treated water is then passed through a RSF[i]. The RSF is followed by three micro cartridge filters of 10, 5 and 1 micron and finally disinfected with a UV lamp. On a site visit in February 2016 the plant was observed to be running in good condition. Water is being sold at 10 INR per sealed 20L jar and according to SISSO staff and the cooperative the demand for water for is higher than the plant can serve [78]. Having a capacity of 8000LPD thus 400 jars are sold daily (compare pictures of the treatment plant in the appendix E).
A similar plant has been setup near to the pilot site in Murshidabad town on the banks of the river Bhagirati. This plant sources its water from the river. The treatment process is the same. According to SISSO staff this plant currently cannot sell sufficient water and did not reach break-even point. The staff working in the plants is appointed by SISSO and receives regular salary, thus the functioning of the plant is not hampered by its economic losses. The staff is well trained to manage the treatment process which is monitored throughout the day. The treatment is conducted in batches: first lifting the water then mixing the alum and bleaching powder and waiting for a couple of hours for the flocs to settle, then filtration is started and takes a couple of hours to fill the clear water tank. Finally the water is filled into the jars manually and sealed with a heat gun. Water is partly collected and partly being delivered to the houses. Customers pay a deposit for the jar the first time they receive water and exchange an empty jar for a full one from then on, only having to pay for the content [78].
Although the conventional system of chemical coagulation and RSF can work with trained staff which is backed by an organisation which provides support in sourcing chemicals and other spare parts, it is

***i It is labelled SSF but according to the filtration rate of around 2 m/hr it falls out of the category of SSF, the pretreatment with coagulation also indicate that the process is rather a typical RSF process than a SSF process***

generally a big risk to implement this technology in a remote rural setting and leave it to a community which might not be able to source chemicals, apply correct dosing and follow the operation and maintenance procedures [73]. Thus alternatives are looked into:

## 4.2 ALTERNATIVE MULTI STAGE FILTRATION SYSTEMS WITH ROUGHING FILTERS

There is no specific literature term which refers to alternative systems. When referring to alternative systems in contrast to conventional or advanced systems, a special focus is given to systems which meet the following criteria:

- Technology is simple and robust, so that it can be manufactured, operated and maintained locally by unskilled[j] community members
- Based on natural treatment processes thus low in energy and chemical demand
- Environmental friendly by using local and regenerative resources

Basically all the presented alternative systems build upon SSF as a main treatment step.

### 4.2.1 SLOW SAND FILTRATION (SSF)

Slow filtration through sand for water supplies is technically documented to be applied since the beginning of the 19th century, first in Scotland, then London and Paris and other countries in Europe, Japan and Asia [79]. The general process has probably been applied since several thousand years. First water treatment plant based on SSF in Kolkata supplied safe drinking water by 1870 [80]. Nowadays still many drinking water treatment plants around the world apply SSF and produce good quality water.
The process of a SSF is straightforward: influent water passes through the sand bed by gravity with a filtration rate of 0.1 to 0.2 m/hr. The fine sand with a diameter around 0.2mm and low uniformity coefficient clogs after 1 to 3 months and is cleaned by scraping of the top layer. No pumping energy is required for the treatment process, except for a feeding head. Basic design characteristics for SSF are the filtration rate or speed, the grain size diameter and its Uniformity Coefficient, as well as the dimensions of the sand bed and gravel support. Useful manuals for the construction of small scale SSF have been develop by the Water and Sanitation for Health Project [81], by the International Reference Centre for Community Water Supply and Sanitation [72], the American Water Works Association[82], Water & Sanitation in Developing Countries (SANDEC) [73] as well as the Indian Central Public Health & Engineering Organisation [75,76], whereas further general water treatment literature have short design guides (compare chapter 6.3, Table 11).

#### 4.2.1.1 TREATMENT PERFORMANCE

The mechanism of SSF was firstly believed to only strain impurities mechanically. Several processes remove the suspended particles in a combination of mechanical straining, sedimentation, adhesion due to inertial and centrifugal forces, diffusion, as well as mass, electrostatic and electro kinetic attraction.
Only decades later it was understood that a thin layer on the sand made up of algae, plankton, diatoms, protozoa, rotifers and bacteria (“Schmutzdecke”) was responsible for the main treatment step and capable of removing organics, nutrients and pathogens by biodegradation and transforming them into minerals which deposited on the filter bed. Depending on the temperature, nematodes and protozoa living in the biofilm graze on intestinal bacteria. Algae produce toxins which reduce chances for bacteria to survive [79,83]. Compared to RSF (80-90%), SSF are more efficient in overall pathogens removal (98-99%), thus lower chlorine doses need to be applied to disinfect the water prior to distribution [84].

***j With some basic training***

In some cases, when the influent water quality is high and has little pathogen contamination SSF can also be considered as the only unique treatment step, and is considered to disinfect the water as it can remove bacteria, virus and protozoa up to 4 logs. Many other water quality parameters are also reported to be removed efficiently (compare Table 2).

*Table 2 Water contaminants removal performance of SSFs*

| Parameter | Unit | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| Turbidity removal | % | | | | | high | | 76 | |
| Treated Water Turbidity | NTU | | <1 | | < 1 | | <1 | | <1 |
| True Colour | % | | 30-100 | 25 | | | 25-30 | 46 | 25-40 |
| Pathogens in general | log | 3 - 4 | | 2 - 4 | | high | | | |
| Enteric bacteria (e.g. E. coli) | log | 2 - 3 | | 2 - 4 | 1 - 3 | | 1 - 3 | | 1 - 3 |
| Enteric viruses | log | | | | 2 - 4 | | 2 - 4 | | 2 - 4 |
| Giardia Cysts | log | | | 2 - 4 | 2 - 4 | | | | |
| Cryptosporidium Oocysts | log | | | | > 4 | | | | |
| Total Organic Carbon (TOC) | % | | | 25 | | low | | 32 | |
| Dissolved Organic Carbon (DOC) | % | | | | < 50 | | | | 5 -40 |
| Assimilable Organic Carbon (AOC) | % | | | | | | | | 14-40 |
| Chemical Oxygen Demand (COD) | % | | 60-75 | | | | | | 46-75 |
| Biochemical Oxygen Demand (BOD) | % | | | | | | | | 46-75 |
| Zn, Cu, Cd, Pb | % | | 30-95 | | 95-99 | | | | |
| Fe | % | | high | | > 67 | mid | 30-90 | | 30-90 |
| Mn | % | | high | | > 67 | mid | 30-90 | | 30-90 |
| Pesticides | % | | | | | | | | 0-100 |
| Zoospores | % | | | | | | | | > 99 |
| Nitrate | % | | | | | | | | 95 |
| Arsenic | % | | | | < 47 | mid | | | |

| LEGEND for the columns<br>Source | Description |
|---|---|
| A - WHO - Slow Sand Filtration [79] | General findings of the author based on literature research. |
| B - IRC - Slow Sand Filtration for Community Supply [72] | Based on literature research [85] |
| C - AWWA - Manual of Design for Slow Sand Filtration [82] | Based on various sources for Giardia lamblia cysts and coliform bacteria[86,87] , for viruses[88] and for bacteria phages[89] |
| D - WVU - Tech Brief SSF [90] | Based on publication [91] |
| E - WHO - Linking Tech and O&M [92] | 200 litre steel barrels (0.45cm diameter) connected by hoses; 45-60cm filter bed and 5cm layer of fine gravel; $V_f$ 0.1m/hour |
| F - IRC - Facilitating Community Water Supply [74] | Based on "Conventional SSF units"[93] |
| G - Case Study [94] | Case Study Cikapungdung, Indonesia |
| H WST - Biol. Aspects of SSF [95] | Based on publication [96] |

SSF has the limitation to be operational only with low inlet turbidity levels as the filter would else clog quickly, requiring frequent cleaning. In case of a surface water source having turbidity levels

above 10NTU pre-treatment steps are required. The conventional setup of a SSF treatment plant thus consists of a spacious sedimentation tank which reduces the input turbidity of the raw water, followed by the SSF.
In most cases the SSF does not remove all pathogens completely, thus a final disinfection step is applied usually with chlorination in order to have a residual disinfection capacity in the distribution network (Figure 5). Other than post disinfection the process usually does not require any chemical dosing.

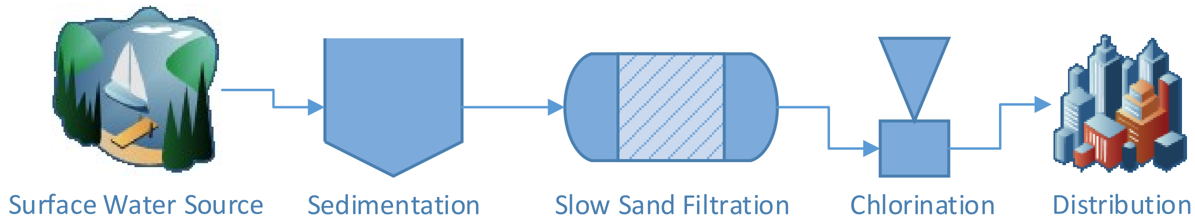


***Figure 5 Conventional Slow Sand Filtration Process***

A further limitation for the application of SSF is that it has slow flowrates requiring large filtration areas, approx. 20 to 40m² per MLD, making plants for bigger supplies huge. This is one main reason for SSFs being gradually exchanged with other treatment options such as RSF in urban areas with space limitations. For rural areas with available space the technology is still the safest and most economical way of drinking water treatment, as the construction and operation is simple and maintenance costs are low.
In the last decades several development cooperation projects have been initiated to support the setup of SSF in rural communities. One such project was the SSF project:

#### 4.2.1.2 EXAMPLE: SSF DEVELOPMENT COOPERATION PROJECT

The so-called SSF project looked into setting up community-based treatment plants based on slow sand filtration between 1975 to 1986. It was implemented by the International Reference Centre for Community Water Supply and Sanitation (IRC) funded by the Dutch government in cooperation with local institution in 6 partner countries. The project based its ideas on the development of "new" low cost technologies together with NGOs after technology driven agency projects which had imported equipment from the industrialised countries failed in the prior decades.
The SSF project started in Colombia, India, Jamaica, Kenya, Sudan and Thailand, where pilot plants in rural communities were built, information events on SSF treatment were held and academic exchange took place. Design documents and manuals were developed focussing on participatory approaches and simple construction plans which could be implemented by field staff together with communities [72].
When evaluating the pilots it was found that many plants had challenges in their maintenance. Technical problems occurred as the conventional pre-treatment with sedimentation could not cope with the high turbidity levels. In 1987 the evaluation of the projects suggested to focus more on suitable pre-treatment technologies. A second stage of the project limited to India and Colombia started to focus more on the pre-treatment steps, various pilots with different pre-treatment technologies were looked into [74].

## 4.2.2 ROUGHING FILTERS

The capacity of SSFs to improve water quality is limited by the quality of the incoming water. Even though SSFs have been observed to cope with 30 – 50 NTUs [82], it is suggested that SSFs perform best at inflowing water quality below 10 NTU. This is also due to the fine filter media which gets quickly clogged by suspended particles. Filters with coarser-grained filter media are called roughing filters. If inflowing water quality is very poor, a roughing filter can be interposed as a pre-treatment step in order not to overstrain the treatment capacity of SSF [97,98]. The combination of HRFs with SSF is also referred to as multi-stage filtration (MSF) which can even be more competitive compared to RSF [99] . Typically, roughing filter contain granular material with a diameter of 4 to 25 mm. Inflowing water is treated through a combination of adsorption, sedimentation and biochemical reactions such as oxidation as contaminants attach to the surface of filter material. As a result, organic and dissolved matter is converted into water, carbon dioxide and inorganic salts while turbidity is lowered and metals such as iron and manganese precipitate [73].

### 4.2.2.1 TREATMENT PERFORMANCE

***Table 3 HRF typical removal efficiencies of various treatment plants***

| Parameters | Unit | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Treated Water Turbidity | NTU | 5-20 | | 5-50 | <5-15 | <5 | 5-50 | <50 |
| Absolut Turbidity removal | Δ NTU | < 500 | | 35-450 | <285 | <25 | 35-350 | 255 |
| Relative Turbidity removal | % | < 98 | 85-95 | 87-90 | 80-95 | 66-80 | 90 | 84 |
| Bacteria Reduction E.coli | log | | > 0.3 | 0.4 - 2 | ~1 | ~0.4 | 1 | |

| LEGEND for the columns<br>Source | Description |
|---|---|
| A - IRC - Slow Sand Filtration for Community Supply [72] | Based on from HRF in Fau, Sudan[100] |
| B - AWWA - Manual of Design for Slow Sand Filtration [82] | Based on average values for various HRF[100] |
| C - SANDEC Roughing Filter Manual[73] | General findings for various HRFs |
| D - Evaluation of MSF [101] | 103 KLD 3 stage L=6m, 38-25mm(3m), 25-13mm(2m),13-6mm(1m), $v_F$ = 0.3-0.5m/hr, T = 0-25°C (Peru), based on Pardon 1989 |
| E - Evaluation of MSF [101] | 50 KLD 4 stage L=5m, 38-25mm(2m),25-19mm(1m), 19-13mm(1m), 13-6mm(1m), $v_F$ = 0.5-0.9m/hr, T = 10-25°C (Peru).based on Pardon 1989 |
| F - Evaluation of MSF [101] | L = 4.4 m, 50 - 25 mm(2.7m), 20 - 15 mm(85cm), 10 - 5 mm (85cm); $v_F$= 0.3 m/hr |
| G - Performance of MSF [99] | Based on HRF: L = 1.87 m, 15mm (75 cm), 10mm (75cm) and 5mm (37 cm)[102,103] |

Main selection criteria for the type of roughing filter is the average turbidity level. Horizontal Roughing Filters (HRF) can deal with the highest turbidity levels followed by the upflow roughing filter in series, while the upflow roughing filter in layers can deal with least turbidity loads. The HRF thus stays in the focus of this study, being the most robust and suitable pre-treatment device for a region with strong monsoon rains which lead to rapidly changing raw water turbidity. HRFs have been observed to cope with peak turbidities of 500 or even 1,000 NTU [73]. According to various authors, HRFs have turbidity removal efficiencies of around 66 to 98% while guaranteeing a treated water quality lower than 50NTU and mostly keeping it up to 5 NTU. They further reduce bacteria loads of E.coli between 0.3 and 1 log (compare Table 3).

#### 4.2.2.2 EXAMPLE: SANDEC ROUGHING FILTER DEVELOPMENT COOPERATION PROJECTS

Around 1980 several initiatives in which SANDEC EAWAG from Switzerland was involved evaluated the functioning of SSFs in rural areas in countries like Brazil, Cameroon and India and developed solutions to address technical problems. The efforts especially focussed on the development, evaluation and documentation of roughing filters for pre-treatment of the raw water in order to enhance the performance of the SSF (Figure 6).

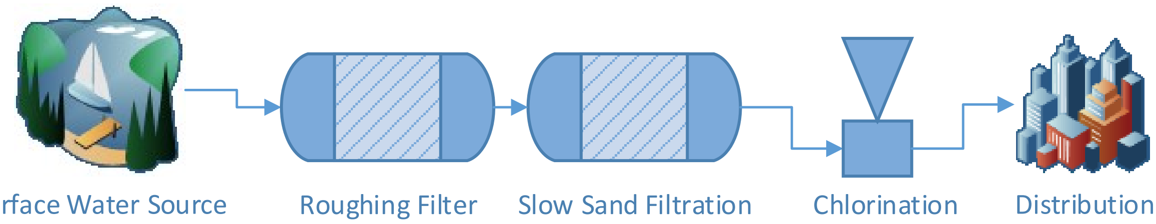


*Figure 6 Setup of MSF plant including roughing filter as pre-treatment for SSF*

First Manuals developed by 1986 elaborated designs for Horizontal Roughing Filters, mostly consisting of 3 chambers with decreasing size of filter media which the raw water travelled through from coarse to fine material. Design criteria depended on the required flowrate, the maximum suspended solid concentration in input water and desired output quality as well as filter runtime prior to washing and the possible allowable head loss. As filter material gravel, broken stones or rocks from a quarry, broken burnt clay bricks, plastic materials, burnt charcoal and coconut fibre were considered, whereby the latter two had limitation due to their biodegradation. Recommended filtration rates depend on the input water quality and range from 0.5m/hr for suspended solid (SS) concentrations above 300mg/l to 1.5m/hr for SS below 100mg/l [100]. Operation experiences in the upcoming years in India, Peru, Colombia, China and Sudan led to the publishing of an updated manual. HRF design criteria only changed slightly, reducing the required size of the filter tanks and the recommended filtration rate (compare 6.3.1). Main additions were other types of roughing filters. In addition to the horizontal flow in series, design specifications were also developed for downflow in series, upflow in series and upflow in layers. Dynamic intake filters added an additional step prior to the roughing filters to buffer turbidity peaks. The manual further comprises of details for the design and construction of flow control devices, back washing and cross flushing arrangements as well as monitoring provision for head loss and water quality [73]. A number of future studies were conducted referring to these manuals [101,104–108].

### 4.2.3 MULTI STAGE FILTRATION (MSF)

#### 4.2.3.1 EXAMPLE: TRANSCOL MSF PROJECT

In parallel to the roughing filter project, the outcomes of the SSF project were evaluated and it was found that the main technical bottleneck of SSF is the limited adaptability to high input turbidity level (compare 4.2.1.2). The evaluation of the project led to the formation of a follow-up project in Colombia named Transcol project aiming to upscale community-based water supplies based on surface water with SSF treatment and roughing filter pre-treatment. The project was implemented in cooperation with the “Instituto de Investigación y Desarollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico" (Cinara) from the University of Valle [74]. In this project, a range of treatment plants were set up, well-maintained and their performances evaluated over a longer period. All treatment plants had coarse gravel roughing filter pre-treatment units which reduced the incoming turbidity load, thus the SSFs in general reached turbidity values below 1NTU with removal efficiencies of only 50-87%. Faecal coliform bacteria could be removed between 1.7 to 3.06 logs which led to an average of less than 1 CFU/100ml for 5 of the 9 monitored units (compare Table 4).

***Table 4 Mean values of SSF treatment performance of several small to medium sized SSF treatment units in Colombia monitored in the Transcol project*** [101]

| Parameter | Unit | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|
| Treated Water Turbidity | NTU | 0.9 | 0.9 | 0.6 | 0.8 | 0.6 | 1.1 | 0.6 | 0.8 | 0.4 |
| Absolute Turbidity Removal | *Δ NTU* | 4 | 3.3 | 3.9 | 4.3 | 2 | 2 | 1.1 | 1.1 | 0.4 |
| Relative Turbidity Removal | % | 82 | 79 | 87 | 84 | 77 | 65 | 65 | 58 | 50 |
| Effluent Faecal Coliforms | *CFU/100ml* | 0.8 | 1.4 | 0.9 | 1.5 | 0.7 | 1.8 | 0.5 | 4.3 | 0.9 |
| Faecal Coliform Removal | log | 3.06 | 2.33 | 3.35 | 2.43 | 2.04 | 1.89 | 2.14 | 1.70 | 1.76 |

| **LEGEND for the columns** | |
|---|---|
| **Source** | **Description** |
| A - Javeriana[101] | 160 KLD, 2 Filterbeds; Area = 67.4m²; $V_f$ = 0.10 m/hr |
| B - El Retiro[101] | 1685 KLD, 4 Filterbeds; Area = 540m²; $V_f$ = 0.13 m/hr |
| C - Colombo[101] | 85 KLD, 2 Filterbeds; Area = 27m²; $V_f$ = 0.08 m/hr |
| D - Canasgordas[101] | 792 KLD, 3 Filterbeds; Area = 275m²; $V_f$ = 0.12 m/hr |
| E - Restrepo[101] | 68.5 KLD 2 Filterbeds; Area = 16.8m²; $V_f$ = 0.17 m/hr |
| F - La Marina[101] | 645 KLD, 2 Filterbeds; Area = 168m²; $V_f$ = 0.16 m/hr |
| G - La Rivera[101] | 333 KLD, 2 Filterbeds; Area = 198m²; $V_f$ = 0.07 m/hr |
| H - Shaloom[101] | 87 KLD, 2 Fitlerbeds; Area = 24m²; $V_f$ = 0.15 m/hr |
| I - Ceylan[101] | 786 KLD, 2 Filterbeds; Area = 252m²; $V_f$ = 0.13 m/hr |

Various forms of coarse gravel filters as described in the SANDEC projects [73] were compared. One plant was set up to conduct tests of variation of flowrates on roughing filters including HRF. The HRF of the plant had a total length of 7.13m with 3 compartments consisting of 13-19mm(3.27m), 6-13mm(2.32m and 1.6-6mm(1.55m) and a cross sectional area of 1.57m², thus deriving at capacities of 11-28KLD depending on the filtration rates of 0.3 to 0.75m/hr for the HRFs. This size is exactly in the range of water needed to be supplied in the project village Jyot Sujan, thus making the performance results specifically interesting for future benchmarking of the treatment plant developed in this study. The bacteriological performance looks very promising with average faecal coliform values below 1 CFU/100ml and turbidity performance complies with the permissible standard staying below 5NTU (1.3 to 3.4) for the final treated SSF water. Removal rates seem not to vary for the different flowrates and stay in between 77 and 82% turbidity removal and 1.99 to 2.26 log faecal coliform bacteria reduction for the HRF with filtration rates between 0.3 and 0.75m/hr. The SSF system also stays quite stable between 70 and 79% turbidity removal and 2.38 to 2.79 log faecal coliform reductions for filtration rates of 0.1 to 0.15m/hr. Influent water quality also fits with the measured pond water quality thus this kind of setup seems suitable for our project village (compare Table 5).

*Table 5 MSF systems with HRFs in Colombia and in West Bengal India [101], [108]*

| Stage | Parameter | Unit | A1 | A2 | A3 | A4 | B |
|---|---|---|---|---|---|---|---|
| Inflow | Water Turbidity | NTU | 74 | 35 | 29 | 31 | 68 |
| | Faecal coliforms | CFU/100ml | 24758 | 8843 | 16823 | 26226 | 1300 |
| HRF | Flow | m/hr | 0.30 | 0.45 | 0.60 | 0.75 | 0.70 |
| | Treated Water Turbidity | NTU | 13.0 | 8.0 | 6.2 | 5.8 | 5.0 |
| | Absolute Turbidity Removal | Δ NTU | 61 | 27 | 23 | 25 | 63 |
| | Relative Turbidity Removal | % | 82 | 77 | 79 | 81 | 93 |
| | Treated Water Faecal Coliforms | CFU/100ml | 182 | 90 | 124 | 145 | 90 |
| | Faecal Coliform Removal | log | 2.13 | 1.99 | 2.13 | 2.26 | 1.16 |
| SSF | Flow | m/hr | 0.1 | 0.1 | 0.15 | 0.15 | 0.09 |
| | Treated Water Turbidity | NTU | 3.4 | 2.4 | 1.3 | 1.7 | 1.0 |
| | Absolute Turbidity Removal | Δ NTU | 9.6 | 5.6 | 4.9 | 4.1 | 4.0 |
| | Relative Turbidity Removal | % | 74 | 70 | 79 | 71 | 80 |
| | Treated Water Faecal Coliforms | CFU/100ml | 0.7 | 0.2 | 0.2 | 0.6 | 0.0 |
| | Faecal Coliform Removal | log | 2.41 | 2.65 | 2.79 | 2.38 | 3.00 |
| Total (MSF) | Absolute Turbidity Removal | Δ NTU | 70.6 | 32.6 | 27.7 | 29.3 | 67.0 |
| | Relative Turbidity Removal | % | 95.4 | 93.1 | 95.5 | 94.5 | 98.5 |
| | Faecal Coliform Removal | log | 4.55 | 4.65 | 4.92 | 4.64 | 4.00 |

| **LEGEND for the columns** | |
|---|---|
| **Source** | **Description** |
| A1- A4 - Evaluation of MSF, Cali, Colombia, [101] | Period 1 to 4: 11 -28 KLD 3 stage HRF L=7.1m, 13-19mm(3.27m), 6-13mm(2.32m), 1.6-6mm(1.55m), SSF with 3.14 m², $d_{10f}$=0.2mm, $C_u$=1.5, media depth 1m, |
| B - Evaluation Roughing Filter, Gosaba, West Bengal, India [108] | 4KLD 3 stage HRF L=5m, 15mm(2m),10mm(2m), 5mm(1m), $v_F$=0.7m/hr; SSF with 4.2m², d=0.23, media depth 0.5m, $v_F$=0.1m/hr |

#### 4.2.3.2 ALTERNATIVE MSF SETUPS IN INDIA

Various small scale community MSF plants were also setup in India and even in West Bengal. In a current GOI report for arsenic mitigation pond based HRF, SSF schemes have been mentioned and funds for their implementation suggested [109].

##### 4.2.3.2.1 HRF-SSF IN GOSABA

A documented case in Gosaba, South24 Parganas, West Bengal, India is reported in 2008 to function very smoothly and efficiently serving 1000 people with 4LPCD drinking water. The 5m HRF system with 2m 15mm, 2m 10mm and 1m 5mm chambers was designed for flowrates up to 1m/hr whereas the SSF equipped with $d_{10}$=0.23mm sand of 0.5m depth and 4.2m² area was run at 0.1m/hr. As per monitoring report final bacteriological water quality of the final filtered water is 0 total coliform and faecal coliform CFU/100ml, turbidity values comply with acceptable standards of 1NTU and overall turbidity removal is higher with 98.5% as compared to the pilot plant runs in Colombia. [108](compare Table 5).

#### 4.2.3.2.2 PHED POND BASED SCHEMES

The PHED website mentioned 19 pond-based schemes with HRF and SSF under a category of rainwater harvesting. It is mentioned that around 73971 people are being supplied water from these schemes, whereby one bigger scheme, Mathurabill in Barrackpur 1 supplies water to 31892 people whereas the other schemes are smaller catering to 740 to 6347 people. Most plants have been setup in South and North 24 Parganas, and a few in Dakshin Dinajpur, Pas. Medinipur and Birbhum.

#### 4.2.3.2.3 WATER AID POND SAND FILTERS (PSF)

Wateraid Bangladesh published implementation guidelines for Pond Sand Filters which includes detailed design criteria for 2 versions a 300 and a 500 people version considering 23 LPCD. Both models use a Down-flow Dynamic Roughing Filter followed by an Up-flow Dynamic Roughing Filter as pre-treatment and a coarse SSF as final treatment step. Filter material for the roughing filter is Khoa (broken burnt clay bricks). Both units have a similar setup, the first down-flow roughing filter consists of 3 layers with 4.75-6.3mm(15cm),6.3-12.5mm(30cm) and 12.5-25mm(30cm) from top to bottom. The following upflow filter is equipped with 12.5-25mm(15cm), 9.5-12-5mm(42.4cm) and 6.3-9.5mm(42.5cm) layers and the SSF has coarse sand of d=0.15-1.1mm in a height of 90cm. [47]. The systems set up in Bangladesh are reported to work well [110] although issues with bacteriological quality have been reported [111,112].
One possible issue related to the hand tube well driven schemes might be the intermittent operation which could influence the efficiency of the biological layer in the SSF. Studies have shown that intermittent operation is less efficient than continuous operation in relation to bacteriological removal (log 3.7 compared to log 1.7 for E.coli), although turbidity removal can be more effective due to the longer sedimentation period during the pausing of flow (87 against 97%) [113]. Plants have been set up on the basis of this guideline by Wateraid India in Orissa.

#### 4.2.3.2.4 SOLAR BASED MSF IN DESARAJUPALLI

The author was involved in setting up participatory community based drinking water supplies in the framework of an climate change adaptation project from 2012 to 2014[114]. In this project a solar based 10KLD MSF plant sourced by an irrigation pond was implemented in Desarajupalli, Andhra Pradesh. The plant has a 3m² upflow roughing filter 40, 20, 6 and 3 mm gravels having a design flow rate of and 0.37m/hr and a 6m² SSF filter with 0.2mm UC 3 sand of 60cm height running at a flow rate of 0.18m/hr. Disinfection with chlorine is being done manually in the clear water tank The elevated plant provides drinking water by stand posts to a scheduled cast community by gravity. After ensuring chemical water quality by laboratory analysis bacteria is monitored regularly with $H_2S$ field testing kits. With the in kind contribution of the community the entire water supply could be setup with only 500,000 INR grants. Plans and picture of the plant is given in Appendix E.

### 4.2.4 REMOVAL OF PESTICIDES, TOXINS AND PATHOGENS

A good catchment area management takes care of toxic and biological contaminations. Nevertheless a multi-barrier-system should be set up to tackle undesired anthropogenic pollution. Some contaminants cannot be fully removed with SSF, e.g. pesticides which can be toxic to human and occur in catchment areas with agricultural activities. One treatment option for the removal of pesticides is the application of activated carbon filtration. Further pollution to surface water sources can be pathogens which find their way into surface water sources from open defecation or waste water being discharged in the catchment area. Effective disinfection is required in order to purify the water. While slow sand filtration is seen as a milder form of disinfection, post and residual disinfection is preferable, especially for a distribution network [115].

### 4.2.4.1 ACTIVATED CARBON FILTRATION (ACF)

*Table 6 Removal of Heavy metals with activated carbon*[k] [116]

| Element | Inflow [mg/l] | Outflow [mg/l] | Relative removal [%] |
|---|---|---|---|
| Cadmium | 30 (50, 100,200) | 4 (8.1, 30.2, 67.8) | 86 (84, 70, 66.1) |
| Lead | 30 (50, 100,200) | 5 (13, 27, 60.8) | 83 (74, 73, 69.6, 50.6) |
| Chromium | 30 (50, 100,200) | 14.8 (25.9, 70.4, 151.9) | 50.6 (48.2, 29.6, 24) |
| Nickel | 30 (50, 100,200) | 3 (6.1, 15.20, 31.8) | 90 (87.8, 84.4, 84.4) |
| Zinc | 30 (50,100) | 4.9 (9.4, 23.8) | 83.6 (81.2, 77.2) |

Filtration through activated carbon, or biological activated carbon (BAC) often in the form of granulated activated carbon (GAC) have good capacities for removal of emerging pollutants. Heavy metals are reported to be removed up to 90% (compare Table 6).

*Table 7 Removal of emerging pollutants with activated carbon(sources in legend)*

| Emerging Pollutant | source | Inflow [ng/l] | Outflow [ng/l] | Relative Removal [%] |
|---|---|---|---|---|
| Acetaminophen | a | 10650 | 47 | 99,6 |
| Androstenedione | a | 182,5 | 72 | 60,5 |
| Atrazine | b | 650 | 6,1 | 99,1 |
| Atenolol | c | 719 | 14 | 98 |
| Caffeine | b | 17 | 10 | 41,2 |
| Carbamazepine | c | 232 | 48 | 79 |
| DEET | a | 701 | 256 | 63,5 |
| Diclofenac | a | 85 | 1 | 99 |
| Dilantin | a | 153 | 78 | 49 |
| Fluoxetine | c | 23 | <0.5 | >98 |
| Gemfibrozil | a | 18 | 3,5 | 81 |
| Hydrocodone | a | 57 | 25 | 56,1 |
| Ibuprofen | a | 8760 | 7325 | 16,4 |
| Iopromide | a | 5,0 | 1,4 | 72,0 |
| Meprobamate | a | 318 | 227 | 29 |
| Metolachlor | b | 122 | 10 | 91,8 |
| Naproxen | c | 19 | <0.5 | >97 |
| Pentoxifylline | a | 34 | 25 | 26,5 |
| Sulfamethoxazole | a | 426 | 69 | 83,8 |
| Testosterone | a | 150,5 | 39 | 74,1 |
| Triclosan | c | 61 | <1 | >98 |
| Trimethoprim | a | 144 | 4,4 | 97 |
| LEGEND for sources | | | | |
| a | full scale GAC at drinking water facility #2, average values [117] | | | |
| b | full scale GAC at drinking water facility #1 [117] | | | |
| c | full scale WWTP with BAC after ultrafiltration and pre-oxidation [118] | | | |

Many trace organic contaminants like mineral oils, odour, taste, organic colour, pesticides and herbicides, AOX, PFT, pharmaceuticals and personal care products are removed [119], partly at rates greater than 90% (compare Table 7). Limitations of the removal efficiency are given with raw water

***k The adsorption of heavy metals by the adsorbents was studied using batch experiments. Twenty milligram of AC was added to 20 ml of different concentrations of heavy metal standard solutions (30, 50, 100 & 200 ppm), while the pH of the solution was adjusted to 2.0 using 1.0 N HCl***

having high concentrations of natural organic matter, as it competes for binding sites with the pollutants and also remobilise weakly bound contaminants. Depending on the water solubility the contaminants can start to break through after 2000 to more than 90000 treated bed volumes [117].
Design parameters for dimensioning of ACF are the iodine no. , Empty Bed Contact Time (EBCT) and treated bed volumes. The iodine no. is media specific, whereby a media with higher iodine no. has more adsorption capacity. For a contaminant to adsorb to the media a minimum EBCT is needed, thus a certain media volume and flowrate has to be designed so that the required EBCT can be ensured. Depending on the contaminants the media has a life time measured in treated bed volumes after which it can either be recharged or replaced.

#### 4.2.4.2 DISINFECTION

Biological contaminations like protozoa, bacteria and viruses can cause various diseases like gastrointestinal illness but also hepatitis, cholera, typhoid, tuberculosis, legionnaire's disease, enteritis, dysentery, Giardia and Cryptosporidium [120,121]. These contaminations can be removed by disinfection.
Disinfection can be achieved mechanically by filtration with membrane technology thereby removing pathogens according to their size, biologically with SSF, by application of chemicals like chlorine, chlorine dioxide or ozone, by irradiation with UV light or thermic by boiling among the most common[115]. While state-of-the-art disinfection with UV light and ozonation are safer from the point of view of disinfection by-products, the application of chlorine or chlorine dioxide are the only disinfection methods providing a residual disinfectant for the distribution network which ensures safe water at the point of consumption. For the rural setting with a distribution network possibly prone to post-contamination, chlorine application seems the most suitable. Simple ways of applying chlorine are using bleaching powder or liquid chlorine. Dosing into the water leads to Free Available Chlorine (FAC) and combined chlorine, of which FAC is more powerful in disinfection and is thus referred to when measuring the residual chlorine in water. Limitations to FAC disinfection is the pH value, as higher dosing of chlorine is required for higher pH and disinfection capacities at pH higher than 8.5 are practically not given, on the other hand disinfection works better at higher temperatures and is thus suitable for subtropical regions [75,122].
A methodology for the correct dosing of chlorine is the CT approach as followed by the USEPA. A value for concentration multiplied by time is given in a table in which the desired log reduction of a pathogen type (usually Giardia and Virus) in dependency of temperature and pH is given. While Giardia is one of the most difficult pathogens to kill (CT of 15 as compared to <0.25 for E.coli, or max. 6 for pathogen viruses at 25°C and pH=7, [123]), it can be used as the reference parameter for which the values are to be complied with. Depending on the size of the water supply log reductions are to be complied with. While SSF is considered to guarantee a 2 log reduction of Giardia and Virus it might be safe to aim at a 3 log reduction and thus achieve another 1 log with a disinfectant. The table provides the CT value of 17 for 0.4mg/l FAC at 25°C and pH of 8 which then means that e.g. 0.4mg/l FAC would require to be maintained for 42,5 min [124].
Similar to the USEPA approach the GOI CPHEEO O&M manual for rural water supplies provides the example for satisfactory disinfection with 0.3 mg/l FAC and 30min contact time for a pH of 8 to 9 [75]. In order to achieve this level of residual chlorine of dosage of 1 to 8mg/l are required depending on the chlorine demand of the water [125].

### 4.3 ADVANCED SYSTEMS

There are many other state-of-the-art water treatment technologies which can treat surface water and each of them is more or less suitable or necessary depending on the specific contamination of the source. In most cases a combination of various technological processes is required, where each process step aims at certain contaminants and prepares the water for the next technological step.

Several combined steps in a treatment plant also act as a multi-barrier system which provides more safety in case one of the steps does not perform as desired.
Suitable for the treatment of a mesotrophic to eutrophic pond water could be algae removal by microfiltration, then pre-oxidation, destabilisation and flocculation followed by multi-media (pressure) filtration combined with secondary coagulation and flocculation, ozonation and activated carbon filtration and final disinfection with chlorine dioxide or UV disinfection. For more eutrophic raw water, membrane systems like ultra or microfiltration with prior flocculation and post treatment with chemical oxidative or adsorptive processes might be necessary to remove toxins, odour and taste [126].
Looking at new and upcoming contaminations like drugs, pharmaceuticals, pesticides and other toxins or nanoparticles just to name a few emerging pollutants advanced treatment combinations seem necessary. While currently widely researched bank filtration is not applicable due to the underground in the project region being arsenic contaminated, other technologies could be applicable like membrane filtration or distillation, ion exchange, capacitive deionisation, adsorption, (solar) distillation or pasteurization and enhanced biofiltration to name only a few [127].
An actual advance in the future of drinking water treatment is seen in more efficient catchment area management providing more suitable water resources and making advanced water purification unnecessary [128]. This aspect is taken up at the project site where efforts are applied to catchment area management (compare chapter 6.2)
In this study, one advanced technology is briefly presented as it being applied and monitored in the project site as a potential advanced alternative to the MSF system and thus also evaluated in regards to its sustainability in chapter 9.

### 4.3.1 PRESSURE FILTRATION WITH ACTIVATED FILTER MEDIA (AFM)

AFM is a filter media produced by Dryden Aqua Ltd. which can replace sand in gravity and pressure RSF systems. AFM is made from green glass and is activated to a permanently negatively charged amorphous alumino-silicate filter media of various grain sizes between 0.25 to 4mm. According to the manufacturer, the filter media does not become biological and can be operated at higher filtration rates for gravity based systems up to 5m/hr is recommended. High removal efficiencies of above 95% are predicted down to 1 micron. Further advantages are that for backwashing, air scouring is not needed and the filter media would never need to be exchanged.
From the process point of view the system works similarly to the conventional RSF system, except for an additional aeration or oxidation step prior to the filtration in case the raw water has a low DO level. At the project site the AFM system treating surface water is equipped with a raw water tank which is continuously aerated. After aeration the coagulant Poly Aluminium Chloride (PAC) is mixed via a zeta potential mixer prior to the pressure filtration with a filtration rate of 1.25 m/hr through a $2m^2$ filter bed of 1.2m depth. The treated water is stored in a separate clear water tank from where it can be used for backwashing the filter. The clear water is then disinfected together with the water from the MSF plant prior to distribution [129,130]

### 4.3.2 DISINFECTION WITH MIXED OXIDANTS

A mixed oxidant solution is generated by electrolysis process from NaCl and purified water. The company Trustwater has suggested its application as an improved technology for water disinfection over conventional approaches such as conventional chlorination, ozonation, ultraviolet radiation and boiling. The Trustwater 110 Mixed-Oxidant Disinfection System produced a mixed-oxidant solution called Ecasol for disinfection purposes and thereby, according to the manufacturer, achieves exceptional levels of inactivation for Escherichia coli [131] and Cryptosporidium oocyst [132], as well as removal efficiency of persistent biofilms. The system is integrated as part of the advanced setup at the treatment plant, sourcing purified pressurised water from the AFM system – which, moreover, is softened - and a brine solution locally produced by pure NaCl and the same water [133].

## 4.4 SOCIO-ECONOMIC ASPECTS OF COMMUNITY BASED WATER SUPPLIES

### 4.4.1 SUSTAINABILITY

It has been observed in many development cooperation projects that the technology itself is often not the answer to a problem. Technological solutions have social, political, economic and environmental implications which are to be considered and addressed consequently when aiming at the sustainability of a project.

As defined by Galvis[101] *a water supply or sanitation system is sustainable when it: continuously provides an efficient and reliable service at a level which is desired; can be financed or co-financed by the users with limited but feasible external support and technical assistance; and is used in an efficient way, without negatively affecting the environment.*

In order to provide a reliable service, the system thus not only needs to be technologically sound but also operated by its users. In order to ensure that the users are capable and willing to operate and maintain the system, ownership has to be developed. Since the 70s the answer to creating ownership has lied on participatory approaches. Consequently in the documentation of the SSF project (compare chapter 4.2.1.2) a strong focus is already laid on community participation at all the levels of the project (planning, construction and operation and maintenance) [72]. Lessons learned from these approaches finally lead to a comprehensive approach to community-based water supply programmes named Facilitating of Learning, Action, Implementation and Reflection (FLAIR). On the level of involved actors in the development of a community-based water supply, it is understood that regional education centres (universities and schools) and regional health services need to work together with the communities, and that the technology provider is only a facilitator to implement the construction. Capacity building in the form of trainings and workshops can never be a one way information provision by the technology provider; it needs to be an interaction in which a joint learning requires the technology provider to firstly learn about the local conditions and capacities in order to be able to arrange the setup which will meet these provisions, thus enabling the system to function in the specific context. In this way the technology needs to be adapted to the community and not the community trained in being able to use the technology [74].

Following this approach the aspects considered when assessing the long-term viability are its technical performance and reliability, its social and environmental impacts to the direct beneficiaries as well as the wider society, and its economic implications, affordability and efficiency in producing benefits.

### 4.4.2 ECONOMICS OF WATER SUPPLY

A major hurdle for the sustainability of each project is the funding of its operation and maintenance, especially long-term preventive maintenance, in contrast to minimal emergency repairs.

Funds are generally expected to be paid by the users. Very different from the highly subsidised urban water supply for the middle class in metropolitan cities, the poorest members of society are expected to pay for the services. Although official governmental publications mention 50% of government funds being available to Panchayats (the other 50% of funds needs to be sourced from user fees for O&M) [40], it is difficult for water committees to get their hands on these funds. In Indian cities, residents usually pay a tariff depending on the amount consumed per connection, which is lower for low consumption (from 8 to 22.5 KL per month), or which can be free (like in Delhi) or cost up to 10 INR per KL (like in Hyderabad), and is more expensive for higher consumptions (above 25 to 200 KL a month) with about 18,64 to 45 INR (Mumbai and Bengaluru respectively) [134]. The consumption of 40LPCD for a 5 person household would thus cost from nothing to a max. of 60 INR per month. With the current average per capita income of around 93000 INR that would be a maximum of 0.4 % of the income paid for water[135]. On the other side expenses for rural population for water supply also vary largely, public water supplies are often free, providing intermittent supply with stand posts, community supplies charge between 20 to several 100 INR per month as a flat rate or based on consumption per 20L barrel between 10 to 40 INR for 20L, which in the worst case would lead to expenses of 1200,- INR per month for a 5 person household considering only 4 LPCD, this would already translate into 7,7% of the average income, but possibly more than 20% of the income of a household whose earnings come from daily labour in rural areas.

According to international practices, 0.2 to 1.4 % of the average income are paid for water and wastewater services whereas the 10% of the population with the lowest income pay 0.8 to 10.3 % of their income [136]. In the SSF and Transcol projects, between 0.9 to 2.5% of the income of families were collected as water fees [101].

Water fees for covering the expenses of a water supply of course depend on the type of installation, the investments and running costs for O&M. According to the WB PHED, the planned investment for a simple tube well attached ARU can be as low as 280 INR per capita, whereas an integration of an arsenic removal plant in an existing groundwater based scheme can cost around 360 INR per capita with O&M of 5 INR per capita and month, whereas the setup of a new groundwater based scheme with ARP would cost around 1000 INR per capita and the setup of a new large scale surface water scheme costs around 2000 INR per capita with O&M of around 5 INR per capita and monthl.[137]. Current reports show actual occurred costs for the setup of a water supply in West Bengal with 4051 INR per capita [109]. In this regard the currently reported investments by PHED in pond based MSF schemes seem cost efficient. In total 172 million INR for 73971 people are invested, this results in an investment of 2326 INR per head or 2.3 lakhs per KLD (as only 10 LPCD is mentioned to be provided) [138]. Studies in India show that the rural population is willing to pay between 50 and 2000 INR as an initial capital investment and on average around 25 INR per month for O&M for a household connection of piped drinking water [139]

# 5 CURRENT SITUATION AND NEEDS IN JYOT SUJAN, WEST BENGAL

The needs assessment creates reliable data on the situation of drinking water supply, sanitation and available capacities as well as willingness to contribute and pay for the project. A following field survey identifies available quality and quantity of surface water resources. In-depth interviews with community representatives of the involved Gram Panchayats (village administration), Zilla-Parishads (district administration) as well as with the PHED (Public Health engineering Department) are conducted to receive the approval for further developing the detailed project proposal [37,50].

An overview on options of suitable treatment technologies and approaches for the implementation of a community-based water supply is generated and compiled in posters (compare Appendix H).

At the grassroots level the direct beneficiaries (members of the community) are involved in awareness creation and joint conceptualisation of implementation options. The community representatives are organised in the VWSC, which is the decision–making body concerning the water supply scheme on the level of the direct beneficiaries.

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***l These figures are calculated on the basis of prices of the 2006 Masterplan considering a per capita supply of 40 LPCD, according to the inflation prices in 2016 would be approximately 2 times higher for civil construction as well as O&M which then matches the current figure of the GOI 2015 report.***

## 5.1 BASELINE SURVEYS

The basic conceptualisation of the water supply serves as an entry point for the discussion with the community and its stakeholders. A structured survey begins with qualitative questionnaires with 5 key informants, these are the Upa Pradhan and Panchayat member of the Jyot Sujan, the chairman of the local Gram Sabha, sub assistant PHED engineer in charge of the area, president of the local NGO Pather Pachali, which had already run a arsenic mitigation programme in the village, and a member of the local masjid committee. The main information obtained from the survey verifies and adds to previously collected information on demography, geography, infrastructure, situation of water supply and potential community involvement in project activities.
Quantitative questionnaires are used for the household survey, which covered approx. 90 % of the households (n=413). In each household responses from a female and a male adult representative are collected. For this assessment the village is divided into 8 parts: North West (NW), North East (NE), Southwest (SW), South East (SE), West North (WN), West South (WS), Malpara North (MN) and Malpara South (MS) (Map 1). In addition to receiving information on the current individual situation regarding drinking water related issues, awareness of risks and willingness to contribute to possible solution approaches, the survey supported in identifying the needful and suitable location for the setup of the integrated scheme. For this purpose the responses of quantitative questionnaires are analysed with five criteria, namely:

- Benefits from project implementation perceived by the community.
- Community interests towards project deliverables.
- Community contribution towards implementation of the project.
- Identified sanitation and drinking water needs.
- Monetary contribution from community towards infrastructure maintenance.

### 5.1.1 DEMOGRAPHIC ASSESSMENT AND GENERAL NEEDS

The villages Jyot Sujan and Malpara have a population of approx. 2000 out of which approx. 1500 are above 18 years belonging to about 400 households. There are 200 pupils studying in primary school, and 50 children in ICDS (integrated child development service). Jyot Sujan has a community Mosque where about 100 people offer prayers. The main occupation of both communities is farming, 40% of the surveyed people are farmers, and women are mostly house wives, amounting to 45 % of the surveyed population. Apart from farmers, about 14% of the population are occupied with labour jobs on a daily basis. Fishery and animal husbandry are also a source of income for the villagers. The average monthly income for each household ranges from 1500 to 4500 INR. General needs identified from the interview partners are provision of safe drinking water, improvement of sanitation facilities and increase of awareness on hygienic practices regarding water contamination. Further solid waste and waste water management would be welcome.

### 5.1.2 BASIC GEOGRAPHICAL AND CLIMATIC CONDITIONS


*Figure 7 Location of Project Site (source: OpenStreetMap)*

Jyot Sujan and Malpara are partly in the Diar Chaitanpur and partly in the Khosbag Mouza of Murshidabad Jiaganj Gram Panchayat in the Murshidabad district. The next bigger village Khosbag is 2km away, Murshidabad is 5km away reachable by ferry and Berhampore is around 15km away reachable by road. Kolkata is around 220km away and can be reached by train in around 4 to 4.5 hours or by road in 6 to 7 hours (Figure 7). The village is situated in the plains of the river Bhagirathi, flowing 300 to 700 meters away from the settlement with a flowrate between 800 and 12000 CuSec depending on the season[140]. The village surroundings are grass lands used for animal husbandry, ponds for aquaculture and agricultural fields used for growing rice, wheat, pulses, spices, vegetables. Fruits are mainly grown in mango orchards and banana gardens. There is a substantial use of chemical fertilizers, pesticides and insecticides in the agricultural (paddy, vegetable, fruits (mango orchards)) and use of medicine and food for the aquaculture in the ponds. The fields are irrigated with flood irrigation fed by the water from the river Bhagirathi, and shallow or deep tube wells partly canalized to the fields. The agricultural runoff goes to the river Bhagirathi. The top soil is sandy alluvial (mix of sand and clay) and in different strata sand and clay layers are present with partly clay patches. For a soil mixture of sand, silt and clay, the assumed hydraulic conductivity is found to be 0.1 m/day. The temperature in the area ranges from Min 8° to Max 43° C in a year. The rainy season stretches from June till September and the average annual rainfall is 1400 mm.

### 5.1.3 EXISTING INFRASTRUCTURE

Transportation to the village is possible by boat and motor- or man-driven carts. The people in the village mostly use bicycles, and some motor bikes. Electricity is interrupted for 1 hour every day in average. Single and three phase power supply is available at 200 to 220 volts and 440Volts supply is available for mills. An 11000 Volt transformer is located in the village. For electric load connections permission has to be obtained from Azimganj electricity office. For cooking, wood, cow dung and residue of agricultural harvest is used. Diesel and petrol is used for pumps, motors etc. Mobile network of 2G is available with service providers like Reliance, Airtel, Vodafone, MTS and Uninor. GPRS data connections have an average download rate of around 15 kB/s, recently faster 3G network is also available.

### 5.1.4 CURRENT WATER SUPPLY AND FUTURE DEMAND

*Figure 8 Tube well at household level*

*Figure 9 Village Pond*

Jyot Sujan and Malpara have no public water supply. Almost all households have individual tube wells which are used for drinking water and all other water needs. Less than 10% of the households buy bottled water or have a filter system at home. The price for bottled water ranges between 20 to 40 INR per 20L canister. Some houses located near to lakes and ponds also use ponds for washing, cleaning, bathing and irrigation. Some tube wells have difficulties in pumping water during the dry season as the ground water level decreases by about 3 m in dry seasons which can last from 2 to 4 months each year. Some of the tube wells are sealed by the PHED as they had high levels of arsenic, according to PHED statistics 14 of the 21 public tube wells in Jyot Sujan (Diar Chaitanya Pur) have arsenic levels above 50µg/L and only 2 are safe with levels below 10µg/L [141] (compare Appendix D).
In a first site screening, 23 tube wells randomly selected in the village are tested for arsenic: 65% of the samples have arsenic levels higher than acceptable drinking water quality standard of 10µg/L, 39% exceed the permissible limit of 50µg/L and 17% even exceed 100µg/L (Map 1). This indicates that only one third of the population should continue to drink water from their current source.
Regarding sanitation, practices reach from improved (sanitary) pit latrine, unimproved (unsanitary) pit latrine, temporary shallow pits to open defecation on the field. The household waste, garbage and grey water are collected in a shallow pit, partly near to the tube wells. There is no waste water or solid waste management system in the village.
The assessed average household water demand per day and some special water demands of the community are shown in Table 8. They differ from the assumed 40 LPCD for stand post and 70 LPCD for rural household connection.

*Table 8 Daily drinking water demand in Jyot Sujan and Malpara*

| Usage Purpose | Stand post per person | House Connection per household* |
|---|---|---|
| **Drinking** | 4 L | 20 L |
| **Cooking** | 4 L | 20 L |
| **Personal Hygiene** | 12 L | 100 L |
| **Sanitation** | | 30 L |
| **Domestic animals or other uses (average)** | | 30 L |
| **Total** | 20 LPCD | 200 L/D |

*in case of a house connection and usage of water for all needs for 5 people

| Special water demands | |
|---|---|
| Masjid with health centres 100 people 5 times a day demands 5 L each time. | 2500 L/d |
| Primary school, 200 pupil, 5 L each | 1000 L/d |
| ICDS integrated child development service, 50 children,5 L each | 250 L/d |
| **Total** | 3750 L/d |

With 50 house connections and the rest of the population covered with stand posts approx. 50KLD would be required for the water supply for the entire project area covering 2000 inhabitants.
Additional water demands for irrigation, animal husbandry, commercial activities like food processing etc. have not been taken into account as they are not carried out on regular basis in the community. Instead an average additional usage of 30 L/d per household has been assumed.

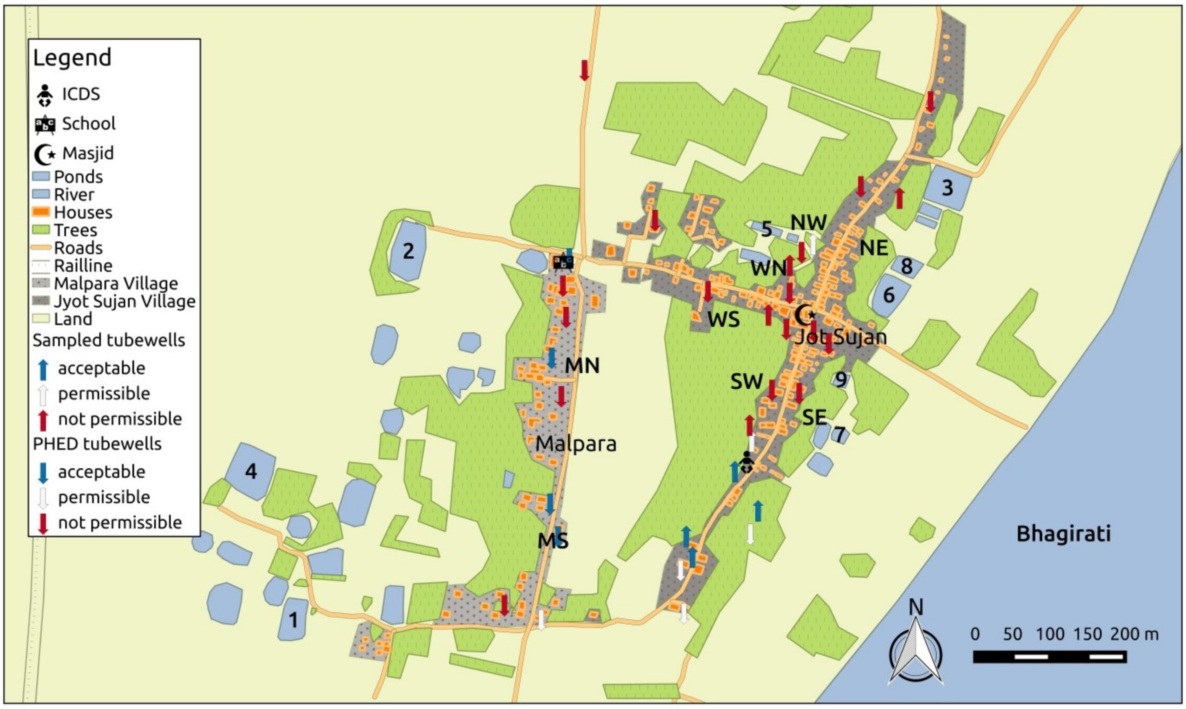
#### 5.1.5 QUANTITY AND QUALITY OF SURFACE WATER SOURCES

Around thirty ponds are identified in the surrounding of the villages of which 16 are potentially available for the usage as a water reservoir. The biggest challenge is to have a pond of sufficient perennial water carrying capacity.

The first 10 ranked ponds are shown in in the village map below, in which the first ranked pond is in the southwest of the village Malpara (compare Appendix J).

Water quality of the ponds is assessed in November 2012 and varies according to their usage, with worse qualities for those used as drain collector, for jute rotting and better for the fish ponds or irrigation water reservoirs. Of the assessed parameters values for Do, BOD, COD, Turbidity, Alkalinity, Ammoniacal Nitrogen and Bacteria partly exceeded the CPCB criteria for surface source [125,142] (Appendix J).

The prioritised pond was used for fish breeding and had slightly elevated BOD and COD level between 8 to 15 and 26 to 33 mg/L respectively in addition the TDS value was slightly elevated between 293 and 564 mg/L. Turbidity ranges between 7.2 and 43 NTU, whereas Total Coliform and Faecal Coliform are in the range of 1100 and 4 respectively. Other assessed parameters are in the permissible range of IS10500, indicating a general suitability of this pond as a source.




***Map 1 Nine most suitable ponds in the vicinity of the villages ranked from 1 to 9, village parts[m] and arsenic contamination of own sampled and PHED sampled tube wells[143]***

## 5.1.6 POTENTIALS OF RENEWABLE ENERGIES

Wind energy and solar energy potentials are assessed on site. The annual average wind speed in m/s is 2.64 with the monthly variations between 2 in October and 3.5 in May. This relates to a low wind-power density class. Good wind resources require annual average above 6 m/s [144] For design criteria of structures the basic wind speed of 50m/s has to be considered.

A better potential is available for solar energy. The average annual solar intensity in KWh/m²/day ranges from up to 6 during March to May down to 4 from June to October, with an average of 4.58 for the entire year, which is 1.5 times as much as e.g. in Berlin [145].

Regarding biomass, rice shells, rice stem, cow manure and parts of the banana plants are the most promising co-substrates for stable and efficient biogas production apart from the sludge from the wastewater. Total solid contents (TS) and volatile solid contents (VS) of 90% and 75% respectively for

***m MS-Malpara South, MN-Malpara North, SW-Southwest, SE-South East, WS-West South, WN-West North, NW-North West, NE-North East of Jyot Sujan***

the rice shell range to 8% and 6% respectively for the upper part of the banana stem, whereas the wastewater has rather high TS of 11.6% compared to European rural wastewater TS of 4%. A good mixture of these sources seems to be promising [146].

## 5.2 ATTITUDE OF LOCAL BENEFICIARIRES

To ensure the community is willing and motivated to take responsibility and contribute to its setup, the attitude of the villagers is assessed regarding the awareness on the existing problem, the perceived benefits and the interests in the project. In order to increase the sense of ownership in the community, the project envisages to involve as many local actors as possible in the assessment, planning, designing as well as construction, operation and maintenance of the water supply. It is thus assessed in how far skills necessary for the various tasks are available in the community. The interview partners mentioned that has skilled labour for electric works, for masonry and plumbing as well as unskilled labour. Local materials like bricks, sand and cement are available with members of the community.

### 5.2.1 AWARENESS ON PROBLEMS WITH CURRENT WATER SUPPLY SITUATION

Water quality problems are shared by over 50% in the complete village, with the most severe ones in NE(85%) and NW(82%), least problems seem to be in WN(30%). While water quantity is seen as a problem only in Malpara by 10%, about 50% of the respondents in Malpara have recorded presence of water transport problems. Both latter problems seem to be negligible in Jyot Sujan.

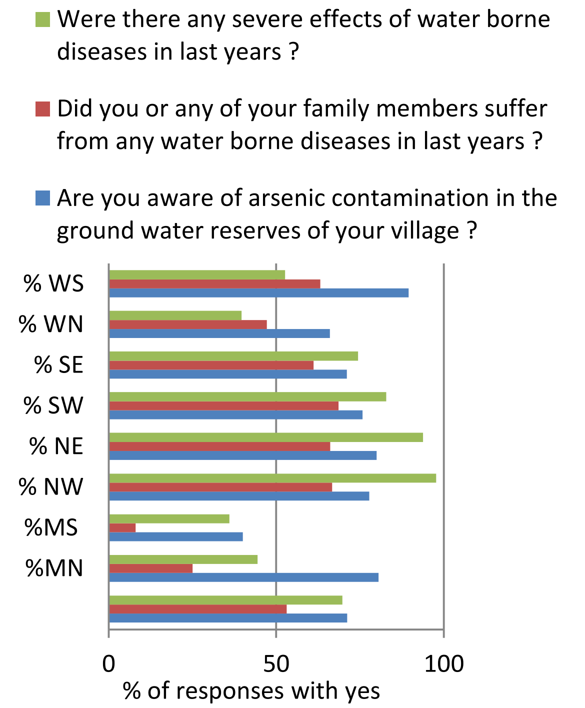



*Figure 10 Aware on arsenic contamination and health risks in the various parts of the village*

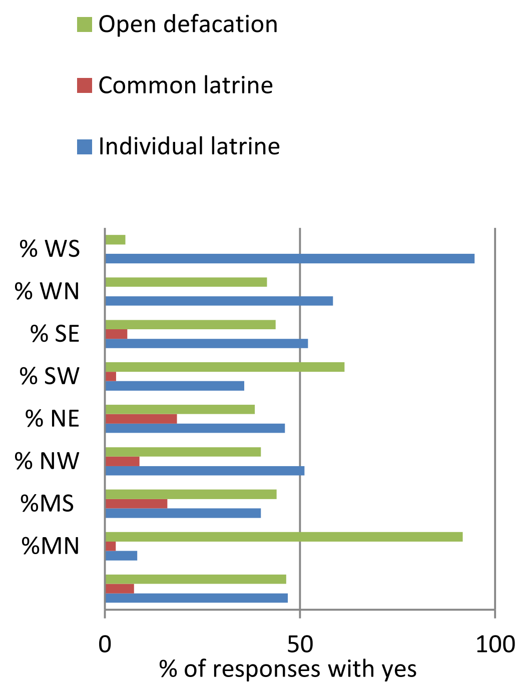



*Figure 11 Sanitation practices in the various parts of the village*

Only 70% of the overall population seem to be aware of arsenic contamination of the groundwater sources in the village, with highest awareness in WS (90%) and lowest in MS (40%). A Similar proportion (68%) perceived that severe water-borne diseases were prevalent in the village, with higher awareness in NE (93%) and NW (98%) and lowest awareness in MS (35%), WN (39%) and MN (42%). Personal experiences with water-borne diseases in the family in the last year could be shared with 55% on average, where more experiences are made in SW (70%), NE (68%) and NW (68%) (Figure 10). More than 40% of the total respondents are found to be practicing open defecation. The highest percentage for people practicing open defecation is seen in Malpara part of the village with higher intensity in MN, followed by SW and SE part of Jyot Sujan village. Common latrines are seldom found: less than 10% of the entire population, with none in WS, WN and around 20% in NE and MS. Almost half of the population possess individual latrines, with 90% in WS and only 10% in MN. Still only 10% declared that sanitation units are not available at all, with 45% in MS and 0% in WS and WN, whereas overall 30% found them to be in a bad shape, with 55% in WS and 5% in MN (Figure 11). 35% of all respondents found sanitation units not sufficiently available, with 70% in MN and 5% in WS. It is evident that the Malpara area and the south of Jyot Sujan are in most dire need of sanitation facilities, as there are not sufficient sanitation units, nor are the existing ones in usable condition.

### 5.2.2 PERCEIVED BENEFITS OF THE PROJECT

All 8 surveyed regions provided a similar picture on the perceived benefits. Except for the NE where only 98% perceived all benefits all other community parts agreed to 100% to expect safe water to provide them with:

- Better health
- Better standard of living
- Higher life expectancy
- Earning more money
- Cleaner environment

Furthermore, 99% of all inhabitants believe that water purification, as well as improved sanitation facilities, would minimize diseases prevalent in the village. Similarly, 99% believe that a piped water supply based on a surface water source would solve the problem of arsenic contamination.

### 5.2.3 COMMUNITY INTERESTS AND CONTRIBUTIONS TOWARDS IMPLEMENTATION OF THE PROJECT

All community members are eager to connect their houses to the water supply network and upgrade their sanitation unit to flushed toilets connected to a sewer line. 95%(WS), 97%(MN, NW), 98%(MS) and 100% of the other community parts answered affirmatively to the question of being interested in having a piped drinking water house connection and a flushing toilet.

Almost all the respondents are willing to contribute towards the implementation of the water supply and sanitation up-gradation project; more than 30% of the total respondents are willing to contribute with labour and/or land, water body, tube well. The maximum willingness to contribute labour is in Malpara North, followed by the northern part of Jyot Sujan and the southern part of Jyot Sujan. Willingness to contribute land and water body is highest in the NE and NW part of Jyot Sujan followed by SE and WS in the village.

In order to assess the maintenance capacity of the community, the willingness to pay for the water supply service was surveyed. The users are willing to pay a monthly fee for the operation and maintenance of the scheme. The average amount a villager would pay according to the survey is INR 19.- where MN would contribute highest (32.-) and MS lowest (14.-).

A final agreement between the permanent and temporary members of the VWSC clarifies the role of the two groups. The local members thus take responsibility for the future operation and maintenance of the scheme and collection of the user fees, whereas the temporary members take responsibility for setting up a system based on the jointly elaborated criteria on being easy and economical to operate (compare Appendix I).

### 5.2.4 SUITABLE CONDITIONS FOR THE PLACEMENT OF THE COMPONENTS OF THE WATER SUPPLY

Based on the results from the evaluation of the needs assessment, several factors are in favour of selecting the Malpara part of the village for the location of the integrated scheme: maximum monetary contribution toward infrastructure maintenance, highest open defecation practices and evident water transport and sanitation problems. The next possible location for the integrated scheme could be SE and/or SW part of the village, with higher open defecation practices and water transport problems. In regards to the protecting the catchment area from contamination through open defecation, Malpara and the south part of Jyot Sujan also provide the highest risk potential as the local population chooses locations in the catchment area of the pond for their defecation.
Criteria for the selection of the pond and the location for the HRF, SSF and ACF treatment units are (with decreasing importance):

- Current and potential water carrying capacity
- Water quality of pond from water samples and by usage
- Basic infrastructure and surrounding area for filter units.
- Monetary implications for preparing the source and for operation
- Catchment area requirement and availability
- Potential contamination in the catchment area.

For the selection of the area for the integrated scheme the quantitative questionnaire survey is evaluated focusing on the following criteria:

- Necessity of adjacent habitations for sanitation
- Willingness to connect to the integrated scheme
- Willingness to pay for the water supply service
- Topography of the area for free gravity flow of sewage
- Availability of land for waste water treatment
- Beneficial usage of treated wastewater e.g. in agriculture
- Acceptance of the setup by the villagers
- Infrastructural suitability (access road, electricity, cellphone network)
- Safety of installed equipment
- Protection of catchment area
- Cost analysis regarding investment and running operation and maintenance costs

The surface water source is selected on the basis of a weighted multi-criteria decision matrix (compare criteria mentioned in chapter 5.1.5).
In addition to the surface water based water supply, a groundwater based supply adds additional capacities to the water supply. The location for the installation of the groundwater unit is selected on the basis of the following criteria:

- Availability of arsenic contaminated tube well
- Acceptance by villagers
- Availability of adjacent land for treatment units
- Safety of installed equipment
- Cost analyses regarding investment and running operation and maintenance costs

The results for the overall planning thus consider the best options for the surface water source with HRF, SSF and ACF, the groundwater source with ARU and the integrated scheme with house connection and sanitation units, sewerage and WWTP (Map 2).


*Map 2 Locations for the placement of supply scheme components as per results of the needs assessment*

# PART II
# IMPLEMENTATION

## 6 DESIGN AND IMPLEMENTATION OF TREATMENT AND SUPPLY SCHEME

Detailed specifications for the surface water based water supply system are developed based on literature research, information received during site visits, surveys, interviews, participatory workshops and the needs assessment. These assess details on the water demand and resources, location of treatment units, suitable technologies for catchment area and reservoir management, water treatment and supply [51]. Brief concepts of the supply, sewerage and waste water treatment are given as an outlook in chapter 0 as they could not be taken up during the project due to unavailability of funds (compare 3.4.6). This chapter only covers details of the drinking water treatment plant based on surface water.

### 6.1 BASIC DESIGN CRITERIA

Reintroducing surface water usage for human consumption implies taking special care of typical surface water contaminants related to serious diseases e.g. diarrhoea, hepatitis, typhoid fever and cholera. Hence, awareness on quality maintenance and sound treatment technologies are prerequisites for a successful usage.

Overall prerequisite for setting up a surface water supply scheme is that all stages of the local and regional water cycle are being tackled. The quality of the water resources is to be improved. Integrated Water Resource Management will have to involve all the user groups in the watershed including farmers, fishers among other economic and domestic water users. Pollution sources have to be identified and water resource protection measures put into place.

The treatment process is conceptualised so that no external electrical power and as less as possible chemical consumables are needed. In order to achieve this, the pumping power is sourced by photovoltaic cells and the raw water and clear water tanks are dimensioned as to cater sufficient water to the filter units in order to make them run continuously for 24h a day.

The piped water is protected from external contamination and better quality control through monitoring is possible. The 24/7 supply ensures suitable quality at the point of collection by not letting any contamination infiltrate into the distribution network, due to continuous positive pressure in the pipeline. Having laid a distribution network to the consumer and assuming individual sanitation installations with flushed toilets, the waste water collection has to be set up at the same time.

#### 6.1.1 WATER QUANTITY MEETING WATER DEMAND

Water consumption in a rural area is estimated at 40 LPCD when supplied with stand posts and at 70 LPCD when connected directly to households [147]. As the pilot area does not suffer from general water scarcity and the existing tube well water is suitable for most uses except for direct consumption, the actual demand is reduced and assessed at 20 LPCD for stand posts and 40 LPCD for a house connection (compare 5.1.4).

One part of the project area is to be supplied with drinking water from the surface water supply, while other parts are supplied by a groundwater supply with an Arsenic Removal Unit (ARU). The groundwater sourced from tube wells is treated by an ARU working on co-precipitation and adsorption. The arsenic rich sludge which is generated by this process will be treated in a way that the arsenic will not leach back into the environment. Options such as brick manufacturing are being explored. The part planned to be covered from the surface water supply includes 15 households for the integrated scheme with house connections and 85 households with stand posts, with 5 people per household in average. The 500 people thus require 11.5 KLD water currently. Considering a 10 year population increase with 1.2% growth per year [148], the plant has to be dimensioned for 13 KLD.
At both sources, groundwater and surface water, additional pressure filtration systems based on activated filter media are also installed [51] which each have capacities of treating 60KLD. (compare chapter 4.3.1)

### 6.1.2 TECHNOLOGICAL CONCEPT

A multiple barrier concept is followed with various steps including a multi-stage filtration. It starts at the source harvesting rainwater and diverting it with bunds and channels to a silt trap. With catchment area management contaminations by pesticides, fertilizers, animal and human feces are controlled. The Silt Trap is a next step to catch larger suspended solids. It is followed by a pond acting as a reservoir and sedimentation tank as well as biological buffer to biodegrade some of the nutrients and organics from the catchment. The raw water is then lifted by the raw water pump (RWP) into the Raw Water Tank (RWT) inducing aeration which further oxidizes some organic components and prepares the water for filtration. After another sedimentation step in the RWT the water flows by gravity through to lines of multi-stage filtration. The first Horizontal Roughing Filters (HRF) remove the main part of suspended solids which include some pathogens adhesive to them. The next main treatment step are the Slow Sand Filters (SSF) which remove major part of the pathogens, nutrients, turbidity, color, metals and organics. The final filtration is done through Activated Carbon Filters (ACF) which act as a buffer to remove possible remaining toxics like pesticides, but also remove some taste, odor and color components. The filtered water gets collected in the Clear Water Tank (CWT) and is disinfected to remove the remaining pathogens. Then it is pumped to the Overhead Tank (OHT) by the Clear Water Pump (CWP) from where it can be distributed to the consumers by house connection or stand posts (Figure 12).

### 6.1.3 INTEGRATED SETUP

The overall water supply is integrated in various ways. Firstly, as shown in Map 2, groundwater and surface water sources are combined providing an additional resilience in case of drying up or sudden contamination of any of the two sources.
The other aspect of integration relates to the integration into the natural water and energy cycle. A small part of the supply is intended to be piloted with house connections. Generated wastewater is planned to be collected in piped sewerage and then treated in a Waste Water Treatment plant consisting of a settling tank and a reedbed filter. It is intended to produce biogas from the wastewater sludge and locally abundantly available biomass like banana tree stems or rice hay.
In a feasibility study[146] generation of energy from the biogas is estimated to suffice to run pumps of the treatment plant or even additional pumps which could be required for lifting the effluent from the WWTP to agricultural fields or the river. An implemented substitution for the biogas driven generator is the smart photovoltaic system which provides regenerative energy to the two pumps in the treatment plant. The solar system has battery backup and sources or supplies energy either from the PV cells, the batteries or the grid as per requirement and smart algorithm always keeping the battery backup partly filled for times of load shedding.

Apart from an integrated closed energy cycle the treatment system is also integrated into the water cycle, sourcing the water from the rain and treating it to a level that it can be discharged into the environment e.g. for irrigation, where it can partly evapotranspirate generating new clouds (Figure 12).

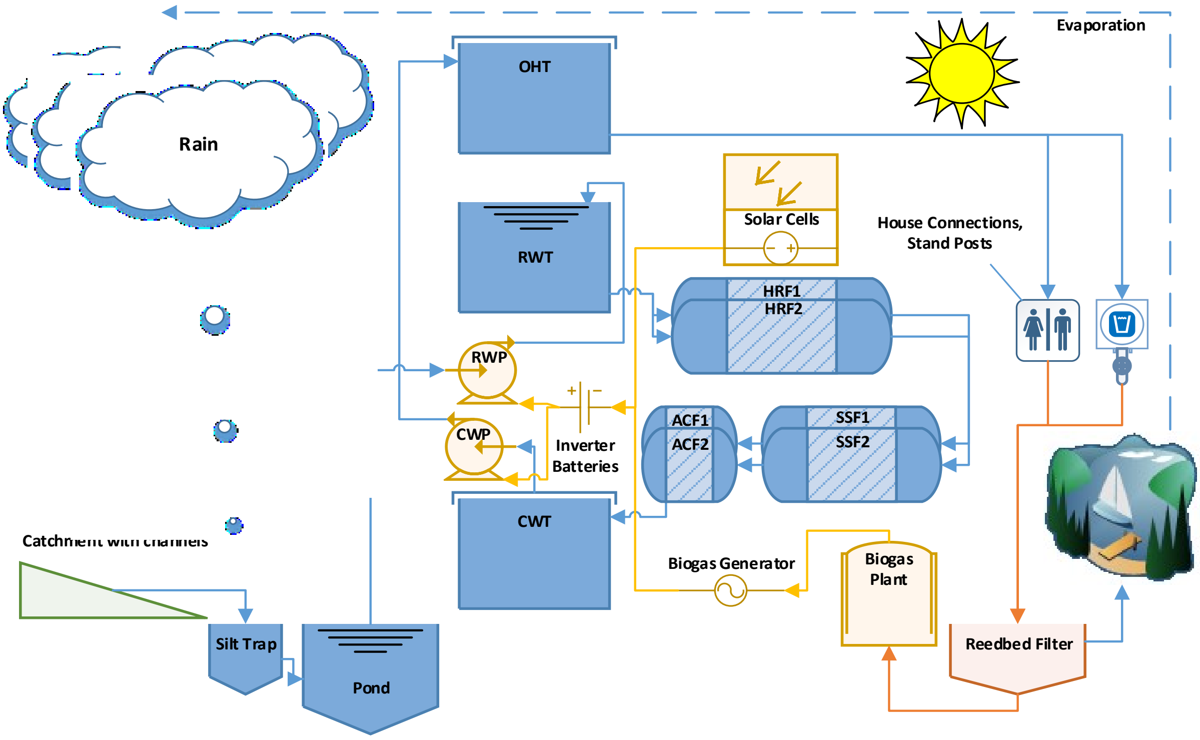



*Figure 12 Integrated setup closing the water and energy cycle: Raw Water Tank (RWT), Clear Water Tank (CWT), Over Head Tank for distribution (OHT), Raw Water Pump (RWP), Clear Water Pump (CWP), Horizontal Roughing Filter (HRF), Slow Sand Filter (SSF), Activated Carbon Filter (ACF)*

## 6.2 WATER SOURCE

Harvesting rainwater by surface runoff and storing it in the pond generates the source of water for the treatment plant. For this purpose the catchment area for the pond is engineered and the pond volume increased to meet the requirements of a perennial surface water source regarding quantity and quality of the water.

### 6.2.1 CATCHMENT ENGINEERING

Design plans ensuring the required quantity and quality of water from the catchment consist of a map for the bunds, channels and culverts to divert water, marking the protection zones including fencing. The channels and bunds are placed according to the topography. The extent of the catchment depends on the reservoir capacity requirement, as well as geo-hydrological and hydrological parameters which are assessed.

#### 6.2.1.1 HYDROLOGY

The project area can be considered as a sub-tropical area with a distinct monsoon period in the summer months beginning mid of June and lasting till September, and a drier period between

November and April. Average precipitation of the five year period prior to project start 2007 to 2011 is 1386 mm annually. In the monitoring year May 2015 to April 2016, it rained more than average with 1978mm. A rain peak of 1033mm in July 2015 and additional downpours of 104mm and 146mm in February and March 2016 respectively contributed to the precipitation pattern[149]. Yearly cumulated potential evapotranspiration is 1522mm[149], with higher evapotranspiration potential during March to May (Figure 13). The catchment area can be considered as flat cultivated area with open sandy loam having with a runoff coefficient of 0.3[150].

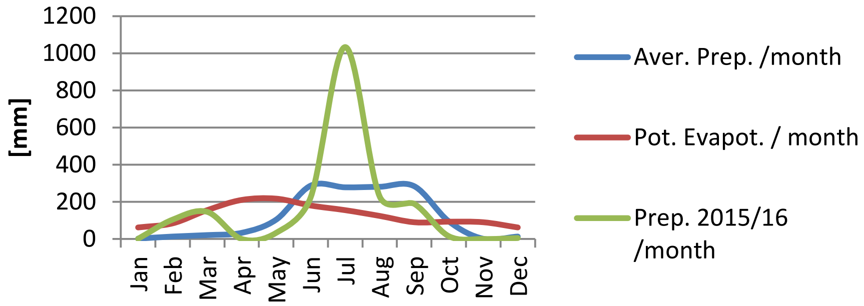
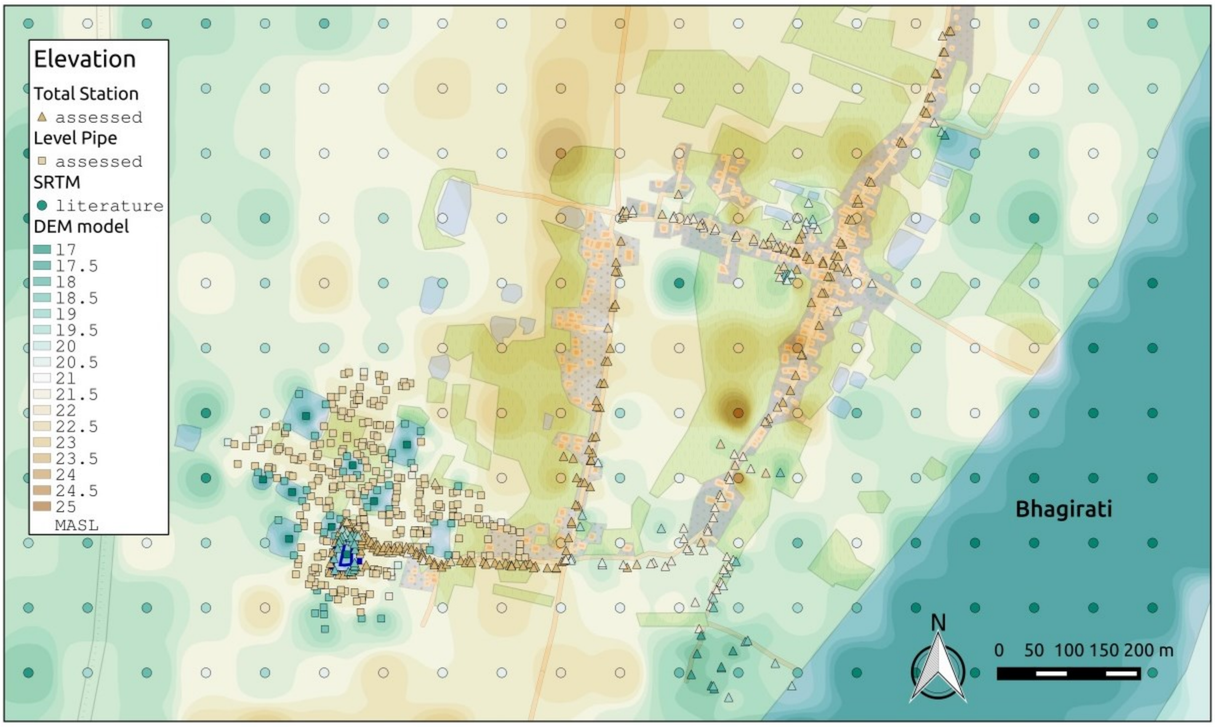



*Figure 13 Precipitation and Evapotranspiration patterns in the region*

#### 6.2.1.2 TOPOGRAPHICAL SURVEY



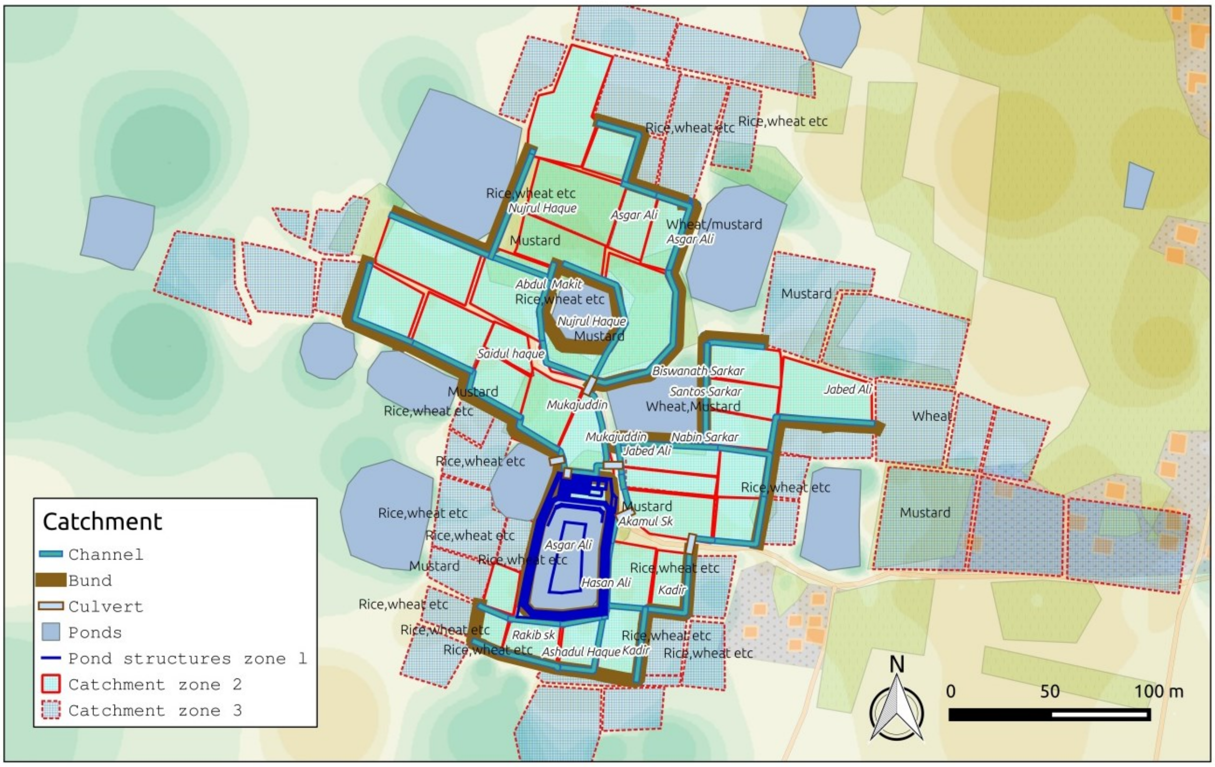

*Map 3 Topography of the project area assess by level pipe and total station as well as SRTM data*

Topographical survey is conducted with a simple level pipe measurement (N=334), total station (N=322) and combined with SRTM 90m grid data [151] (Map 3) . The inhabited village area has an average elevation between 22 and 24 meters above sea level (MASL). Bhagirathi river water level fluctuates between 17 and 20 MASL. The design height 0 which is the maximum filled pond and entrance height of the silt trap is at 20.7 MASL. All structures at the surface water site are constructed at an elevation of 1m above the full pond level, thus at 21.7 MASL. The OHT tank for the water distribution thus has to consider 2.3m elevation to the highest point of service delivery. The surrounding potential catchment area of the pond ranges from 0 to from 1.6 m above the pond entrance. The location for the waste water treatment unit lies at 19.5 MASL and adjoining fields are as low as 17.5 MASL, making them suitable for discharging the treated water but also susceptible to flooding during high river levels.

#### 6.2.1.3 GEOHYDROLOGY

Groundwater levels in the area are strongly influenced by the Bhagirathi river in general and by flood irrigation of the adjoining fields. The pond thus infiltrates, recharging the groundwater level when filled by surface water runoff from the catchment during and after the monsoon season. In the dry season groundwater can infiltrate into the pond when the pond water level sinks below the groundwater level due to evaporation of extraction. When water is not extracted generally the pond water level can be assumed to be the groundwater level. This is measured from October 2013 to April 2016 and shows groundwater levels ranging from 1 to 2.5 meter below ground level. The pond, which has a total potential depth of 4.5 meters, is thus perennial due to the groundwater inflow when it reaches levels below 3.5m to 2m depth depending on the season in the year. Detailed observations of the pond level are given in chapter 7.1.1.

### 6.2.2 CATCHMENT STRUCTURES




*Map 4 Plan for engineering of the catchment area showing owner of the plots and main usage of the plots*

The selected pond has a catchment area mainly to the north east reaching up to Malpara. The direct surrounding to the North West and to the south are also slightly higher elevated and thus potential catchments. The area though has many ponds (depressions) in which the water from major parts of the catchment gets collected and which fill up prior to reaching the pond. Thus the un-engineered catchment provides water to the pond only at a later stage of the monsoon period and only seldom during regular rainfalls. As per observation of the local farmers, the pond still fills up in the second

half of the monsoon every year and then overflows to the neighbouring pond which then overflows to the southwest. 35000m² of potential catchment area are to be engineered with 1600m of bunds and channels, which divert the surface runoff directly to the pond (Map 4). Channels are designed as earth excavations of 0.3m depth and 0.5m width. The material excavated from the channels is directly used to build the bund next to it. In total, approx. 240m³ of soil has to be moved.
Before beginning with the construction of the treatment plant, including filters and OHT, the catchment area is set up to cover approx. 25000m² of the 35000m² of potential catchment area. Although the entire area is engineered, some of the fields are later cut-off due to agricultural activities, it is decided to first work with the 25000m² as it suffices with the assumed calculations, and possibly increase the catchment in a second stage if necessary.
Two public toilets are built just outside the potential catchment area zone next to the road and maintenance agreements with local residents signed. The treatment plant including the pond is fenced in December 2014 and repaired in June 2015.

### 6.2.3 CATCHMENT AREA MANAGEMENT

Catchment area is communicated to the stakeholders and stakeholders guided by the water committee are putting efforts in maintaining its management.
For the management of the catchment it is divided into 3 zones in which different scope of activities are permitted and others have to be controlled:
Catchment Protection Zone 1: Pond with structures for water treatment inside the surrounding bunds (zone from which the rainwater directly flows into the pond).
This area is densely fenced and has only one locked main gate, only activities related to the water treatment system are allowed here.
Catchment Protection Zone 2: Direct catchment area catchment engineered with channels and bunds (zone from which water runoff is intended to be collected for the filling of the pond).
This area is public and marked with channels, the local population and farmers have to take care that the following activities are not taking place:

- Open defecation
- Feeding ground for livestock
- Washing place
- Industrial activities
- Solid waste disposal place
- Burial ground
- Uncontrolled usage of pesticides and fertilizer

Protection Zone 3: Wider potential catchment area around the engineered catchment area still having a higher elevation than the pond (zone from which water runoff could flow into the pond in cases of heavy rainfall or flood).
In this area the activities mentioned for zone 2 are to be minimized whereby pesticide and fertilizer usage has to be controlled.
Main activities in the catchment are the cultivation of mango and banana orchards and farming of wheat, rice, mustard and vegetables like cucumbers, eggplant and bitter gourd. Fertilizers are applied mostly during January and December. The core period for application of pesticides is the second half of the monsoon from July to October, thus the core time for filling of the pond. In this period cautious coordination between the operator and the farmers has to take place. The entrance to the silt trap is fitted with a sluice gate so that water can be stopped to enter in case of intense pesticide application during a rain event. Types of pesticides and fertilizers are assessed and specific water test conducted.
Further catchment area protection measures are crop selection, usage of less toxic fertilizers and pesticides, organic farming, controlled water extraction. Agreements for measures and water collection within the catchment area are worked out. Areas of cooperative owners are mapped and

areas which would rather need to be excluded from the catchment area as owners do not agree to satisfy conditions for sourcing water.
Regular maintenance activities which have to be taken up by the water committee are:

- Repair of catchment area fencing for ensuring protection zone 1
- Repair of bunds for protection of inflow of contaminated water in zone 1
- Cleaning of catchment canals and dams prior to each monsoon season
- Cleaning of hume pipes and performance checking of entrance gate to pond
- Closing of entrance gate in case of any contamination in the catchment area and diversion of collected water into adjacent pond

### 6.2.4 PRE-TREATMENT WITH SILT TRAP

The cultivated catchment area has loose soil and sand which get washed in through the channels in case of stronger rain events. To prevent the pond from quick silting, a silt trap with three chambers is designed. The silt trap has an entry shutter which can be closed when catchment water flow into the pond is not desired, in case of any contamination in the catchment. A second shutter is placed next to the silt trap for draining catchment water into the adjacent pond which is not used as a drinking water source, so undesired water can quickly be diverted and desired water harvested for the pond. The captured silt material can easily be excavated in the dry season when the water level of the pond falls below the silt trap bottom. The material can then be used for repairing the pond bunds. The silt trap is designed with only local bricks, assuming Class 1 bricks with 10% water absorption, they are laid in 1:1/4:3 mortar (Figure 14).

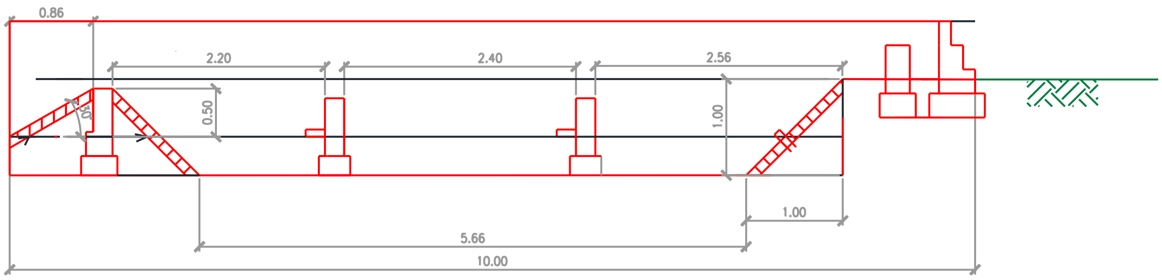



***Figure 14 Side section of the silt trap showing the three compartments divided by the two over fall weirs in the middle, the entrance to the right and the overflow to the pond to the left; dimensions in [m] (complete design set is given in Appendix K)***

### 6.2.5 POND AS RESERVOIR

Having a scanty dimensioned pond provided by the village community, it has to be utilised in an efficient way, making full use of the inflows from the catchment area. The design water extraction from the reservoir is 20m³ a day, resulting in 7300m³ per year. The existing capacity of the pond is calculated to be 5600m³ with a maximum depth of 3.5 m and a surface area of 2050m². Initial plans of increasing the size to 2150m² and digging up the pond to a depth of 7m providing a holding capacity of around 10000m³ is later deemed to be unrealistic [152], thus the plan is revised to increasing the depth to 4.5m with a holding capacity of around 7500m³. Considering the average precipitation pattern, the pond is generally filled by the end of July. It is estimated that this keeps the pond perennially filled (compare Appendix L). Excavations are intended to allow steepness with 23° angle at the sides. An additional step is planned at the side of the structures to provide more stability to the bank. To deepen the pond, approximately 2200m³ of soil is to be moved. The excavated material can be used directly for the construction area, which is to be lifted by 1 meter; furthermore the pond is to be bunded with a 1m bund surrounding the entire pond to protect it from any uncontrolled inflow or overflow. In addition a fence with a gate is planned. Basic water quality monitoring parameters are regularly assessed from 2013 onwards. A sketch of the pond is given in Appendix K.

*Figure 15 Manual excavation of pond*

*Figure 16 Construction of silt trap*

## 6.3 FILTRATION SYSTEM

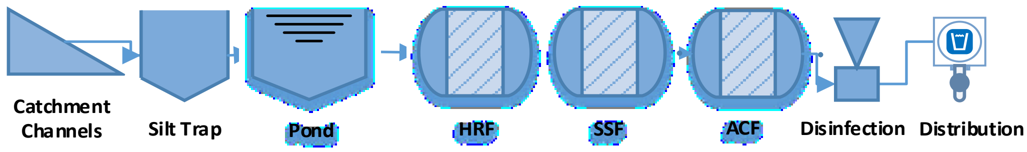



*Figure 17 Filtration process including source and distribution*

The multi-stage filtration system is designed with Horizontal Roughing Filter (HRF), Slow Sand Filter (SSF) and Activated Carbon Filter (ACF). The average treated water requirement is 13KLD, considering a process water loss for cross-flushing and diversion of water after scraping of 10%, the plant has to be dimensioned for an average production of 14.25 KLD. The units are planned considering the available project budget which limits many optimal solutions and requires dimensioning units with the smallest possible design. Nevertheless all designs comply with recognized design criteria. The solar cells are planned to be placed on top, providing shade to the treatment unit and also providing the cells an elevated place where they are protected from potential damages (Figure 18).

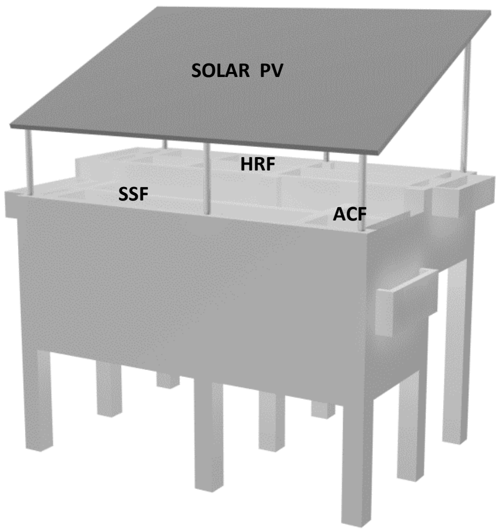



*Figure 18 3D view of filter unit with solar cells on top as shading roof*

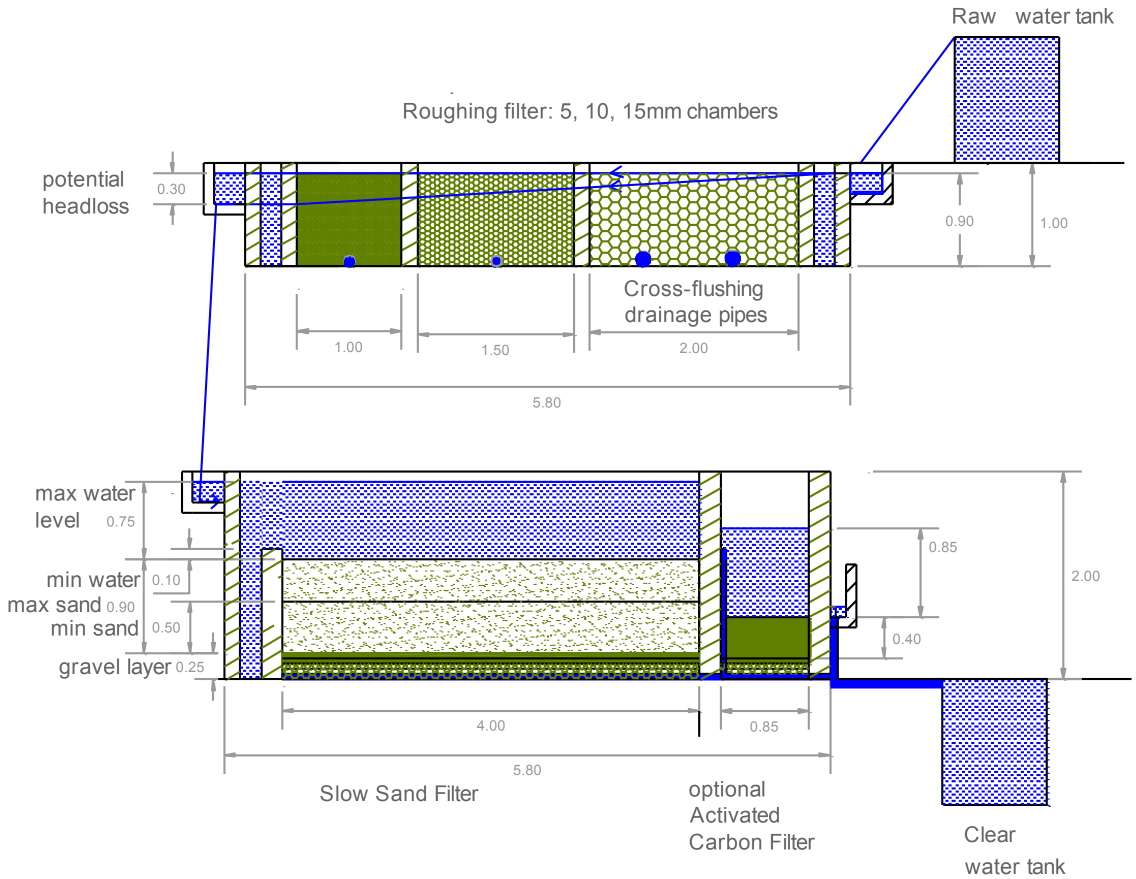



*Figure 19 Section drawing of the HRF, SSF and ACF showing the placement of the filter media*

### 6.3.1 HORIZONTAL ROUGHING FILTERS

The roughing filter is designed to minimize the turbidity load for the SSF. It is intended to have less than 20NTU and preferably less than 10NTU entrance water quality for the SSFs during the entire season. Suitable design parameters basically all refer to one literature source:

*Table 9 HRF design parameters from literature*

| Parameter | Variable | Unit | IRCWD Manual [100] | EAWAG/ SANDEC Manual [73] |
|---|---|---|---|---|
| Filtration rate range | $V_F$ | m/hr | 0,5-1,5 | 0.3-1.5 |
| Average height filter media | $H_{fm}$ | m | 1-1,5 | 0.8-1.2 |
| Length filtration media (flow depth) chamber 1 | $l_{fm1}$ | m | 2-5 | 2-4 |
| Length filtration media (flow depth) chamber 2 | $l_{fm2}$ | m | 2-4 | 1-3 |
| Length filtration media (flow depth) chamber 3 | $l_{fm3}$ | m | 1-3 | 1-2 |
| Diameter grainsize filtration media chamber 1 | $d_{fm1}$ | mm | 10-20 | 12-18 |
| Diameter grainsize filtration media chamber 2 | $d_{fm2}$ | mm | 5-15 | 8-12 |
| Diameter grainsize filtration media chamber 3 | $d_{fm3}$ | mm | 3-8 | 4-8 |
| Head loss prediction for vF range from 0.25 to 1m/hr | $HL_{Total}$ | m | | 0.05-0.15 |

Following the design manual 2 for roughing filters[73] and the constraints given at the site which limit the overall length and also the height of the filter chambers, the following design parameter are developed:

*Table 10 HRF design parameters applied at the pilot site*

| Parameter | Variable | Unit | Value | |
|---|---|---|---|---|
| Total water to be produced | $D_{total}$ | KLD | 14.25 | |
| Flow if continuous filtration of raw water | $Q_{cft}$ | LPH | 594 | |
| no of filter units | $N_{pump}$ | no | 2.00 | |
| Flow continuous filtration of 1 unit | $Q_{ft}$ | LPH | 297 | |
| Filtration rate normal | $v_F$ | m/hr | 0.50 | |
| Filtration rate range | $v_F$ | m/hr | 0.25-1 | |
| Area cross sectional filter | $A_{csf}$ | $m^2$ | 0.59 | |
| Average height filter media | $h_{fm}$ | m | 0.80 | |
| Length filtration media (flow depth) chamber 1 | $l_{fm1}$ | m | 2.00 | |
| Length filtration media (flow depth) chamber 2 | $l_{fm2}$ | m | 1.50 | |
| Length filtration media (flow depth) chamber 3 | $l_{fm3}$ | m | 1 | |
| Diameter grainsize filtration media chamber 1 | $d_{fm1}$ | mm | 15 | |
| Diameter grainsize filtration media chamber 2 | $d_{fm2}$ | mm | 10 | |
| Diameter grainsize filtration media chamber 3 | $d_{fm3}$ | mm | 5 | |
| Head loss prediction for $v_F$ range 0.25 - 1m/hr | | | **$v_F$=0.25** | **$v_F$=1** |
| Head loss filtration media chamber 1 | $HL_{fm1}$ | mm | 16 | 66 |
| Head loss filtration media chamber 2 | $HL_{fm2}$ | mm | 37 | 148 |
| Head loss filtration media chamber 3 | $HL_{fm3}$ | m | 148 | 594 |
| Total head loss | Total | mm | 202 | 808 |
| Head Loss [108] | HL | = | $72*(\mu/\rho g)*(1-\varepsilon/\varepsilon)^2*vF/d^2*lfm$ | |
| with: | | | | |
| Dynamic viscosity (20°C) [82] | $\mu$ | $Ns/m^2$ | 0.001 | |
| Porosity [108] | $\varepsilon$ | % | 0,34 | |
| Density of water | $\rho$ | $kg/m^3$ | 998 | |

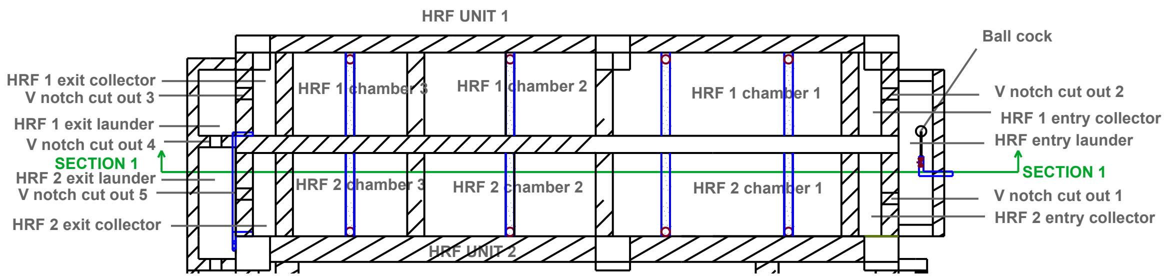


*Figure 20 Plan view of HRF units with piping arrangements and v-notch locations*

Flowrate regulation arrangement is made at the entrance and exit of the HRFs (Figure 20). The level of water in the entry launder is fixed with a ball cock in addition to a ball valve. Between entry launder and entry collector, each HRF line has an individual adjustable v-notch, thus the flow into the filter units can be adjusted by the height of the v-notches. Another two adjustable v-notches are placed between exit collector and exit launder, so that the gradient can be adjusted to up to 30cm. Further the exit launder is partitioned and a provision for a v-notch made. At the bottom of each exit collector one inch drainage pipes are arranged which can be used as sample points and as a source of water for washing of filter media.

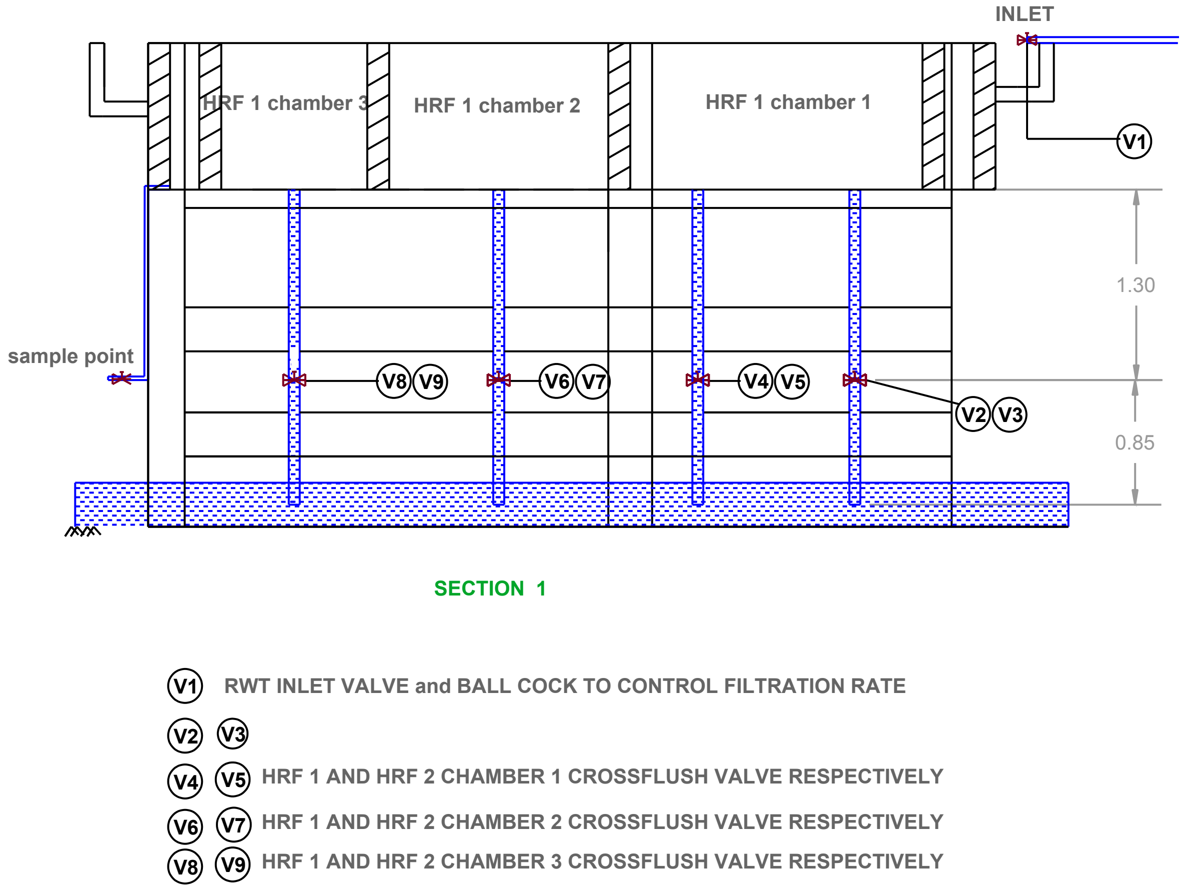



*Figure 21 Section view of HRF units indicating cross-flush pipes, valves and drain*

Cross-flushing arrangement is made for each chamber separately with pipes and valves of 10cm diameter (Figure 21). The longest chamber with 15mm gravel has two cross-flush drainage pipes, whereas the other chambers have one. The valves are placed 1.3m below the floor of the HRFs from where the pipe continues another 85cm to reach 15cm above ground level. The cross-flushing drainage pipe thus produces a suction effect which increases the cross-flushing efficiency of the system. The cross-flush water gets collected and channelled into the silt trap of the pond. The filter efficiency can be predicted with:

$$E_{\frac{C_e}{C_o}} = 0.118 + 0.0231 * d_{fm} + 0.136 * v_F - 0.101 * l_{fm}$$

*Formula 1 HRF Efficiency*[73]

with:

| | | |
|---|---|---|
| $C_e$ | = | filter effluent concentration [mg/l][n] |
| $C_o$ | = | filter inlet concentration [mg/l] |
| $d_{fm}$ | = | media gravel size [mm] |
| $v_F$ | = | filtration rate [m/hr] |
| $l_{fm}$ | = | length of filter bed [cm] |

*n According to the assumptions 1NTU is considered to have 1mg/l SS, compare chapter 8.1*

Considering the prediction of filter efficiency of the individual chambers for kaolin with Formula 1, the filter should be able to handle raw water turbidities of up to 150NTU down to 10NTU at a filtration rate of 1m/hr, whereas in standard conditions raw water around 30NTU should be handled down to 2NTU even at 1m/hr (Figure 22). However, these predictions are to be taken with cautiously as experiences show that performance can vary[107,153].

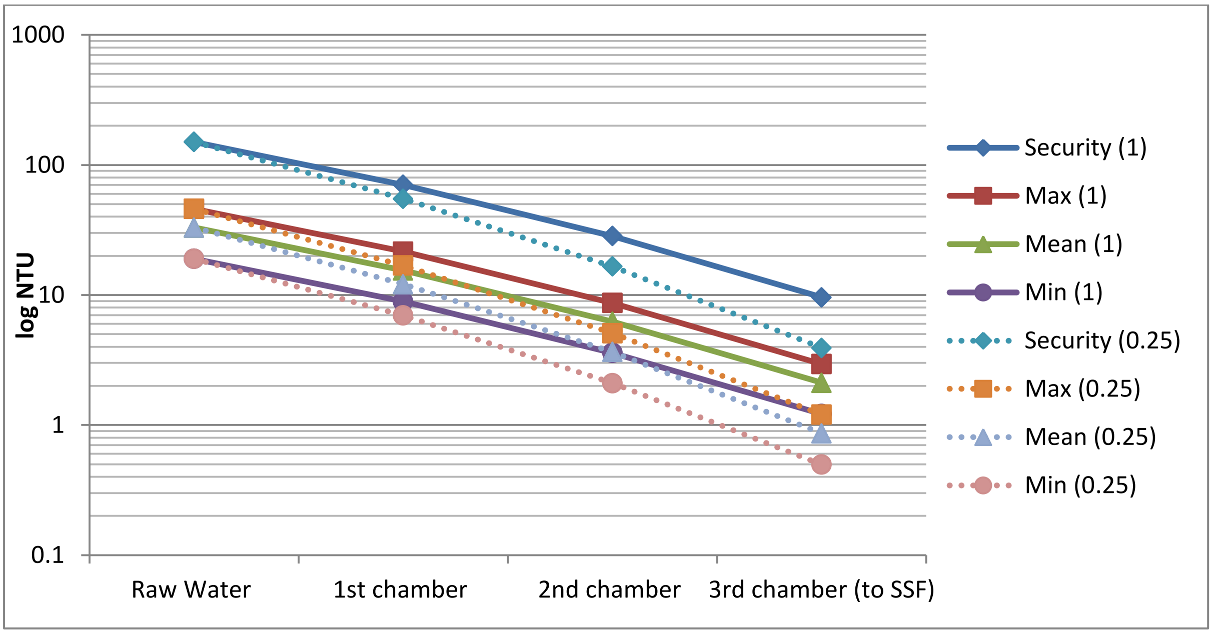



*Figure 22 Predicted turbidity removal of designed HRF for highest and lowest $v_F$=1m/hr and 0.25m/hr*

### 6.3.2 SLOW SAND FILTERS

*Table 11 Design parameters SSFs*

| Parameter | Variable | Unit | 1[154] | 2[82] | 3[155] | 4[156] | 5[75] | 6[157] | 7[158] | 8[84] |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of filter beds | | no | 2 | >= 2 | | >=2 | 2 | | | |
| Filtration rate range | $v_F$ | m/hr | 0.1-0.2 | 0.1-0.2 | 0.1-0.2 | 0.1-0.3 | 0.1-0.2 | 0.1-0.2 | 0.05-0.3 | 0.1-0.2 |
| Diameter grainsize filtration media | $d_{fm}$ | mm | 0.15-0.23 | 0.15-0.3 | 0.2-0.45 | 0.15-0.35 | 0.2-0.3 | 0.2-0.35 | 0.1-0.5 | 0.2-0.4 |
| Uniformity Coefficient (d60/d10) | UC | | 1.5-3 prefer< 2 | <5 prefer <3 | 2-3 | 5 | 5 | 2-3 | wide range | 1.8-3 |
| Heigth sand filled | $hs_{max}$ | m | 1-1.4 | 0.8-0.9 | 0.8-0.9 | min 0.5 | 1 | 0.75-1 | 0.8-1.5 | 0.9-1.1 |
| Minimum height of sand | $hs_{min}$ | | 0.5-0.8 | 0.5-0.6 | | | 0.4 | | 0.5 | |
| Height gravel support | hg | m | 0.3-0.5 | 0.3-0.5 | 0.2-0.3 | 0.2-0.4 | 0.3 | 0.3-0.75 | 0.2-0.4 | 0.3-0.75 |
| Maximum level of supernatant | $DH_{max}$ | m | 1-1.5 | 1 | | | 1 | 1.25 (2/3-4/5hs) | 1.2-1.5 | 0.7-1.2 |
| Turbidity input water max | $Ti_{max}$ | NTU | | 20-30 | | 20 | | 50 | 20 | |

Eight sources have been collected to receive an overview of the design parameters from manuals aimed at construction of SSF for rural communities (compare Table 11).
Although they vary slightly, the core process parameters are similar and are used as guidelines for the site design. The dimensioning regarding sand height and supernatant level can only be realised at the lower edge of the range, due to cost constraints also implied to the feeder tank structure requiring more head for a higher filter. Input Turbidity levels below should be maintained with the designed HRF removal efficiency.
The final design which is given to the contractor for construction has the following parameter:

***Table 12 Design parameters of SSF at pilot site***

| Parameter | Variable | Unit | Value |
|---|---|---|---|
| | | | |
| Total water to be produced | $D_{total}$ | KLD | 14.25 |
| No. of filter beds | | no | 2 |
| Flow continuous filtration of 1 bed | $Q_{ft}$ | LPH | 297 |
| Filtration rate normal | $v_F$ | m/hr | 0.1 |
| Filtration rate range | $v_{Fr}$ | m/hr | 0.05-0.2 |
| Area filter for each bed | $A_{fb}$ | m² | 2.97 |
| Diameter grainsize filtration media | $D_{fm}$ | mm | 0.2 |
| Uniformity Coefficient ($d_{60}/d_{10}$) | UC | | 3 |
| Filter length | L | m | 4 |
| Filter width | W | m | 0.74 |
| Heigth sand filled | $hs_{max}$ | m | 0.9 |
| Minimum height of sand | $hs_{min}$ | | 0.5 |
| Height gravel support | $h_g$ | m | 0.25 |
| Height gravel 1 (1 - 5 mm) | $h_{g1}$ | m | 0.05 |
| Height gravel 2 (5 - 10mm) | $h_{g2}$ | m | 0.05 |
| Height gravel 3 (10-15mm) | $h_{g3}$ | m | 0.05 |
| Underdrainage (15-22mm) | $h_{g4}$ | m | 0.1 |
| Maximum level of supernatant | $DH_{max}$ | m | 0.75 |
| Height of freeboard | $h_{fb}$ | m | 0.1 |
| Total height of filter | $H_{total}$ | m | 2 |
| Minimum height of water on the filter bed | $DH_{min}$ | m | 0.1 |
| Predicted Head loss $v_F*hs_{max}*\mu/k'$[82] | $HL_{fm}$ | m | 0.038 |
| With $v_F$=0.1m/hr and: | | | |
| Intrinsic hydraulic conductivity | k' | N/m | $6.6x10^{-7}$ |
| Dynamic viscosity (20°) | µ | Ns/m² | 0.001 |
| for $d_{10}$=0.21 and UC=2.67[82] | | | |

The predicted initial head loss of 3.8cm still decreases with higher temperatures down to 3.03cm at 30°C. An overview of removal efficiencies for this type of slow sand filters are given in chapter 4.2

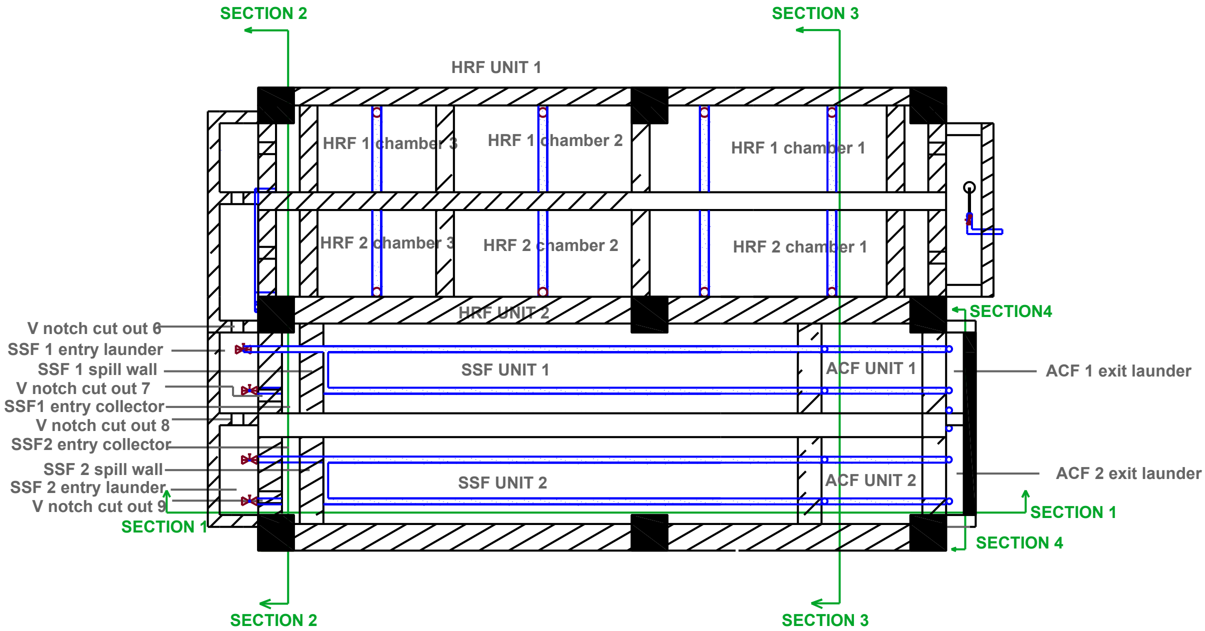



*Figure 23 Plan view of the SSF and ACF units indicating the position of the entry launder, v-notch, entry collector and spill wall*

Similar to the HRF flowrate regulation, each SSF unit can be regulated separately with the help of v-notches. The water enters the SSF entry launder through a cascade from the HRF exit launder to increase the DO level. The entry launder again has the provision to be partitioned into two separate chambers. Two v-notch plates now separate each entry launder chambers from the entry collector. The water flows from the entry collector over the spill wall onto the filter sand (Figure 23) .

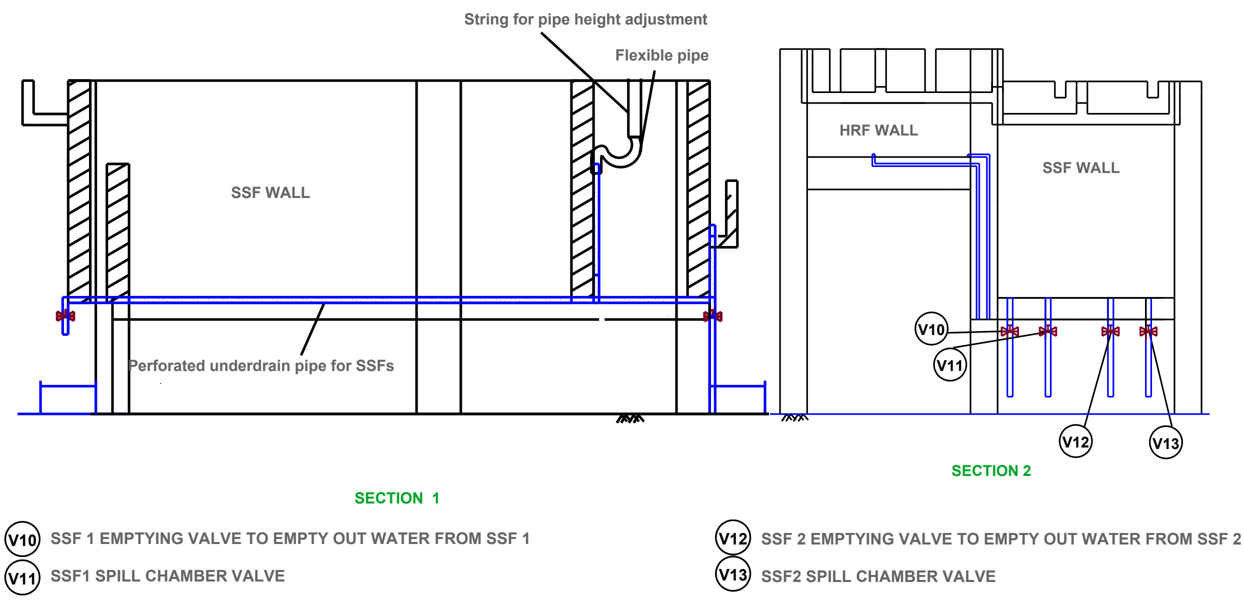



*Figure 24 Section of an SSF and ACF indicating the perforated under drainage pipe of the SSF and the outflow regulation provision of the SSF to the ACF; to the right showing maintenance valves for the SSFs*

The outflow regulation of the SSFs consists of a flexible pipe which can be adjusted by strings in the height of its outflow, thus the head loss can be adjusted (Figure 24).
For maintenance of the SSF the entry collector (spill chamber) and the main chamber can be drained separately, so that the filter bed does not run dry accidently when the operator opens the main chamber drain valve. Piping arrangements for this can also be seen in Figure 23.

### 6.3.3 ACTIVATED CARBON FILTERS

The main design criteria for Granulated Activated Carbon (GAC) filters is contact time of fluid to be treated with the filter media, as well as the adsorption capacity, e.g. measured in iodine number. The contact time for removal of pesticides is given with values ranging from 15 to 30 min. While breakthrough of pesticides could occur after 6 to 24 months, taste and odour breakthrough normally occurs after 2 to 3 years with 10 minutes of contact time[159]. In order to ensure proper treatment, the contact time is designed to have a minimum contact time of 24 min when the SSF filtration rate is at 0.2m/hr, and 48min when SSF filtration rate is at 0.1m/hr. Available iodine values range from 450 to 1200, the higher the iodine value the more adsorption capacity the carbon has and the longer it will work. Unfortunately the price correlates almost directly to the iodine value.

The activated carbon may contribute to the treatment in two ways: firstly as adsorption material and secondly with biodegradation. DOC removal is observed to increase by adsorption for the first 10 to 15 thousand bed volumes. When steady state removals dominate, which are temperature dependent, it indicates that biodegradation is taking place[97].

The following are the design parameters elaborated for the ACF units:

***Table 13 Design parameters for ACF unit at the pilot site***

| Parameter | Variable | Unit | Value |
|---|---|---|---|
| | | | |
| Total water to be produced | $D_{total}$ | KLD | 14.25 |
| No of filter units | | no | 2 |
| Flow continuous filtration of 1 unit | $Q_{ft}$ | LPH | 297 |
| Filtration rate m/hr | $v_F$ | m/hr | 0.5 |
| Area filter bed | $A_{fb}$ | m² | 0.59 |
| Contact time | $t_c$ | h | 0.8 |
| Diameter grainsize filtration media | $D_{fm}$ | mm | 3 |
| Height activated carbon | $h_{ac}$ | m | 0.4 |
| Height gravel support | $H_g$ | m | 0.2 |
| Height gravel 1 (5 - 10mm) | $h_{g1}$ | m | 0.05 |
| Underdrainage (10-15mm) | $h_{g2}$ | m | 0.05 |
| Underdrainage (15-22mm) | $h_{g3}$ | m | 0.1 |
| Maximum level of supernatant | $DH_{max}$ | m | 0.65 |
| Height of freeboard | $H_{fb}$ | m | 0.55 |

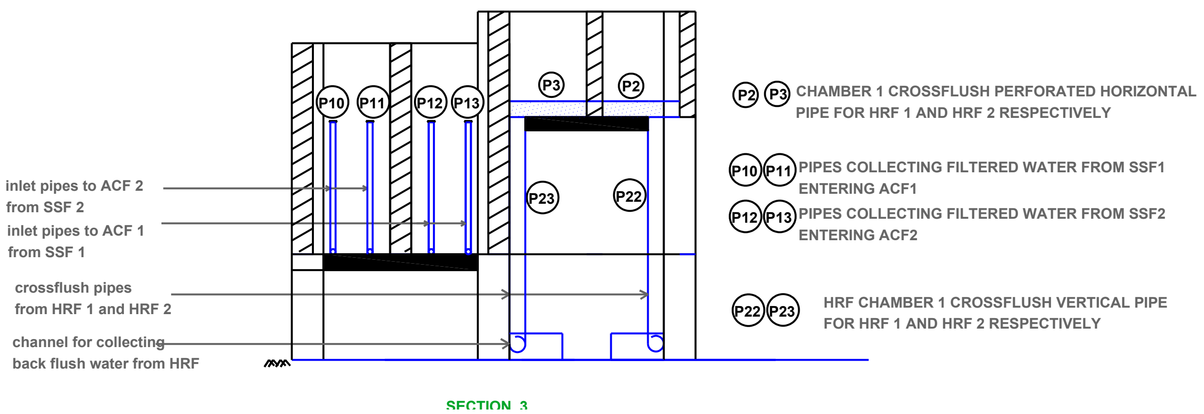



***Figure 25 Section drawing of ACF indicating inlet pipes and section of HRF showing perforated collection pipes and vertical cross-flush pipes***

As indicated in Figure 24 the inlet to the ACF is regulated with a flexible pipe. Two of these pipes enter each chamber (Figure 25)

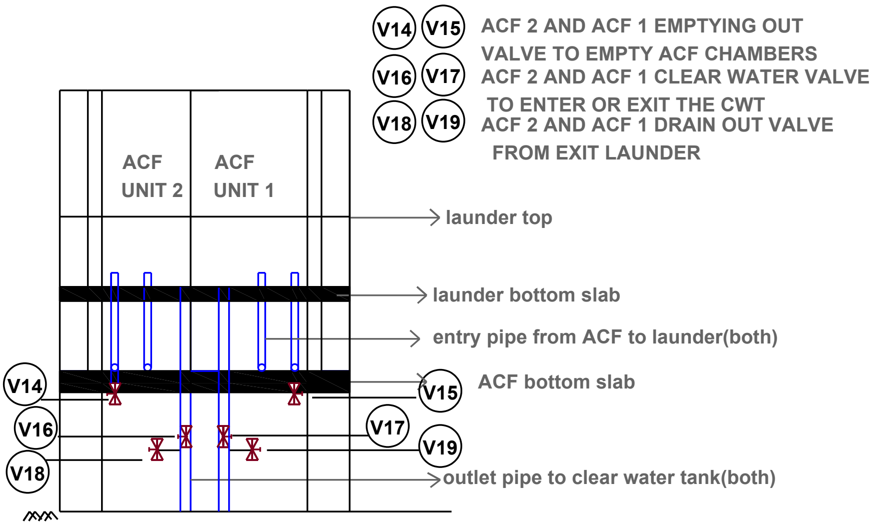



*Figure 26 Section drawing of ACF indicating the maintenance pipes and valves*

The ACF unit is the final polishing unit which does not have any outflow regulation apart from the head created by the flow to the CWT. Valve arrangement are made for the maintenance to empty out each of the ACF chambers, further valves are arranged for the exit launder and the connection to the CWR making it possible to discard filtered water at the final stage, prior to entering the CWT (Figure 26).

### 6.3.4 FILLING OF FILTER MEDIA

Upon finishing the RCC structure it is found that several chambers are not waterproof, especially at the joints of RCC and the pipes and several areas have to be grouted with sealing chemicals. Finally the entire structure is painted with an epoxy coating making it leak-proof and also preventing leaching of calcium and increase of pH and alkalinity [160] which are already slightly elevated in the raw water (compare 7.2). After finally confirming that all individual chambers are water tight and there is no leak bypassing any filter stage - especially in the SSF - the filter media is prepared for filling [129].

#### 6.3.4.1 HRF GRAVEL AND STONE CHIPS

Round pebble-like gravel is not locally available in Murshidabad, and has to be ordered and imported from Kolkata or Purulia and thus is 5 times more expensive than locally available crushed granite stone chips. The stone chips do not have a regular shape, which can possibly have an effect on the filtration performance, thus it is decided to evaluate the different performance of the two media. One of the HRFs is thus packed with round shaped gravel. Both media have been used for roughing filters and are documented to be suitable [73]; a recent study suggested to conduct further research on the difference in performance between these two media [108].
Both media are sieved manually and washed prior to be filled into the chambers; porosity is measured, showing that the stone chips have slightly higher porosity.

*Table 14 Grainsize and Porosity of HRF filter media*

| Material | Size [mm] | Porosity(in %) |
|---|---|---|
| | | |
| Stone chips | 15-20 | 40 |
| Stone chips | 10-15 | 44 |
| Stone chips | 5-10 | 48 |
| Gravel | 15-20 | 34 |
| Gravel | 10-15 | 36 |
| Gravel | 5-10 | 40 |

#### 6.3.4.2 SSF BED PACKING

*Table 15 Packing of SSF filter bed*

| Material | Size [mm] | Height [cm] |
|---|---|---|
| | | |
| Gravel | 20-50 | 8 |
| Stone chips | 15-20 | 5 |
| Stone chips | 10-15 | 5 |
| Stone chips | 5-10 | 3 |
| Stone chips | 4-1 | 2 |
| Sand | >1 | 2 |
| Sand | 0.2 | 90 |

Both chamber gravel supports are packed similarly partly with the gravels left over from the HRF and partly with stone chips. As it is intended to prefer local material, the sand is ordered from a local construction material supplier together with the stone chips. Samples of all filter media are left in water and TDS is measured after 2 days to check on possible leaching; it is found that the TDS does not vary significantly.

The sand for the filters is brought in two batches as the first batch does not provide sufficient fine sand; after sieving to the requirement, only about half of the sand can be used as the other half is too coarse. After sieving, the sand is washed at least five times in the washing basins until the wash water is visibly clean. A final sieving analysis of the filled material shows that the sand in SSF1 has the effective diameter of $d_{10} = 0.21$ mm with a uniformity coefficient $U_C = 2.48$, whereas SSF2 has an effective diameter of $d_{10} = 0.205$ mm with a uniformity coefficient $U_C = 2.68$, matching the design criteria quite well.

#### 6.3.4.3 FILLING OF ACF

The ACF gravel bed is filled similarly to the SSF bed except for the last two fine layers with 1mm sand and 1-4mm stone chips are left away, as the Granular Activated Carbon (GAC) itself has a diameter of 3mm. GAC is filled after two weeks of running the filter in order to wait until the sand is clear washed in order to not unnecessarily exhaust the GAC. GAC is ordered according to design criteria with 3mm granules and with iodine no. 800. It is filled to a height of 40cm on top of the 20cm gravel layer.

### 6.3.5 DISINFECTION

Primarily the reduction of pathogens should be taken care of by the SSF and the filtered water would require only very little additional disinfection. In order to maintain the criteria of having no bacteria in the water, it still has to be disinfected, especially also for supplying it to the village by pipeline 0.2mg/l FAC should be ensured at the last provision point of the distribution network.
Various disinfection options are planned to be tested and compared. The first option is a disinfection device producing mixed oxidants by electrolysation of NaCl. The so-called Ecasol produced should have a FAC concentration of 1100mg/l and can then be dosed with a dosing pump which injects directly into the pipeline from the CWT to the OHT. The dosing pump is triggered by a flowmeter which measures the water flow to the OHT. In this way the concentration of FAC in the OHT water can be adjusted.
As second manual option is the setup of a small mixing tank with a pipeline dripping into the CWT. The mixing tank is filled daily with a liquid disinfectant, and the quantity is calculated by the filtration flowrate of the system. Various disinfection agents are intended to be tried out in comparison to the most easily available bleaching powder (Calcium Hypochlorite). Challenges with the bleaching powder is the precipitation of solids which can easily block the feeding valve.
In comparison to the bleaching powder, readily available liquid chlorine in the form of sodium hypochlorite is much easier to handle and shows good results. Disadvantages are shorter shelf lifetime and a higher price.
As an alternative to chlorine, Alstasan Silvox, a disinfectant based on silver hydrogen peroxide, is tested but found not to be effective in the prescribed dosing.
Disinfection dosing and performance is further described in chapter 8.3.4.

## 6.4 TANK STRUCTURES AND PUMPING SYSTEM

Three tanks with two pumps are required for the treatment system. The raw water pump (RWP) lifts the pond water into an elevated raw water tank (RWT) from where the water is fed into the gravity-based filtration system which discharges its treated water into a clear water tank (CWT). The clear water pump (CWP) lifts the water from the clear water tank to an overhead tank (OHT) from where the water is distributed via a pipeline to the consumers (Figure 12).
Tank structures are designed in order to meet the requirements of the treatment system and the supply to the villagers.

### 6.4.1 DIMENSIONING OF THE TANKS

The requirements for the treatment system are such that the biological process has to continuously be fed with raw water; the process should not stop at any time so that aerobic conditions are maintained, especially in the Schmutzdecke on the SSF [72]. As the system is intended to be run on solar power, either the solar system has to have a sufficiently dimensioned backup to constantly pump raw water even at night, or the tank size has to be dimensioned so that it can provide water during the period in which no electricity is available for pumping. For the Solar Energy Based Slow Sand Filtration (SEBSSF), these two criteria can be optimised in order to keep investment expenses and maintenance expenses low.

The pumping power required for the RWP and CWP is calculated with a required lift of 15m considering pressure losses of valves, bends etc. In order to lift a maximum of 30 KLD in the average of 6 sun hours per day, a 5000LPH (0.0014 $m^3/s$) flowrate is required.

*Table 16 Calculation of required pump power*

| Parameter | Variable | Unit | Value |
|---|---|---|---|
| Max demand surface water scheme | $D_{sws}$ | KLD | 30 |
| Time solar pump | $t_{sp}$ | hours | 6 |
| Flow solar pump | $Q_{sp}$ | $m^3/s$ | 0,0014 |
| Pump head pond to unit / CWT to OHT (Suction, delivery and friction) | H | m | 15 |
| Unit weight of water | $\gamma_W$ | $kN/m^3$ | 9,81 |
| Water horse power required WHP= $\gamma_W$*Qsp*H/0.735 | WHP | HP | 0,28 |
| Pump set efficiency | η | | 0,60 |
| Brake horse power required | BHP | HP | 0,46 |

Research for standard energy-efficient pumps available with local suppliers leads to 1HP sets which are guaranteed to provide a sufficient flowrate. A suitable model with sufficient suction head seems to be the 1HP Kirloskar KDS-116 which has a rated discharge of 7200 to 19260 l/h at a total head of 18 to 6m. Although higher values are given in the specifications, we calculate conservatively with a flow of 5000 l/h (0.0014$m^3$/s).

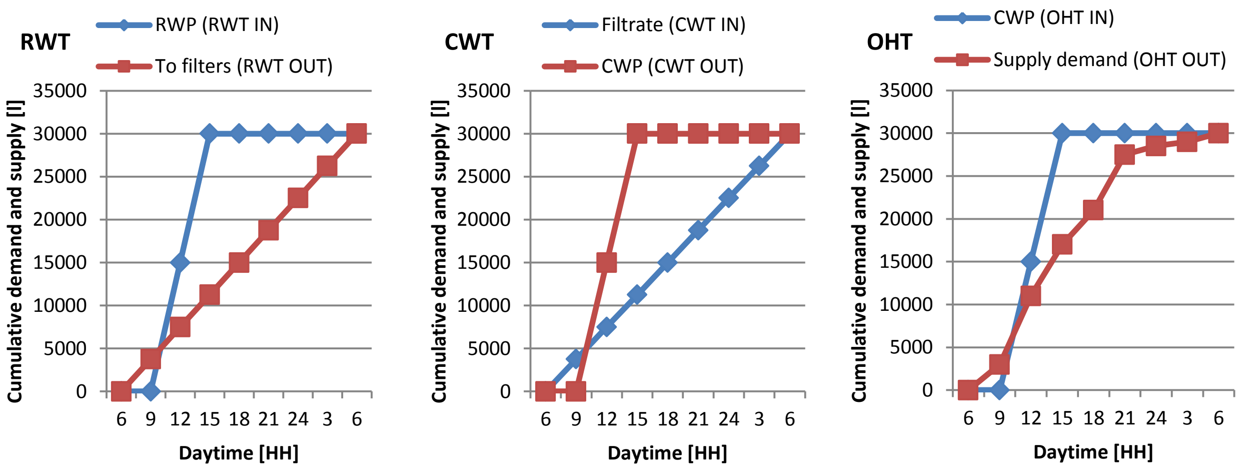



*Figure 27 Cumulated inflow and outflow into the tanks without solar backup*

For the size of the tanks, several options of tank sizes and pump backups are compared in order to take a decision. The first option to look into is having a solar system without backup. This means that the pumps only run for 6 hours from 9:00 to 15:00. The Tank size for the RWT and the CWT then needs to be 22.5m³, whereas the OHT only needs to have 16m³, as the main demand for water is also during the daytime (Figure 27).
Second option is looking into keeping the tanks to a standard size of available 5000L PVC tanks.
With a power backup of 7.3h for both pumps together, it would be possible to have all three tanks sized 4750L. This option is tempting from an investment point of view as a battery backup is less expensive than the construction of tanks more than 4 times the size. 7.3h backup is a risk as a bigger battery backup would lead to maintenance expenses after a couple of years when the batteries have to be refurbished or exchanged. If they were not exchanged, the system would no longer be able to run continuously on normal flowrate. Thus a third in between solution optimised for the solar setup with tanks big enough to run the system on normal flowrate without any energy backup is dimensioned. It has 14000L tanks for RWT and CWT and 12000L. In this way the tank system has a one day reservoir for normal flowrate filtration of 0.1m/hr at the SSF. In addition, this system would require only 3.4h backup (or grid power) to run 30KLD (Figure 28) .
According to assumptions on the demand pattern, a 7500L OHT would also suffice, but as the actual consumption pattern can vary it is decided to construct a 10000L OHT.

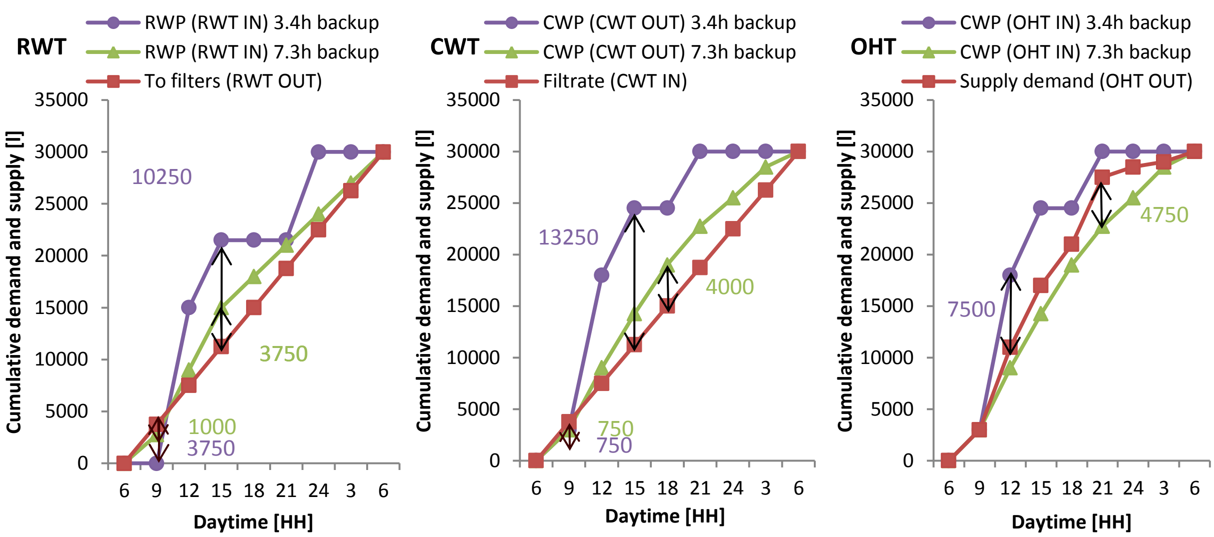


*Figure 28 Optimised tank dimensions with 3.4h and 7.3 hour backup options*

The tank is finally planned as an RCC structure with tank bottom sizes of 5mx2m, also providing a pump house in between the CWT and RWT. Distribution head is 6.4m elevated above ground which is calculated by EPANET to provide sufficient pressure to distribute to the planned number of stand posts and house connections.

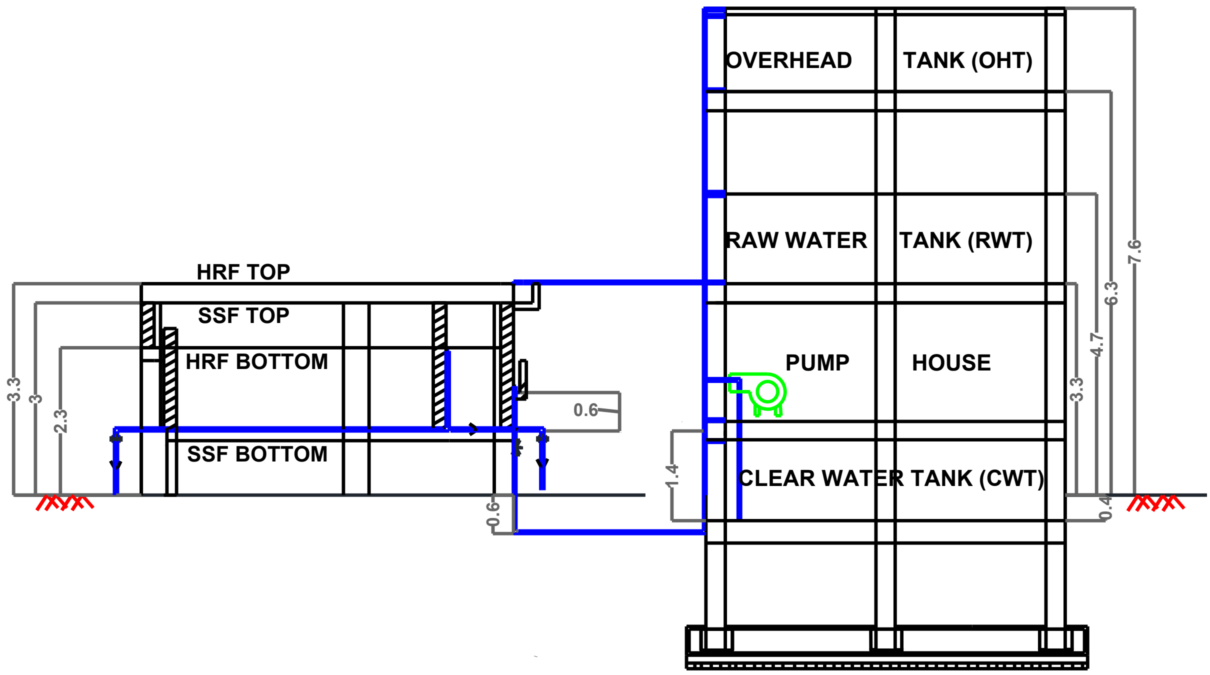



*Figure 29 Tank tower with elevations [m] for free gravity flow*

*Figure 30 MSF in construction*

*Figure 31 Fully setup MSF system*

### 6.4.2 SOLAR SYSTEM

The system is intended to be independent from external energy as the supply in the project region is not reliable and daily load shedding occurs. On the other hand, a solar-based backup system also reduces operation costs and ensures that the biological system stays running and is not shut off in order to save some energy at some point of time, interrupting the biological process and requiring the whole system to start ripening again. As elaborated in the prior chapter, 1HP pumps are selected for the CWP as well as for the OHT pump. Energy required to run the system for 12 hours plus 3.4 backup is calculated to be 750Wx15.4h= 11.55kWh a day. Considering 6 full sun hours, a 2400Wpeak system with a 4KVA smart inverter and 9.6kWh battery backup is designed, together with the local solar company Onergy. The smart inverter can source from the solar cells or the grid and provides power to the pumps with a priority given to the solar cells when enough sun is available. When the batteries are charged and the sun is not available the batteries are used until they reach a certain charge level which can be set, when this is reached grid power is used when available to keep a backup in the batteries in case of load shedding. In this way the batteries always have the 3.4 hour backup available to power the pumps also at night time. For the pump house a switch over between the solar system and the grid power is also planned so that all the equipment in the pump house including computer, online monitoring sensors and the bacteriological laboratory including incubator can run without interruption.

## 6.5 MONITORING SETUP AND OPERATION OF THE SYSTEM

Various monitoring provisions are setup for supervision of daily operation but also specifically for performance evaluation. The entire plant is setup in a way that samples can be taken at various process stages of the multi-stage process and that sensors are placed at locations important to be supervised. The pump house on top of the CWT provides space for a small field laboratory; here various field test kits are placed and water quality tests can be conducted offline. In addition, various online parameters are monitored with sensors and the results are logged into an excel sheet on the server computer which is also placed in the pump house. The Server computer is always online (connected to the solar backup) and has a continuous GSM connection. The computer can thus be accessed from anywhere via Teamviewer[o] and the scada interface accessed or log files downloaded. Thus offline and online monitoring can supplement each other, verify values and show a wide range of parameters on the one side and continuous measurements on the other side.

### 6.5.1 GENERAL PERFORMANCE MONITORING

Being a semi-automatic treatment process, the filtration system requires regular observation by the operators. The following processes are the most important and need to be checked:

- General availability of solar and grid current and functioning of equipment
- Flowrate of intake pump (-> cleaning of intake if clogged)
- Online turbidity values (-> divert to drain if parameters are not met)
- Daily check of flowrates and water levels / head losses of filter units (-> removal of possible clogging by dirt, possibly cross-flushing and/or scraping)
- Cross-flushing of roughing filter preferably at noon time if head loss is more than 20cm (at least once a week)
- Scraping of 2cm top sand level of SSF if head loss exceeds 40cm
- Refill slow sand filter if sand level is lower than 75cm (including gravels support)

A checklist for the performance monitoring of the entire system including online monitoring equipment is developed (Appendix L). Details of daily operation and maintenance activities are given in the separate O&M manual.

### 6.5.2 FLOWRATE MEASUREMENT

As the installed online flowmeters do not perform, flowrates have to be measured manually. Two practical ways are applied; one is by filling a container with a specific volume and timing how long it needs to fill. The other provision which is set up at various places in the filter system (compare 6.3.1) is the v-notch.

***o www.teamviewer.com***

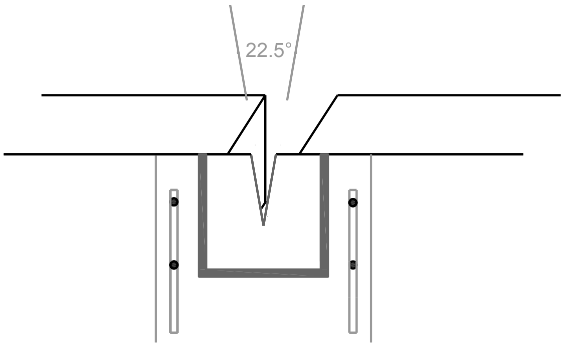



*Figure 32 Setup of the v-notches for measuring and regulating the flow of the filtration process*

For easy measuring of small flowrates the v-notches are specially designed with a small angle so that flowrate changes could be read by eyesight. For this purpose 22.5° is chosen so that the normal flowrate of 4.86 LPM (0.1 m/hr at the SSF) had a height of 3.6 cm. The low flowrate of 2.43 LPM (0.05 m/hr at SSF) had a height of 2.7cm and the high flowrate of 9.72 LPM had a height of 4.8 cm [161]. As the designed v-notch is much smaller than any comparable theoretical design, the actual flows are measured and calibrated.

*Figure 33 Epoxy lining of the filter unit*

*Figure 34 Inlet flow control with ball cock and v-notch*

### 6.5.3 OFFLINE WATER QUALITY MONITORING

Offline monitoring is conducted with simple field test kits and water quality probes. In addition laboratory tests at the JU laboratory have been conducted in order to verify field results or measure parameters which it is not possible to test with field test kits.

For an effective testing, sampling points have been installed which can be centrally accessed in the pump house, here the following stages of the treatment process can be sampled:

- RAW Water from the RWT
- HRF1 treated water
- HRF2 treated water
- SSF/ACF 1 treated water
- SSF/ACF 2 treated water
- OHT distribution water

Sample points and parameters are also shown in Figure 35. Prior to the construction of the pump house samples are taken directly from the pond, the silt trap and the adjacent pond.

A variety of different field test kits and probes are used to conduct the offline assessments. A complete list of the equipment used is given:
- Hach[p] Portable turbidity Meter 2100Q
- Hach pH probe and Pocket Pro pH
- Hach low range TDS probe Pocket Pro LR TDS
- Hach ORP probe Pocket pro ORP
- Hach TDS, DO, temperature multiprobe
- Hach Photometer / Handheld Clorimeter DR900 with chemicals for:
    - Nitrate reagent NitraVer 5
    - Nitrate reagent NitriVer 3
    - Phosphate reagent PhosVer 3
    - Iron Reagent FerroVer
    - Free Available Chlorine Reagend DPD Free Chlorine
- Hach Test Kit CL2 Colorimeter
- Merck[q] Bacteria Testing Kit:
    - Microfil filtration system
    - Vacuum pump
    - Cultura Mini Incubator 230V
    - Consumables:
      - Petri dishes an Chromocult coliform agar,
      - Microfill filtration cups and membrane,
      - Microfilm filter membranes
- Merckoquant arsenic test kit (highly sensititve)
  range/graduation: 0.005-0.010-0.025-0.05-0.1-0.25-0.5mg/l As3+/As5+
- Wagtecl[r] international digital arsenator
- Prerna[s] water quality testing kit:
  pH, turbidity, chloride, fluoride, iron, nitrate, nitrite, alkalinity, hardness, arsenic
- TWAD Board[t] field test kit:
  pH Alkalinity, hardness, chloride, TDS, fluoride, Iron, ammonia, nitrite, nitrate, phosphate, residual chlorine

Measuring methodologies given in the equipment's manuals are followed. For the documentation of offline water quality monitoring during the project period, a monitoring sheet is developed (Appendix 0).

### 6.5.4 ONLINE MONITORING

In addition to the offline measurements provisions are made to monitor several online parameters. The online monitoring system is designed to monitor 32 parameters and is set to operate at a data reading interval of 10 minutes. The following parameters are logged:
- Pump activity
- Flowmeter
- Turbidity
- pH
- Dissolved Oxygen

---

p www.hach.com
q www.merck.com
r www.wagtel.com
s www.prerna.com
t www.twadboard.gov.in

- FAC

As also shown in Figure 35 online sensors are arranged at the following locations:

- 3 pump sensors (Pump act.), type: 220V relays providing information on the pump activity for RW pump, spare RW pump and for the CW pump;
- 3 turbidity meters (Turb), type: SWAN AMI-2 Turbiwell 2-C
  two of them are setup so that their input can be switched: Turb1 for RWT, HRF1 and HRF2; Turb2 for SSF1, SSF2 and OHT; the third one is reserved for the AFM system;
- 7 dissolved oxygen sensors (DO), type Dryden Aqua
  at the pond, RWT, RWT, AFM, CWT, CWT, AFM, HRF, SSF
- Mixed oxygen generation sensor (MO), type: Trustwater Ecasol system
  indicating activity of mixed oxygen generation system (not shown in Figure 35)
- pH sensor (pH), type Veolia
- Free available chlorine (FAC), type Trustwater
  Connected to the distribution line after the OHT
- 7 flowmeters type: INSTRONIX magnetic flowmeter 15mm and 40mm
  for inflow to RWT, RWT to HRF, SSF1, SSF2, AFM, CWT to OHT and OHT to distribution (the flowmeters did not perform properly and are not shown in Figure 35)
- One turbine flowmeter (Flow) standard type connected to a pulse transmitter for monitoring the flow of water from CWT to OHT for triggering dosage of Ecasol

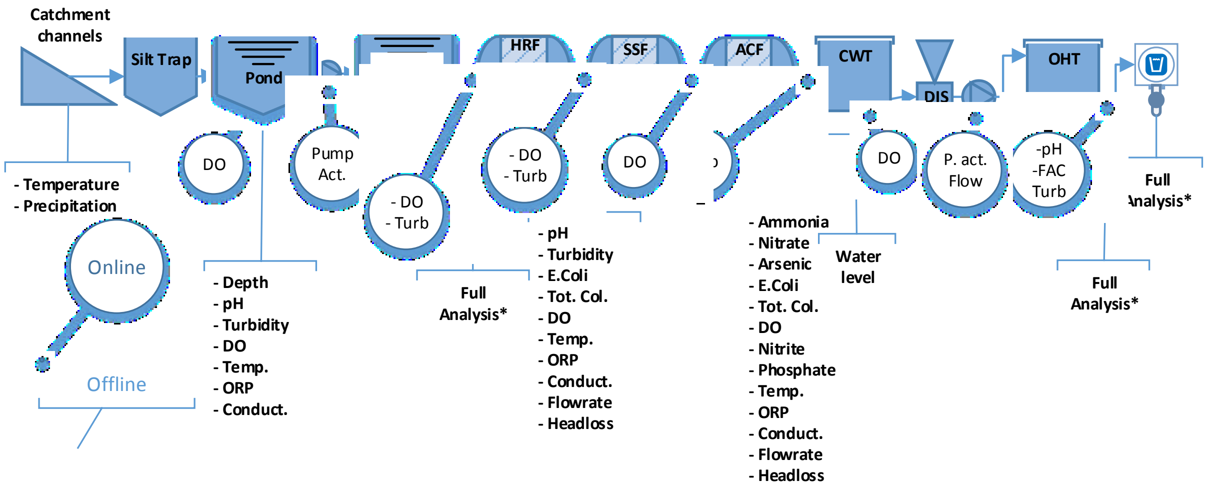



*Figure 35 Online and offline monitoring parameters and sample points in treatment process*
****Full Analysis as per monitoring sheet in Appendix 0***

*Figure 36 Offline monitoring field laboratory*

*Figure 37 Online SCADA computer at the field*

# PART III
# EVALUATION AND OPTIMIZATION

## 7 PERFORMANCE RESULTS

Performance results for the first year of operation including online and offline monitoring results are analysed. First, hydraulic quantitative observations and operational management is dealt with, followed by analysis of water quality measurements. In the coming chapter 8, correlations between various hydraulic parameters are looked into with the intention of concluding on some of the plant's basic operation characteristics and scopes for further improvement analysis.

### 7.1 HYDRAULIC OBSERVATIONS

Available raw water collected through rain water harvesting is being observed in the pond and compared to the assumed design parameters. Flowrates and relations to head loss as well as cross-flushing and scraping intervals as analysed.

#### 7.1.1 CATCHMENT RAINWATER HARVESTING AND RESERVOIR FILLING

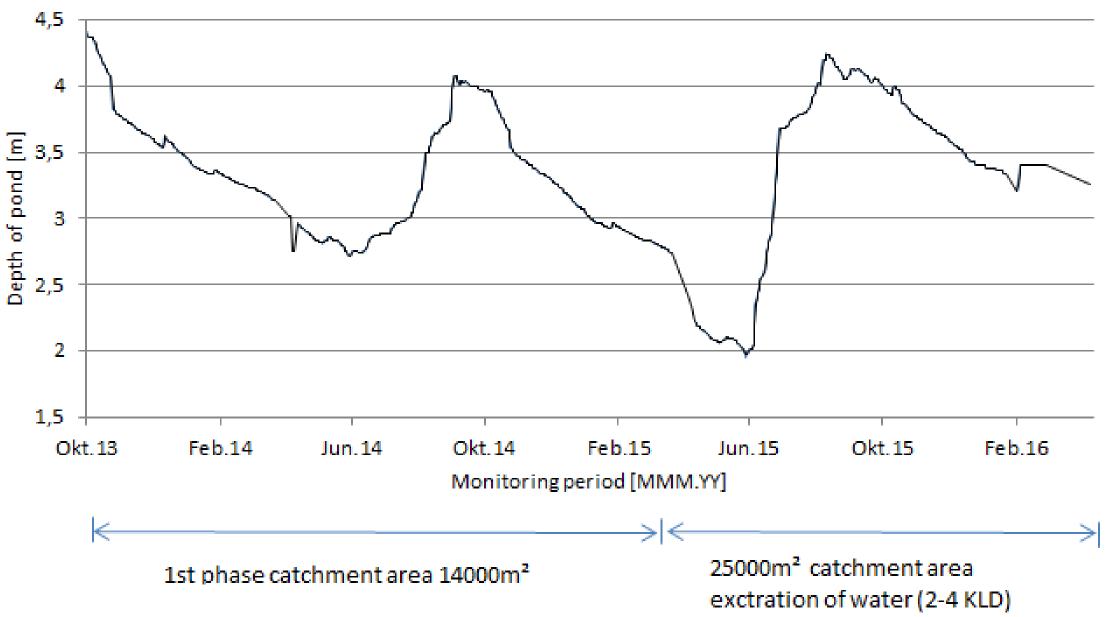



*Figure 38 Depth of pond manually measured with interpolated interruptions between Okt. 2013 to April 2016*

Pond level monitoring starts from the day the pond is excavated in October 2013. Differences of pond water levels can be observed between the first phase of implementation of the catchment area of only 14000 m² till February 2015 and the second phase implementation of the catchment area of 25000 m² together with the extraction of water for the filtration process. The larger catchment area leads to higher water level in the post-monsoon period, and it is able to harvest

water even during less intense rain events outside the monsoon period (e.g. 3.23 m depth of pond in 30th Apr. 16 against 2.35 and 2.83 in 15 and 14 respectively) On the other hand after extraction of water beginning in May 15 the low water level decreased from 2.75 in June 14 to 1.95 in June 15 (Figure 38).
The pond water volume is calculated with actual measured precipitation data in 2015/16 and is then verified with the measurements of the pond water levels showing that the assumptions taken are fitting with the reality (measured, calculated in Figure 39). Consumption during the monitoring period however was only 10-20% of the design consumption (2 -4 KLD), hence the pond did not empty as in the consumption scenarios for 20 or 28m³ per day (KLD). The calculated pond volume under consideration of actual precipitation data and 20m³ consumption still fits well with the average precipitation and 20m³ consumption, showing that the pond would not become depleted throughout the year (calc28m³, calc20m³, aver.20m³, Figure 39). During the monitoring period the precipitation varies from the average precipitation. The measured precipitation shows that there is less rain in the dry period and more rain during monsoon in comparison to the average precipitation pattern in the last 5 year period (measured prec. , aver. prec. Figure 39). This leads to a faster filling of the pond. The findings indicate that the pond suffices as a water source under all assumed scenarios. Details of the pond volume calculations are given in the Appendix L.

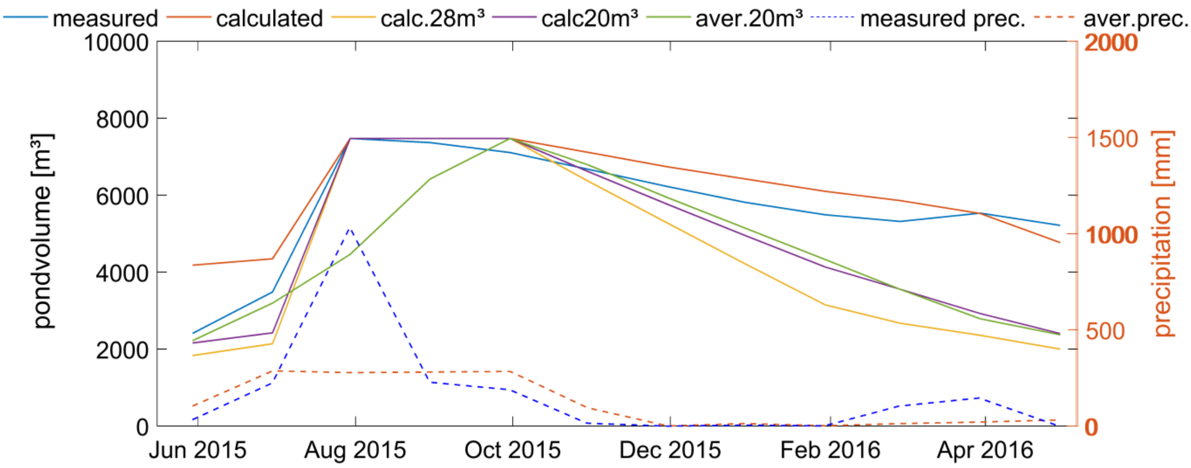



*Figure 39 Design calculation and measurements of various scenarios of pond volumes and precipitation*

### 7.1.2 FLOWRATES AND HEAD LOSS

The drinking water treatment plant's performance depends largely on the flowrate and thus quantity of water produced. While a maximum flowrate is desired on the one hand making the overall size of the plant as small as possible, increased filter runtimes with long scraping intervals are desired on the other hand in order to minimize the maintenance efforts and filter downtime. Both aims of course have the precondition of providing optimal removal efficiency and suitable water quality which is observed in the next chapter 7.2 and then correlated with the hydraulic observations in chapter 8.
Flowrates are measured regularly at various stages of the filtration. As the magnetic flowmeters do not work reliably [162], all flowrate measurements are conducted manually by timing of a certain filled volume and by measuring the height of the v-notches at the entrance and exit of the HRFs and the entrance of the SSFs. The short period of working magnetic flowmeters shows a strong fluctuation in the flowrates of the filters, which can partly be explained by the changing water level of the raw water tank (Appendix O). The flowrate measurements are used to calibrate the v-notch heights which are then a reliable way of measuring the flows. While the theoretical curve[73,161] fits well with

low and high flowrates, the calculated calibrated curve fits better in the range of flow of interest for this plant (Figure 40) and is used for the future flowrate calculation.

Theoretical curve:

$$Q_{cfs} = 4.28\ \mathrm{C} \tan\left(\frac{\theta}{2}\right)(h_{ft} + \mathrm{k})^{\frac{5}{2}}$$

***Formula 2 Theoretical LMNO curve for the prediction of flowrate in v-notch*** [161]

with:

| | | |
|---|---|---|
| $Q_{cfs}$ | = | Flowrate through v-notch in [CFS] |
| $h_{ft}$ | = | head of the water level in v-notch in [ft] |
| $\theta$ | = | angle of v-notch |

coefficients:

| | | |
|---|---|---|
| $C$ | = | 0.59 |
| $k$ | = | 0.0085 |

Calculated calibration curve, better fitting in the range of $Q = [2\ to 10\ LPM]$:

$$Q_{LPM} = 0.36\ h_{notch}^2 + 0.44\ h_{notch} - 0.17$$

***Formula 3 Calculated calibration curve for flowrate in v-notch***

with:

| | | |
|---|---|---|
| $Q_{LPM}$ | = | Flowrate through v-notch in [LPM] |
| $h_{notch}$ | = | head of the water level in v-notch in [cm] |

The wide range of measurements of v-notch heights for each flowrate are due to the diurnal fluctuating flowrates of the system and the delay of stabilisation of water level at the v-notch after a change in the flowrate. The assessed flowrates used in the following chapters are thus to be seen as approximate values.

Flowrates are measured at the entrance and exit of the HRFs as well as the entrance of the SSFs by v-notches. General operation conditions throughout the monitoring period are rather at the lower and standard flowrate range. As the initial normal flowrates around 5 LPM do not show promising results, lower flowrates are tested between mid June 15 to mid Oct 15.

When the system is stable by October 2015 flowrates are slowly increased, but during December and January several operational problems with the electric setup cause interruptions. From February onwards again standard flowrates around 5 LPM are achieved and in April 2016 high flowrates up to 15LPM are tested (Figure 41).

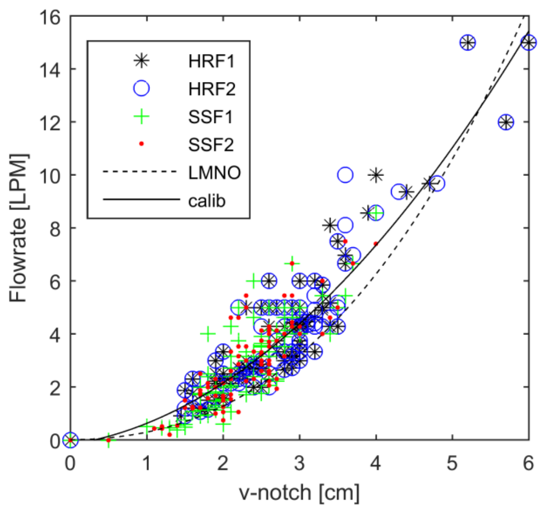



***Figure 40 Calibration of v-notch reading with measured flowrates and comparison with theoretical curve***

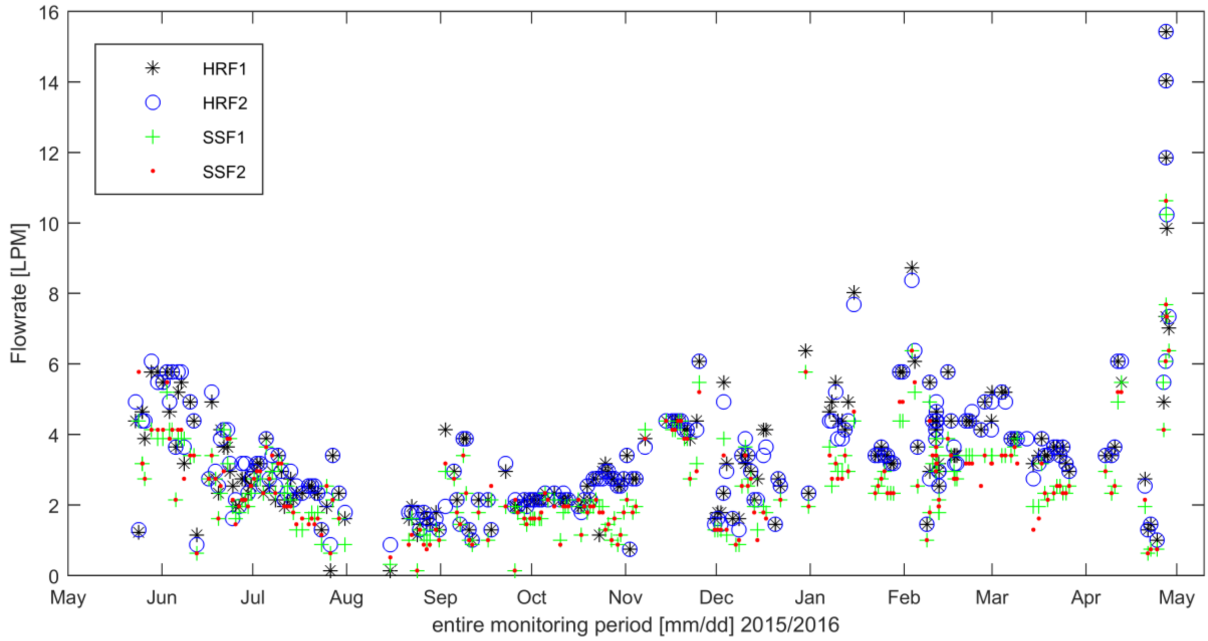



*Figure 41 Flowrates measured with the v-notch at HRF and SSF entrances over the entire monitoring period*

The SSF input flowrates are around 1LPM in average lower than the HRF input flowrates because part of the HRF filtered water is diverted for online turbidity measurement.

### 7.1.2.1 HRF

The HRF system is designed for flowrates between 0.25 to 1 m/hr (2.5 LPM and 10 LPM) whereas the standard flowrate of 0.5m/hr is intended to be maintained most of the time if RW quality permits. In case of RW turbidity higher than 50 NTU the filtration speed is reduced to 0.25m/hr (2.5 LPM) which occurs during the pre- and beginning of monsoon period June 2015 till September 2015 (compare chapter 7.2.1.1). In this period daily monitoring is conducted and thus many values fall in this range. For higher flowrates of around 1m/hr only few measurements are documented. This is because these flowrates occur during the monthly monitoring period end of 2015, beginning of 2016, in this period also tests with maximum flowrates are conducted.

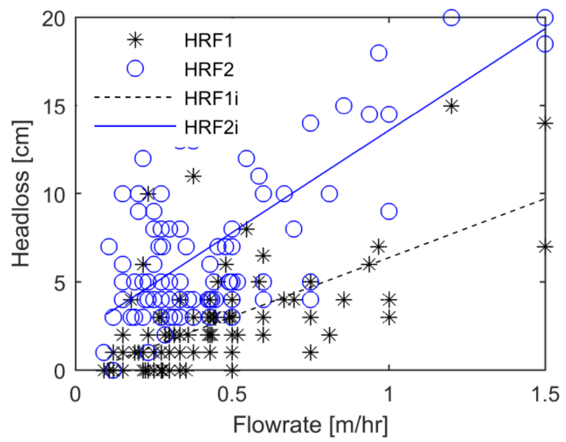



*Figure 42 Flowrate and Head loss of HRFs*

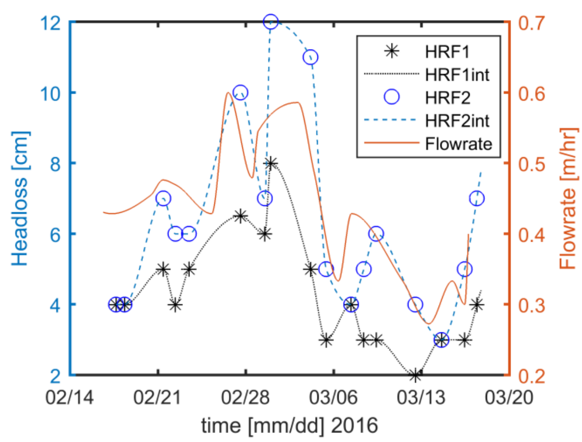



*Figure 43 Head loss and Flowrates in a typical cross flushing interval*

The hydraulic maximum flowrate for the HRF differs for the two HRF media. The stone chip packed HRF1 can handle even more than 1.5 m/hr at a head loss of only 15cm whereas the gravel packed

HRF2 overflows with a head loss of 20cm at 1.2 m/hr and can manage only 1m/hr with a head loss of 15cm (Figure 42). The head loss of the HRFs depends only slightly on the loading of the filter in the comparatively short cross-flushing intervals. As can be seen in Figure 43, in a typical month's cross-flushing period the head loss did not change during the load, but rather with the flowrate. Average head loss for HRF1 and HRF2 at 0.5m/hr is 2 to 4cm and 5 to 10cm respectively compared to a predicted head loss of 3cm.

*Figure 44 Overflow of gravel HRF2*

*Figure 45 Field Monitoring Training*

### 7.1.2.2 SSF

The system design flowrate for the SSFs of 0.05 to 0.2 m/hr (2.5 to 10 LPM) is maintained for the general operational period, whereby during monsoon even a lower flowrate between 1 to 2 LPM is run. For testing purposes the filter is also run at a flowrate of 0.3 m/hr for a short period end of April 2016 (Figure 41). Both SSFs are similar in grain size of 0.2mm (compare chapter 6.3.4) and as per expectations thus also have similar head loss profiles. Both filters have a minimum head loss of 5cm, a head loss of 8cm for the slow flowrate of 0.05m/hr and 10cm during normal flowrate of 0.1m/hr and up to 20cm at 0.2m/hr (Figure 46). This is slightly higher than the predicted head loss of 4cm at a flowrate of 0.1m/hr.

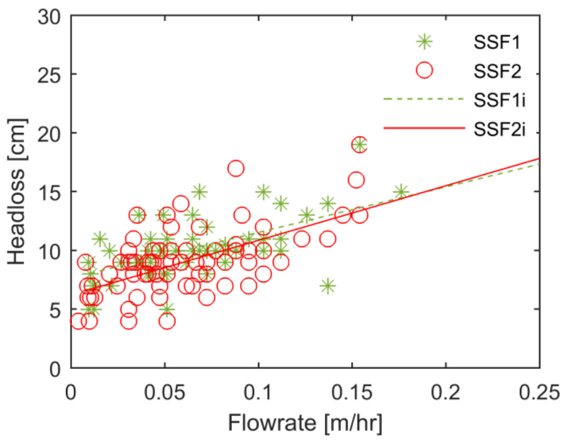



*Figure 46 Flowrate and Head loss of SSFsu*

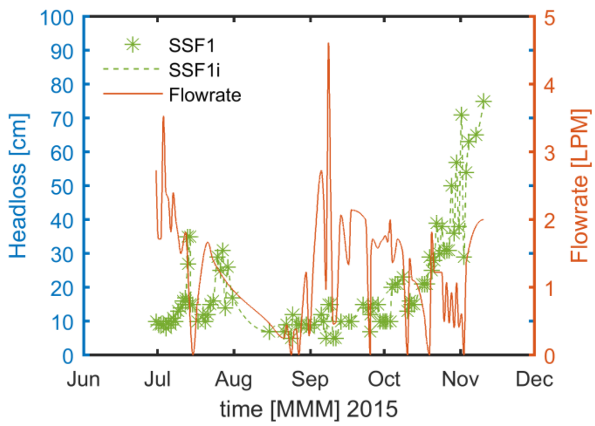



*Figure 47 Flowrate and Head loss during typical scraping interval*

*u Due to the ½ inch piping arrangements for the magnetic flow-meters flowrates of the SSF could only be measured till 0.15m/hr at the entrance of the clear water tank.*

The head loss increase of the SSF with the stage of loading is awaited and used as the indicator for scraping of the SSF. In comparison to the HRF system, the dependency from loading is more important than from flowrate as shown in Figure 47: the rise of the flowrate in September only led to a slightly higher head loss and the head loss increased in November although the flowrate decreased. The SSF does not have any issue in overflowing due to increased flowrate but only due to clogging after a certain period. Regarding the maximum flowrate, the system is thus limited by the HRF system.

### 7.1.3 CROSS-FLUSHING OF HRF

Cross-flushing should be performed as often as necessary but not too often as it consumes water (energy). The interval was chosen to be at least once a month, preferably more often in order to keep the filter media clean and prevent clogging, so that the period till media washing could be prolonged.
Variation of cross-flushing intervals however did not show a clear dependency with head loss. Similarly as in Figure 42, the gravel packed HRF2 shows greater head loss for almost all cross-flush intervals (Figure 48). The complete loading of the HRFs was not tested as more importance was given to the stable performance and frequent cleaning in order to avoid clogging and laborious cleaning of filter media.

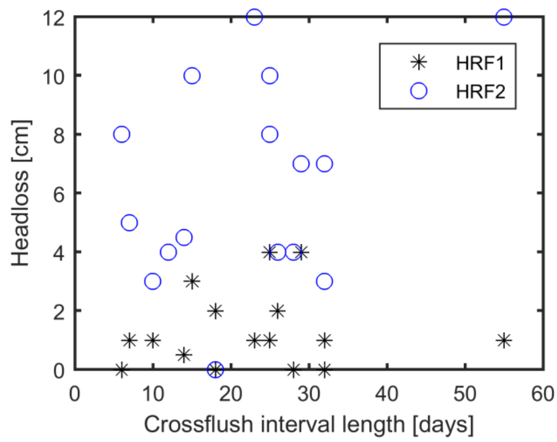



***Figure 48 Lengths of cross-flush intervals against final head loss of HRFs***

### 7.1.4 SCRAPING OF SSF

***Table 17 Scraping interval durations of SSFs***

| Scraping interval | Duration SSF1 | Duration SSF2 |
|---|---|---|
| 1st acclimation | 60 | 58 |
| 2nd ripening | 35 | 31 |
| 3rd perf. 1 | 135 | 139 |
| 4th perf. 2 | 108 | 147 |
| 5th perf. 3 | 53 | |

*Compare*

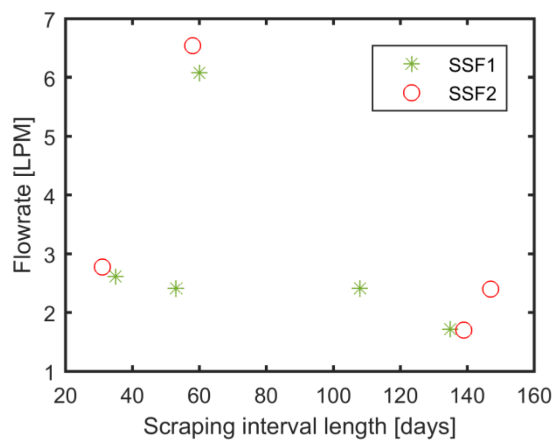



***Figure 49 Average flowrate during scraping intervals***

In the monitoring period of one year, five scraping intervals occur for SSF1 and four for SSF2, each of them with a different length. The first filled SSF2 chamber starts to be loaded on 25.3.15, SSF1 then follows on 27.3. The first starting (acclimation) period is 60 days for SSF2 and 58 days for SSF1 until 24.5 when both SSFs are scraped due to increased head loss. In the second ripening period, scraping already occurs after 31 days on 24.6 for SSF2 and after 35 days 28.6 for SSF1 when head loss increases to 40cm. Third scraping is then done again simultaneously on 10.11.15 for both SSFs, making it 135 and 139 days for SSF1 and SSF2 respectively. Fourth scraping for SSF1 takes place on 26.2.16 after 108 days, whereas SSF2 manages 147 days till 5.4.16. SSF1 has to be scraped again on 19.4 after 53 days having reached a head loss of 44cm. The longer scraping periods above 100 days all have low average flowrates around 2LPM (0.04m/hr). The higher average flowrates around 6LPM (0.12m/hr) have shorter scraping periods around 60 days, indicating that longer scraping periods can be achieved with slower flowrates, loading patterns regarding this conclusion are looked into in the next chapter.

## 7.2 WATER QUALITY

The main aim of the treatment plant is to improve the water quality of the raw water and make it drinkable, complying with the Indian Drinking Water Quality Standard IS10500[163]. The standard comprises of organoleptic and physical parameters, general parameters, toxic substances, radioactive substances, pesticides and bacteriological quality. For most parameters permissible and acceptable (formerly desirable) limits are given, whereby the permissible limit is only applicable if no other water source is available. Not all parameters are monitored or assessed continuously at the site but all parameters of known concern are included in the monitoring program.
The filtration system is providing treated water since March 2015 and monitoring is initiated subsequently. Online monitoring is setup and started on 23rd March 2015. After initial optimization efforts reliable data is produced for some sensors from June 2015 onwards. Intense offline water quality monitoring starts after acclimation and ripening period of the SSF, which takes around 10 weeks. The first phase of regular monitoring begins June 19th and continues until July 17th 2015 with daily tests. Second phase with weekly monitoring continues for another 5 months, which is followed by monthly monitoring, of which results in this study are displayed till April 2016.

### 7.2.1 ORGANOLEPTIC AND PHYSICAL PARAMETERS

No specific test methods were used for Colour, Odour and taste. Odour and Taste of the raw water is perceived as not agreeable, the treated water is accepted by all consumers and no complaints are made. The “soft” and “light” taste in comparison to the widely used tube well water is often mentioned. The colour of the pond water is slightly greenish-brownish, however this colour is removed completely from the visible point of view after treatment, possibly principally by the activated carbon filter.

#### 7.2.1.1 TURBIDITY

The parameter of main concern for a surface water treatment plant (together with bacteriological parameters) is the turbidity value. It is an indicator parameter for the treatment process. The filtration system takes some time to acclimate and reach its stable performance. Two reasons can be seen: First the filter media was absolutely sterile and thus needed a longer ripening period. Recent studies show that acclimation periods in biologically-based drinking water treatment systems have not been properly addressed in many studies to date and that these periods can take several months [164]. Secondly, performance in the first phase was challenging due to high input turbidity values. Thus two phases are analysed separately: the ripening and stabilisation phase from 25.3.15 till 16.9.15 and the stable filter performance phase from 17.9.15 till 2.5.16 (Figure 50).

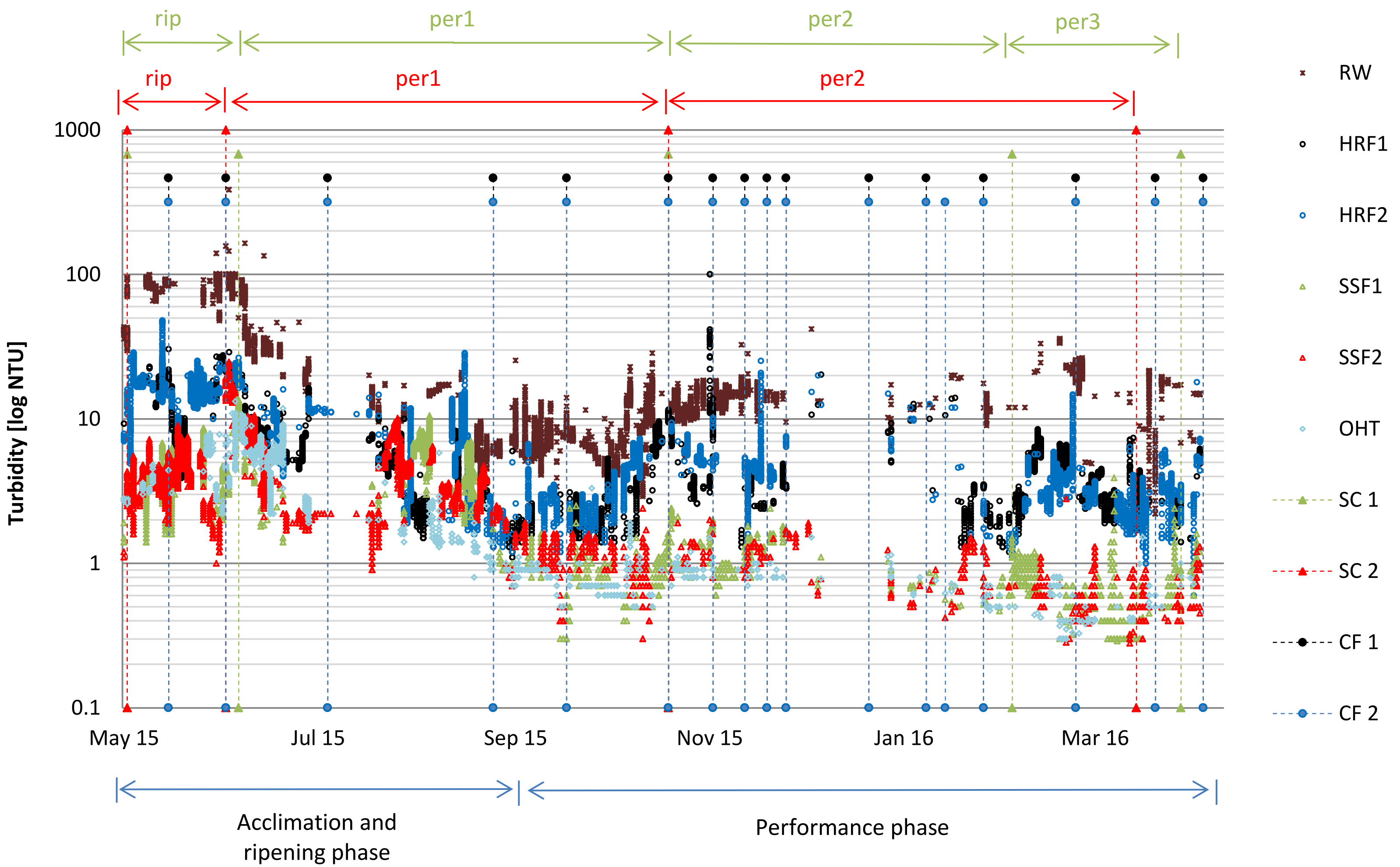



*Figure 50 Turbidity of all treatment stages over the entire monitoring period, scraping (SC) periods (per) and cross-flushing (CF) intervals are indicated*

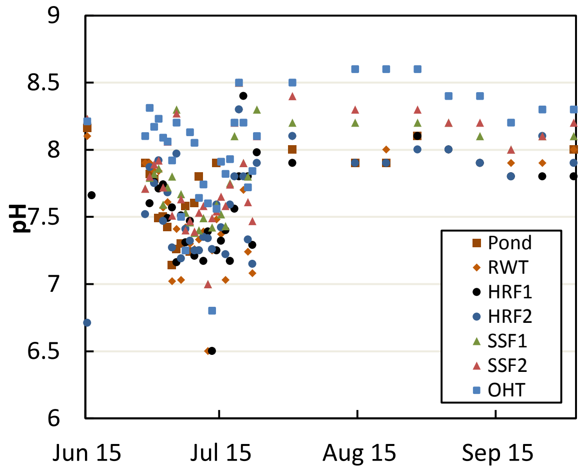
*Table 18 Mean, min, max and standard deviation of turbidity measurements at the filter stages*

| | RWT | HRF1 | HRF2 | SSF1 | SSF2 | OHT |
|---|---|---|---|---|---|---|
| **Entire period 25.3.15 to 2.5.16** | | | | | | |
| min | 2.2 | 1.1 | 0.6 | 0.29 | 0.28 | 0.3 |
| max | 386.0 | 30.5 | 48.1 | 14.8 | 24.7 | 13.2 |
| mean | 21.3 | 5.4 | 6.6 | 1.8 | 2.8 | 2.1 |
| standard deviation | 15.8 | 3.3 | 4.8 | 1.6 | 2.1 | 1.7 |
| **Performance phase 17.9.15 - 2.5.16** | | | | | | |
| min | 2.2 | 1.1 | 0.6 | 0.29 | 0.28 | 0.3 |
| max | 41.8 | 22.2 | 20.0 | 3.9 | 2.8 | 3.3 |
| mean | 11.2 | 3.6 | 3.2 | 0.84 | 1.01 | 0.80 |
| standard deviation | 4.2 | 1.7 | 1.2 | 0.29 | 0.37 | 0.16 |

Turbidity values for the entire monitoring phase have mean values of 21 NTU for the raw water, 5.4 and 6.6 NTU for HRF1 and HRF2 respectively, 1.8 and 2.8 NTU for SSF1 and SSF2 respectively and 2.1 for the final overhead water. Whereas in the period with stable filter performance the mean values are: 11.2 for raw water, 3.6 and 3.2 for HRF1 and HRF2 respectively, 0.84 and 1.01 for SSF1 and SSF2 respectively and 0.8 for the final OHT water, where the OHT water has a standard deviation of only 0.16 (Table 18). The stable filter performance phase thus complies with the acceptable limit of 1 NTU and the max value is within permissible range of 5NTU. The mean value of the entire monitoring phase complies with permissible limit of 5NTU; however, individual values exceed the limit.

## pH

Levels of pH during the entire monitoring period range from 7 to 8.7 averaging around 7.3 to 8.2. As shown in Figure 51 the pH levels increase during the treatment steps. This might be due to the algae development especially in the SSF where a major increase takes place. Another factor is the uncoated concrete structure which leads to leaching of lime in the curing process and thus increases the pH value. The pH value has an influence on chemical reactions in the treatment process: e.g. disinfection with chlorine works best around neutral pH of 7 and does not work well with pH above 8, whereby with pH above 8.5 disinfection with chlorine becomes difficult and requires high dosing.



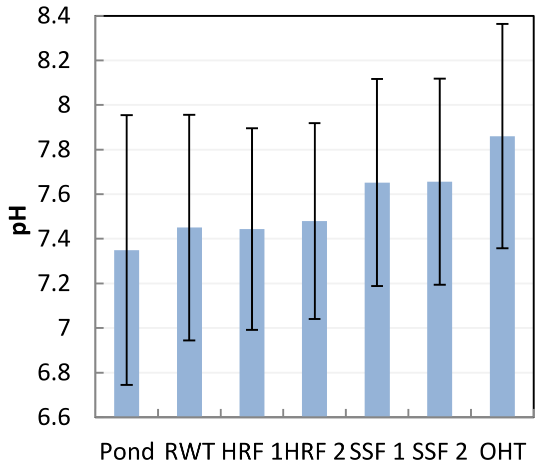




*Figure 51 pH development and ranges at various treatment steps during the performance period*

## 7.2.1.2 TDS

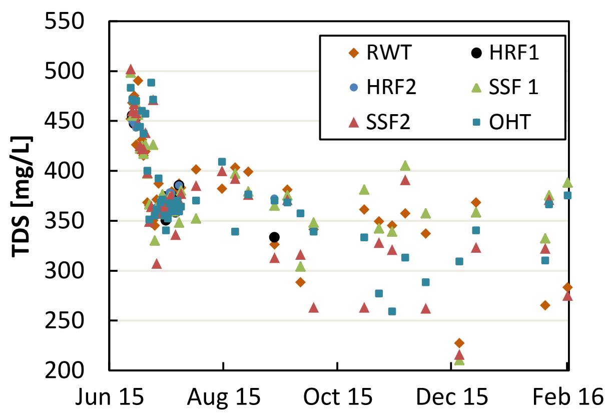



*Figure 52 offline TDS measurements after each treatment step*

TDS is not of concern for surface waters and is always below the acceptable limit of 500 mg/L. It can however be observed that the TDS level decreased during the monitoring period from around 450 to around 300 mg/l similarly on all treatment stages. This can be explained by the rainwater harvested in the month July to September 2015, which had very low TDS and thus diluted the water in the pond. In the pre-monsoon period in June the water level of the pond was low (compare Figure 38) and thus groundwater with higher TDS infiltrated into the pond.

### 7.2.2 GENERAL PARAMETERS

Ammonia and Iron have average concentrations of 0.32 and 0.48 mg/l with some samples exceeding the acceptable limits, but are well removed with 80% and 84% respectively so that they do not play any more role in the treated water (Figure 53). Both parameters would fall under the 80% of acceptable limits in the raw water at least for some samples and could thus be further monitored.

Nitrate and Chloride are well below their limits so that these parameters are not relevant for future monitoring activities. Total Alkalinity slightly exceeds the acceptable value of 200mg/l with 230mg/l and 228mg/l in raw and treated water respectively but stays far below the permissible limit of 600mg/l (Table 19). Nonetheless future monitoring is advisable.

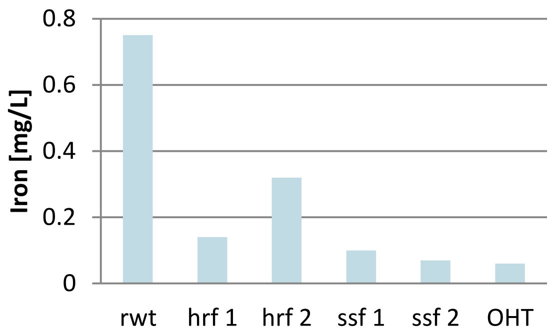



*Figure 53 Iron removal along the treatment steps*

*Table 19 Results of monitoring of IS 15000 general parameters (SD – Standard Deviation)*

| Parameter | Unit | Acceptable | Permissible | Raw Water | SD | OHT | SD | Removal [%] |
|---|---|---|---|---|---|---|---|---|
| **Ammonia (as total ammonia-N)** | mg/l | 0.5 | No rel. | 0.32 | 0.35 | 0.06 | 0.05 | 80 |
| **Iron (as Fe)** | mg/l | 0.3 | No rel. | 0.48 | 0.39 | 0.08 | 0.11 | 84 |
| **Nitrate (as $NO_3$)** | mg/l | 45 | No rel. | 0.78 | 1.42 | 0.62 | 0.66 | 20 |
| **Chloride (as Cl)** | mg/l | 250 | 1000 | 61 | 19 | 48 | 16 | 21 |
| **Free Residual Chlorine (from 1.11.15)** | mg/l | min. 0,2 | 1 | | | 1.07 | 1.17 | |
| **Total Alkalinity** | mg/l | 200 | 600 | 230 | 26 | 228 | 44 | 1 |
| **Total Hardness (as $CaCO_3$)** | mg/l | 200 | 600 | 163 | 29 | 167 | 28 | -3 |

### 7.2.3 TOXIC SUBSTANCES

The main toxic substance in water sources in the region is arsenic. Surprisingly the arsenic levels in the pond are elevated at certain periods. Although the treatment system can remove some of the arsenic, possibly by co-precipitation together with the iron in the water there is measurable arsenic left in the treated water. In the performance period, the average residual arsenic is 7µg/l and thus below the acceptable limit. Nevertheless this parameter stays a parameter of concern which is to be monitored (Table 20).

*Table 20 Offline Arsenic measurement during the performance period*

| Parameter | unit | Acceptable | Permissible | Raw Water | SD | OHT | SD | Removal [%] |
|---|---|---|---|---|---|---|---|---|
| **Total arsenic (as AS)** | mg/l | 0.01 | 0.05 | 0.026 | 0.04 | 0.007 | 0.01 | 72 |

In the scope of the study pesticides are measured once in the water source and tests are not repeated as none exceed the acceptable limit. a-HCH however reaches 80% of the acceptable limit and could thus be considered for future monitoring (Table 21). Pesticides are chosen to be monitored as there is agricultural activity in the catchment area. Reduction of pesticides is approached with catchment area management (chapter 6.2.3) and the final polishing step of the multi-stage filtration by activated carbon. Results on more pesticide and other toxics measurement which are not part of the IS10500 are in the Appendix O.

*Table 21 Pesticides mentioned in IS10500 and measured in the pond water*

| Pesticides | unit | Acceptable | Raw Water |
|---|---|---|---|
| **Atrazin** | µg/L | 2 | 0.0006 |
| **Aldrin** | µg/L | 0.03 | 0.01 |
| **a-HCH** | µg/L | 0.01 | 0.008 |
| **Chlorpyrifos** | µg/L | 30 | 0.006 |
| **o,p DDE** | µg/L | 1 | 0.003 |
| **p,p' DDE** | µg/L | 1 | 0.007 |
| **o,p' DDD** | µg/L | 1 | 0.008 |
| **Endosulphan I** | µg/L | 0.4 | 0.04 |
| **Lindane (γ-BHC)** | µg/L | 2 | 0.01 |

### 7.2.4 BIOLOGICAL PARAMETERS

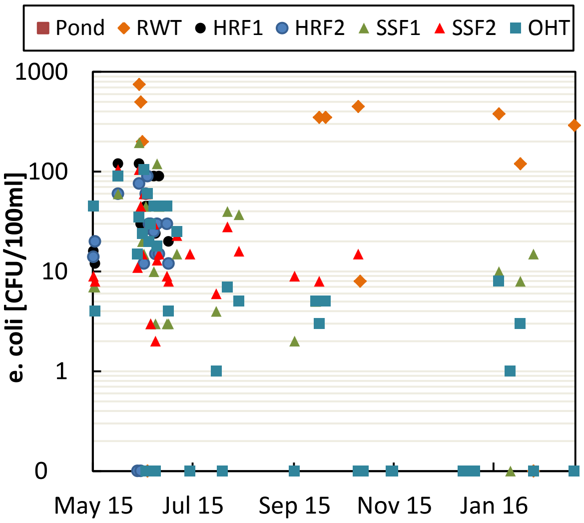



*Figure 54 E.coli at all MSF treatment stages during the entire monitoring period [MMM/YY]*

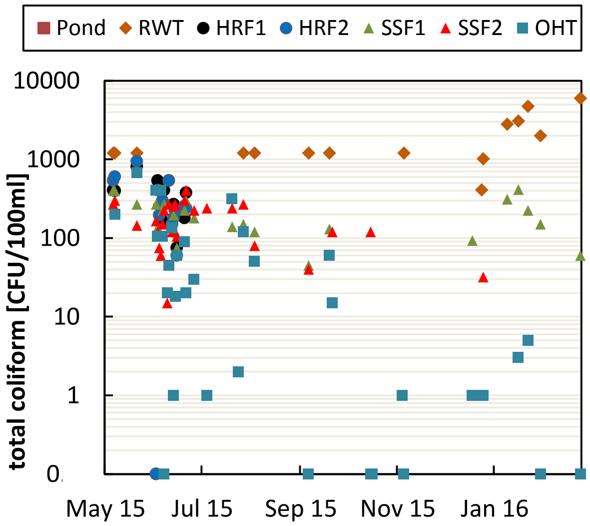



*Figure 55 Total Coliform at all MSF treatment stages during the entire monitoring period [MMM/YY]*

Bacteriological contamination is the main concern in surface waters which are exposed to potential runoffs containing faeces from humans and animals. Various disinfection processes are tried until compliance with 0 colony forming units per 100ml/ is achieved. During the performance period average raw water concentrations of E.coli and total coliform are 176 and 1854 CFU/100ml respectively. The SSFs could reduce these to 6.9 (95% removal) and 128 CFU/100ml (95% removal) respectively, whereas the OHT water had 1.5 (99.1%) and 6.25 CFU/100ml (99.7%) respectively. Thus overall a 1 to 2 log removal is achieved by the SSFs while the disinfection process generally achieves bacteria free water.

### 7.2.5 OTHER WATER QUALITY PARAMETERS OF INTEREST

Although not mentioned in the IS10500, nitrite is mentioned in the WHO guidelines; measured levels are however not of concern. Phosphate is not a problem for health but indicates the amount of nutrients in the water and is often the limiting factor for algae growth which can lead to problems by clogging the treatment process. Dissolved Oxygen (DO) is measured in the pond at the suction inlet, in the raw water tank closely above the ground, on the SSF1 filter bed close above the sand and on the ACF bed (outlet of the SSF).
A major concern is that the SSF media gets anaerobic and then the "Schmutzdecke" culture dies which impacts the biological treatment.

*Table 22 Average measurement results for nitrite, phosphate, DO and ORP*

| Parameter | unit | WHO guideline | Raw Water | SD | OHT | SD | Removal [%] |
|---|---|---|---|---|---|---|---|
| Nitrite | mg/l | 3 | 0.09 | 0.43 | 0.07 | 0.4 | 18 |
| Phosphate | mg/l | n.a. | 2.18 | 0.66 | 1.57 | 0.7 | 28 |
| DO | mg/l | | 4.19 | 1.16 | 6.41 | 1.01 | |
| ORP | mV | | 191 | 61.3 | 193 | 68.6 | |
| Temperature | °C | | 28.2 | 4.2 | 28.2 | 4.2 | |

Oxygen levels fluctuate and offline readings taken once a day during the day time only provide a glimpse of the actual oxygen concentrations. The online readings indicate the diurnal fluctuations. In the selected period DO fluctuates between 2 and 6mg/l at the various stages (Figure 56).

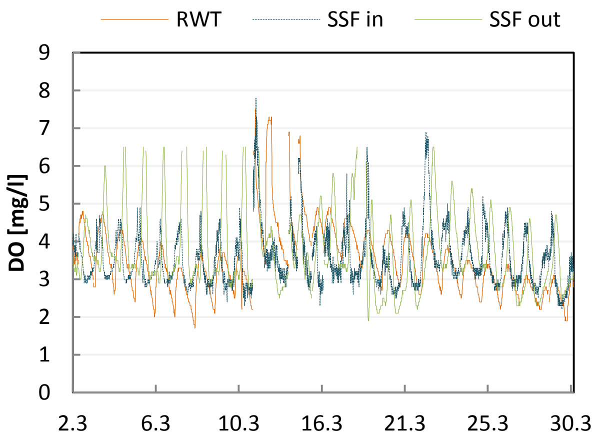



*Figure 56 Online Dissolved Oxygen measurements for March2016 [DD/M]*

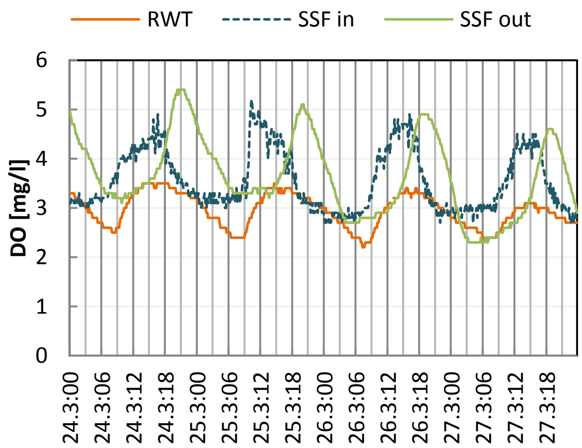



*Figure 57 Close up of readings showing diurnal fluctuations from March 24th to 27th [DD/M:HH]*

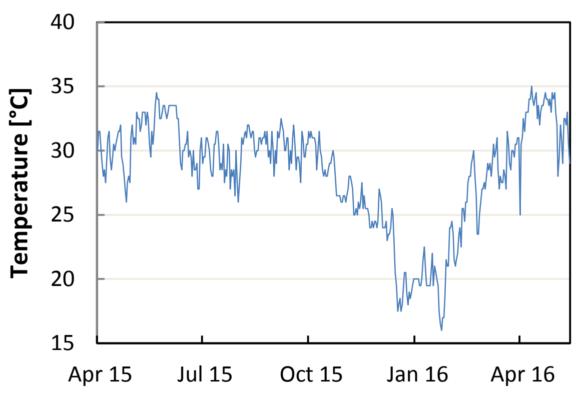



***Figure 58 Mean water temperature at the site during entire monitoring period [MMM/YY]***

A close-up shows the diurnal fluctuations. It can be seen that in the raw water and the SSF input the oxygen level begins to rise in the morning hours and decreases at night. The SSF output has a delay of around 6 hours in this fluctuation. This is approximately the time the water takes to pass through the filter bed (Figure 57). More observations to the oxygen fluctuations are given in Appendix P.

Average temperature at the treatment plant is 28.4°C, which peaks up to 35°C around April to June and has minimum values down to 17°C in January.

ORP measurements show fluctuations between 100 and 300 mV with some exceptions of higher values up to 500mV. Levels higher than 485mV have been observed to decrease survival rates of bacteria [165]. This value is never reached.

# 8 EVALUATION AND OPTIMIZATION OF PERFORMANCE

Optimization is aimed at focussing on enhancing final water quality regarding turbidity and bacteria as well as maximising flowrate and longest scraping intervals. Parameters considered are loading patterns at various scraping intervals, pre-treatment of HRFs and influence on the SSF performance, final achieved water quality and bacteria removal and the influence of flowrates and oxygen levels on removal efficiencies as well as final water quality.

## 8.1 OPERATION CHARACTERISTICS

The basic operation characteristics of the filters are described with their loading of the pollutant they aim at removing during an observed process period. The main pollution parameter for removal of the multi-stage filtration system is turbidity. Turbidity relates to Suspended Solids (SS), the correlation depends on various factors among them particle size and types of particles. A typical correlation range in surface waters is that SS in mg/l range around 0.7 to 1.5 times the turbidity value in NTU for turbidity below 50 NTU [166]. In the following 1 NTU is assumed to correlate to 1mg/l SS so that the absolute load of the filters can be given in kg. The load of the individual filter steps are calculated in the following way:

Concentration of suspended solids (SS) $c_{ss}$ in [mg/L]

$$c_{SS} = c_T * f_{T_{SS}}$$

***Formula 4 correlation between turbidity and suspended solids***

with:

$c_T$ = turbidity in [NTU]

$f_{TSS}$ = factor for converting turbidity to suspended solid [mg/L*NTU]( in our case 1)

Load σ of SS in mg during a period from $t_1$ to $t_2$ in days

$$\sigma = \int_{t1}^{t2} (c_{SSin} - c_{SSout}) * v_f \; dt$$

***Formula 5 calculation of filter load during a certain period***

with:

$c_{SSin}$ = concentration of SS coming into the filter in [mg/L]

$c_{SSout}$ = concentration of SS coming out of the filter in [mg/L]

$v_f$ = filtration velocity in [L/day]

For integrating the non-continuous measurements of the online turbidity values and filtration velocities are interpolated. The source code for calculation can be found in the Appendix 0.

### 8.1.1 SSF LOADS DURING SCRAPING INTERVALS

Loads in kg SS are calculated for each scraping interval mentioned in 7.1.4 except for the starting interval when the filter is acclimated. As shown in Figure 59 in total 75.9 kg in 3129 m³ of water enters the system between 24.5.2015 and 19.04.2016 of which 72.4 kg (95.3%) are removed.
Input loads to the two parallel filter lines range from 10 to 32 kg per scraping period of which the majority is removed by the HRFs (7.9 to 26.3 kg). The SSFs remove only 1.85 to 10.25 kg per scraping interval, whereby the removal during the 2nd performance period is almost similarly distributed with 10.1 to 10.3 kg for HRFs and SSFs respectively. During the initial ripening period with high input turbidity the HRFs remove more than five times as much as the SSFs with 26.3 against 4.6 kg.
The water quantity entering the MSF during a scraping interval ranges from 339 to 1950 m³ for the two lines and between 146 to 686 m³ per SSF. The lower quantities passing through the SSF occur due to the usage of process water in cross flushing, washing of filter media with HRF filtered water, bypassing and draining filtered SSF water when starting and stopping the filtration interval and in online monitoring of the HRFs. In total 943m³ or 30% of the inlet water is used as process water (Figure 60).

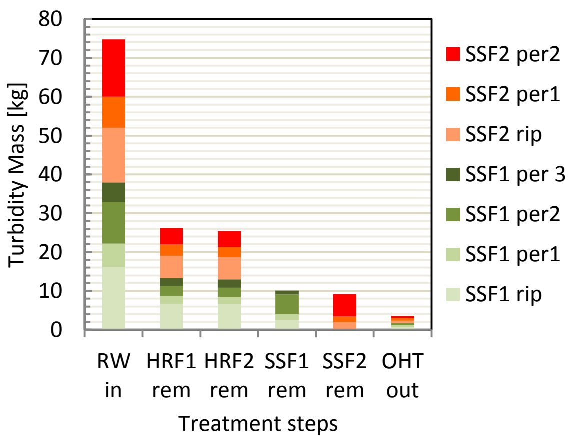



***Figure 59 Turbidity Mass loads removed at each treatment step***

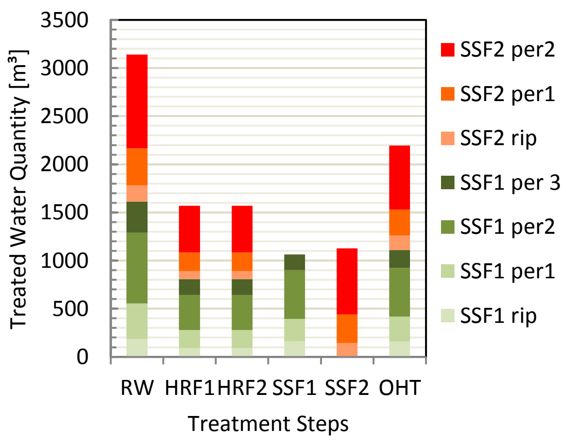



***Figure 60 Treated Water Quantity at each stage of the filtration***

The ripening interval and the 2nd SSF2 performance interval have the highest total input load to the MSF with 32.24, 28.12 and 29.14 kg for ripening SSF1, ripening SSF2 and performance interval 2 SSF2 respectively. This is also reflected in Figure 50 where the high raw water turbidity partly above 100 NTU is shown during this interval. At the same time consequently the ripening interval has the lowest total treated water quantity with only 319 and 298m³ for SSF1 and SSF2 respectively, as well as the shortest runtime of 35 and 31 days for SSF1 and SSF2 respectively (Table 17). The SSF1 and SSF2 are capable of removing only 2.4 and 2 kg respectively.

Lowest loading of SSFs occurred in the 3rd performance period of SSF1 with only 0.95kg and the 1st performance interval of SSF2 with 1.45 kg. Highest loads were removed in the 2nd performance interval of both SSFs 5.12 and 5.8 kg for SSF1 and SSF2 respectively. The surface load of the SSFs ranges from 0.32 kg/m² for SSF1 in the 3rd performance interval to 1.95 kg/m² for SSF2 in the 2nd performance interval. The 2nd performance interval for both SSFs shows the highest loading capacity (Figure 61).

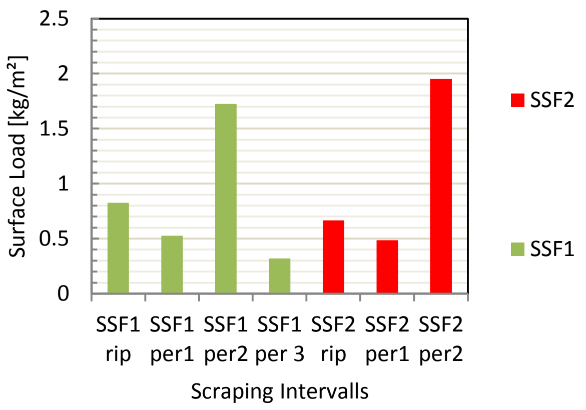



*Figure 61 Surface Loading of SSF for different scraping intervals (performance phases)*

## 8.1.2 LOAD AGAINST WATER QUALITY

Plotting the SSF average input and output water quality against the surface load shows that the highest surface loadings in performance interval 2 of 1.72 and 1.95 kg/m² can be achieved at an average SSF input WQ of 7.5 and 6.4 NTU and output WQ of 0.92 and 0.83 for SSF1 and SSF2 respectively. For very similar input WQ during performance interval 1 of 5.6 and 6 NTU much lower surface loads of only 0.53 and 0.49 kg/m² and output WQ of only 2.37 and 3.14 are achieved for SSF1 and SSF2. Almost similar output WQ of 3 and 4 NTU are achieved with higher loads of 0.82 and 0.66 kg/m² during the ripening phase when input water qualities are 16.1 and 15.3 NTU for SSF1 and SSF2 (Figure 62).

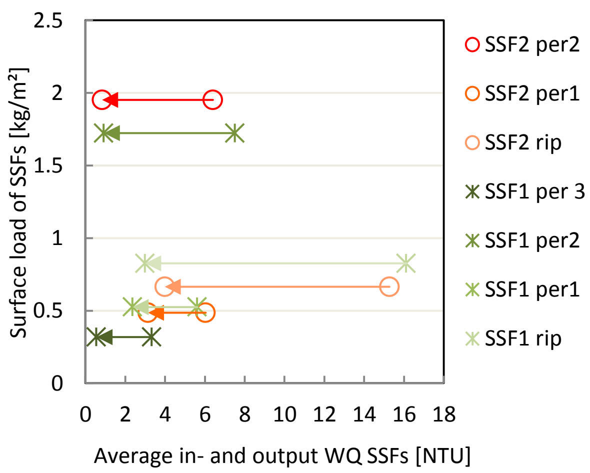



*Figure 62 SSF influent and effluent turbidity indicated with arrows during various scraping intervals related to surface loading*

This either shows that the SSFs were not yet working stable in performance phase 1 or that some other parameters were more preferential in performance phase 2. One hint against the stabilisation theory is that the third performance period of SSF1 could only take up 0.32 kg/m² although quality wise 3.3 was brought down to 0.55 NTU.

## 8.1.3 LOAD AGAINST TURBIDITY REMOVAL

Turbidity removal efficiency differs across the various scraping intervals, while the highest overall removal efficiency is achieved in the SSF1 performance phase 3 (98.2%), the lowest efficiency is achieved with SSF1 in performance phase 1 (89.7%). Highest removal efficiencies for the SSFs are achieved in the second performance phase (91.7 and 91 % for SSF1 and SSF2 respectively). In this phase the HRFs have the lowest performance of 49.1 and 45.9 % for HRF1 and HRF2 during SSF1 performance phase 2, and 57.4 and 56 % for HRF1 and HRF2 during the SSF2 performance phase 2. Remarkable are the high removal efficiencies of the SSFs during the ripening phase of 83.1 and 76.7 % for SSF1 and SSF2 in comparison to the lower removal efficiencies during the performance phase 1 of only 73.7 and 58.3% for SS1 And SSF2 (Figure 63).

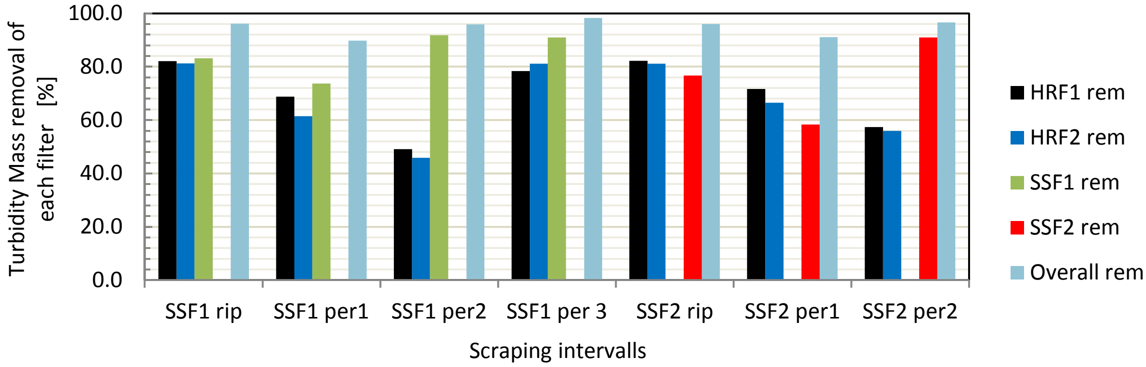



*Figure 63 Removal efficiency of the individual filters during the various performance phases*

Comparing the correlation of the removal efficiencies of the different phases with the surface load shows that the highest surface loads of 1.72 and 1.95 kg/m² also achieve the highest removal efficiencies of 91.8 and 92% for SSF1 and SSF2 respectively, and except from the 3rd performance phase of SSF1 (which has the lowest surface load of all the scraping intervals of only 0.32 kg/m²) surface load and removal efficiency correlate positively (Figure 64). It can be concluded that a high surface loading of an SSF is desirable not only to reduce operational work but also for removal efficiency.

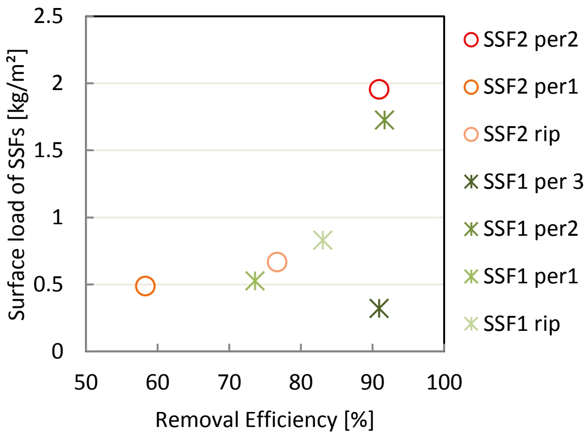



*Figure 64 Removal efficiency related to surface loading of SSFs*

### 8.1.4 LOAD AGAINST FILTRATION VELOCITY

During performance phase 2, highest surface loads are achieved with highest average filtration velocities of 0.068 and 0.067 m/hr for SSF1 and SSF2. The low surface load during performance phase 1 also has low average filtration velocities of 0.025 and 0.03 m/hr for SSF1 and SSF2 similar to the even lower surface load of performance phase 3 of SSF having an average filtration velocity of 0.044 m/hr. The ripening phase makes an exception with high filtration velocity of 0.066 and 0.069 m/hr for SSF1 and SSF2 at medium surface loads of 0.83 and 0.67 kg/m² for SSF1 and SSF2 (Figure 65). Again with exception of of the 3rd performance phase of SSF1 a positive correlation can be concluded suggesting higher filtration velocities.

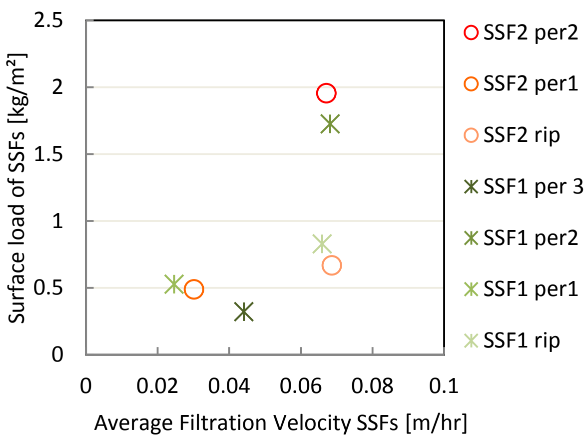



*Figure 65 Filtration velocity in relation to surface loading of SSFs*

### 8.1.5 BEST SCRAPING FREQUENCY FOR SSF

The monitoring period is not long enough to conclude a general scraping frequency, clogging of SSF is very much dependent on the input water turbidity and also algae growth in the treatment system. The latter can be decreased by shading the launders which lead water from the HRF to the SSF. Turbid waters result in a once per month scraping frequency, whereas better pre-treated waters and shading result in a 4.5 month period prior to requiring scraping. Scraping is thus suggested when a SSF head loss of 40 cm is reached, rather than after a fixed period.

### 8.1.6 SSF DIVERSION TIME AFTER SCRAPING

Scraping has an impact on the water quality of the SSF as firstly all the water has to be drained and then also the filter surface is disturbed. It can be assumed that the filter actually has to re-ripen and could take days or even weeks. Observations at the site do not support this theory. Figure 66 shows a typical scraping process of SSF1, the filter was scraped at 9:20 and directly filled with water again. The first 5 hours nothing could be noted as the water takes some time to pass the filter media. Around 6 hours after the scraping a peak with 400% the initial water quality passed but only for a short period, 1 hour after the peak the filter had 200% of the initial WQ, 6 hours after the passing the WQ reached 175% and after 12 hours 150% of initial turbidity.

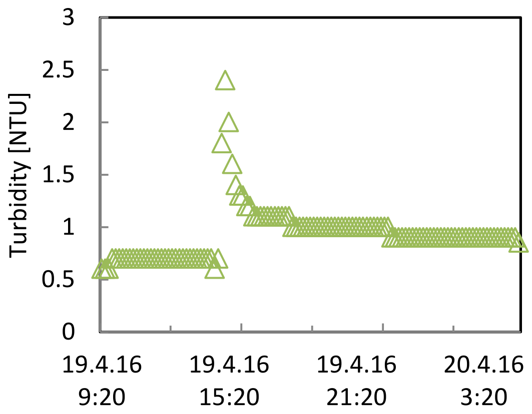



***Figure 66 Scraping process of SSF1 and influence on the water quality [DD/M/YY HH:MM]***

Diversion of water would certainly provide a safeguarding of the distribution water. From the above observations 12 hour bypassing would be enough, considering the intention not to lose too much water in the process.

## 8.2 OPTIMAL PRE-TREATMENT STEPS

Pre-treatment starts in the catchment area followed by the silt trap and sedimentation in the pond. Further sedimentation also takes place in the raw water tank which needs to be washed regularly. Catchment area pollution prevention and treatment improvement has its limitations in the cooperation of the stakeholders and the users of the catchment area. Timely management of the inflow to the silt trap is required to prevent potential high turbid waters or contaminations of any other kind in the catchment entering the raw water reservoir, while an overly conservative approach affects the overall quantity of harvested water. Sedimentation in the pond can be enhanced with the usage of chemicals or by aeration, but both induce additional costs. The last step of the pre-treatment consists of the HRFs. These can be operated in a manner most suitable to the further treatment by the SSFs.

### 8.2.1 INPUT WATER QUALITY AND REMOVAL EFFICIENCY OF SSF

SSFs work well and reliably only up to a certain input turbidity. In order to comply with the acceptable turbidity limit of IS 1500 of 1NTU, it seems necessary to keep the input water quality of the SSFs below 8NTU (Figure 67). This is also the range in which the SSFs have their optimal performance regarding removal efficiency (Figure 68). For staying within the permissible limit of 5NTU in the final treated water, the interpolated approximation in Figure 67 indicates that SSF2 should not have higher inputs than 20, whereas SSF1 seems to be able to handle slightly higher inputs of around 25 NTU.

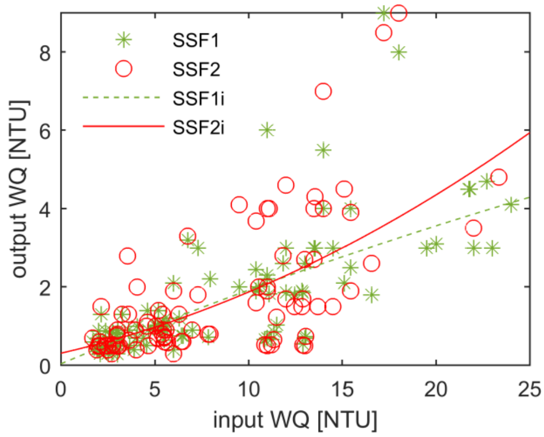



*Figure 67 Input and output Water Quality (Turbidity) of SSFs*

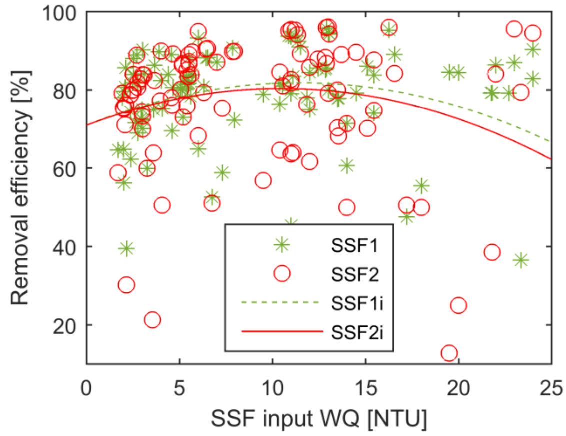



*Figure 68 Input Water Quality and Removal Efficiency of SSFs*

Input water for the SSFs is provided by the HRFs thus the operational changes have to be made at the HRF in order to ensure the preferential WQ of 20 or even 8NTU. Improvement in this regard seems necessary as even in the performance phase only 78% and 54% of SSF1 and SSF2 sample values complied with the acceptable level of 1 NTU, although 90% of all SSF1 and SSF2 samples stay below 1.2 and 1.3NTU respectively (Figure 69). The fitting curves in Figure 67 and Figure 68 also show the better performance of SSF1 in regards to input WQ.

### 8.2.2 INPUT WATER QUALITY AND REMOVAL EFFICIENCY OF HRF

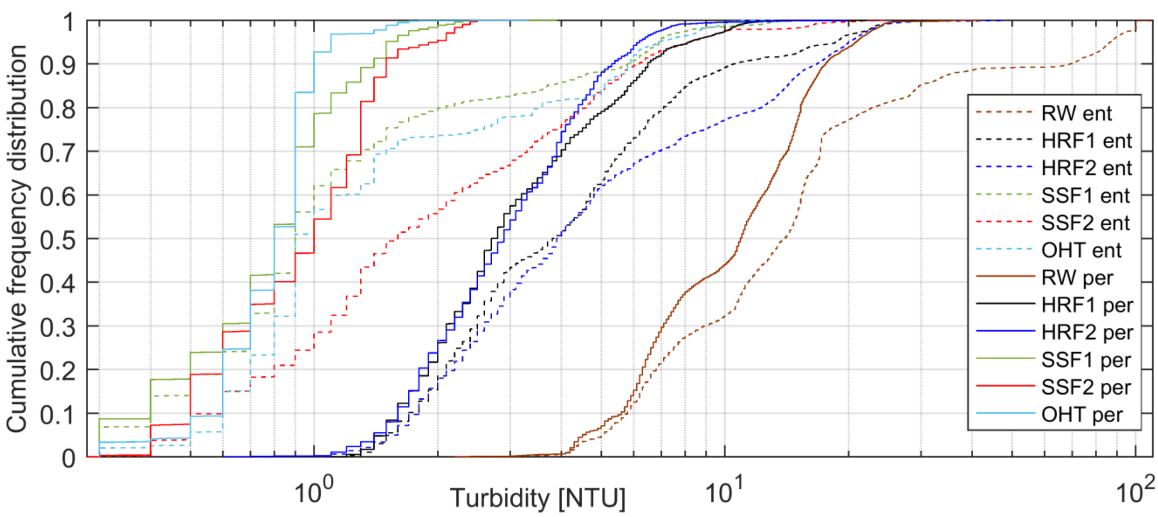



*Figure 69 Cumulative frequency distribution of Turbidity values of treatment results of all stages in the filtration process during entire and performance period*

Interestingly the performance ranking of HRF1 and HRF2 differs between the entire phase and the performance phase. While 90% of the output turbidity in the entire monitoring period for HRF1 is below 10.5 and for HRF2 below 16.7 NTU, during the performance phase HRF 2 outperforms HRF1 with 5.4 against 6.5 NTU for 90% of the cases respectively. Possibly the gravel packed HRF2 experienced a different ripening process from the crushed stone chips in HRF1 and thus increased its removal efficiency. The initial better performance of the crushed stone chips can possibly be explained with charged surface of freshly crushed stone chips.

The preferred turbidity of 8 NTU is achieved by 85 and 73% by HRF1 and HRF2 respectively during the entire monitoring period, and by 95 and 99% by HRF1 and HRF2 respectively during the performance phase (Figure 69).

Figure 70 indicates that output water qualities of HRFs can go up to 25 NTU. Considering the cubic fitting curve, 20 NTU seems to be ensured if the input WQ has turbidity lower than 100 NTU, but even higher turbidity seem to be manageable below 20NTU sometimes, where removal efficiencies average up to 85%. Input WQ has to stay below 25NTU in order to be able to treat the water to 8NTU. Removal efficiencies in this range average around 60 to 70%. Although higher removal efficiencies are achieved with higher turbidity (Figure 71), the required final output WQ of the HRFs cannot be assured and thus input water qualities to the HRF are desired to stay below 25NTU and can be coped with until 70 NTU. Apart from catchment area management and sedimentation enhancement in the pond the flowrate of the HRFs could be adjusted in order to achieve desired output WQ (compare chapter 8.4).

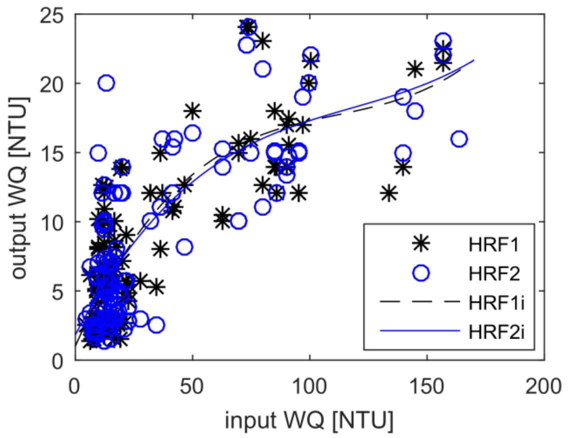



*Figure 70 Input and output Water Quality (Turbidity) HRFs*

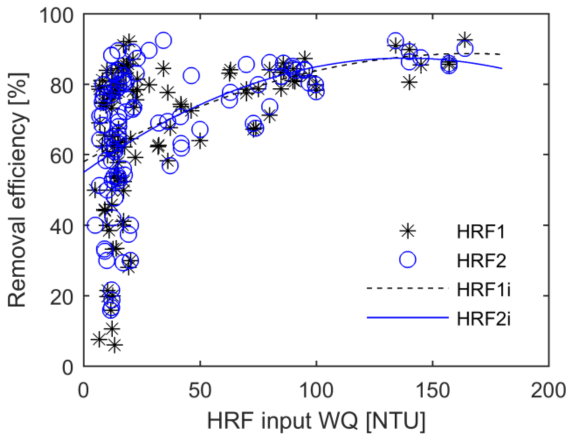



*Figure 71 Input Water Quality and Removal Efficiency of HRFs*

For the SSFs the efficiency of the HRFs is less important at lower raw water turbidity but more important at higher raw water turbidity inputs to the system. Although the HRFs fulfil this tendency, of being more effective percentage wise, the final result is not satisfying and does not meet the requirements of the SSFs.

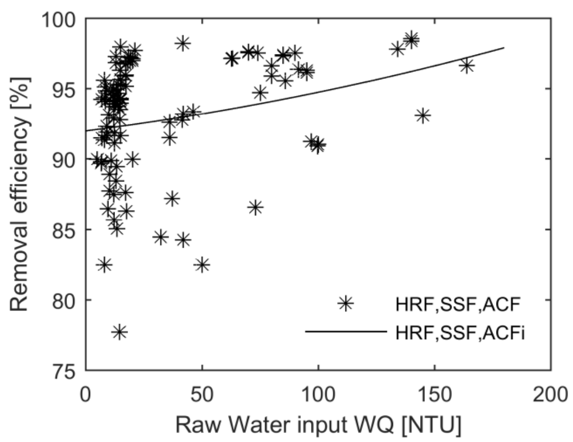



*Figure 72 Overall turbidity Removal Efficiency of entire system*

Overall removal efficiency of the MSF correlates positively with the input water quality, which is desirable. It averages from 92 to 98%, but even 98% removal efficiency does not reach acceptable limit of 1NTU if the raw water input water has more than 50 NTU. Except for the monsoon season the raw water input quality stays clearly below 50 NTU, averaging around 20 NTU(Figure 50).

A conclusion from the interpolated overall removal efficiency is that the input water quality to the system needs to be lower than 14 NTU, having a removal efficiency of 93% in order to ensure 1 NTU, whereas the input WQ could go up to 80 NTU, having a removal efficiency of 94% for achieving 5 NTU.

## 8.2.3 CROSS-FLUSHING AND REMOVAL EFFICIENCY OF HRF

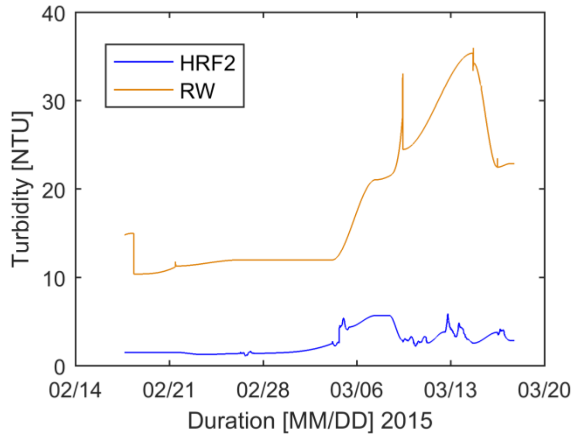



***Figure 73 Inlet and Outlet turbidity of HRF2 during the cross flushing interval with highest loading***

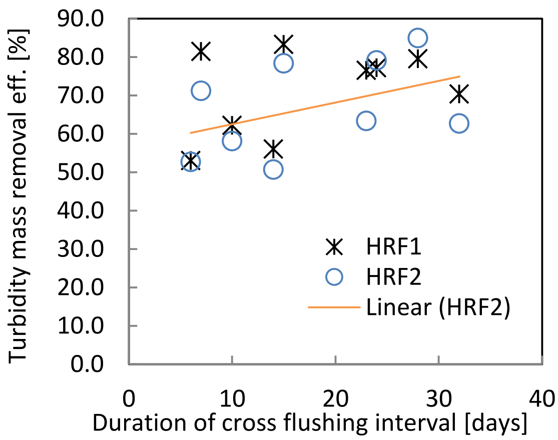



***Figure 74 Duration of cross flushing interval against turbidity mass removal efficiency***

The cross-flushing intervals are kept so short that the filters never fully use their suspended solid loading capacity. The filters are loaded between 0.27 and 2.57 kg per interval which lasts between 6 and 32 days. Even during the cross flushing interval with the highest loading of 2.57kg in 28 days with a removal efficiency of 85% the filter does not break through and seems to still have capacity (Figure 73). As a conclusion, the turbidity mass removal efficiency also does not seem to depend on the duration of cross-flushing; if at all a fitting curve rather shows a positive correlation, indicating that longer cross-flushing intervals lead to higher removal efficiencies. This observation might be explained by the long settlement phase after a cross-flush, as shown in the next chapter

## 8.2.4 HRF WATER DIVERSION TIME AFTER CROSS-FLUSHING

After a cross-flush of a HRF it takes around 12 hours at a HRF flowrate of 0.5m/hr until the turbidity has reached its initial quality (Figure 75). In short cross-flushing intervals 12h is a considerable part of the overall plant capacity which is either lost or used as inferior quality of pre-treatment. In order to minimize the charging of SSF with high turbid water the HRF effluent can be discarded after the cross-flushing process. This time period is to be minimised as to not lose unnecessary quantities of water. A minimum time of 6 hours should be considered in order to reach 150% of the prior quality. If possible 12 hours waiting would of course be better in order to continue to feed the best possible quality into the SSFs.

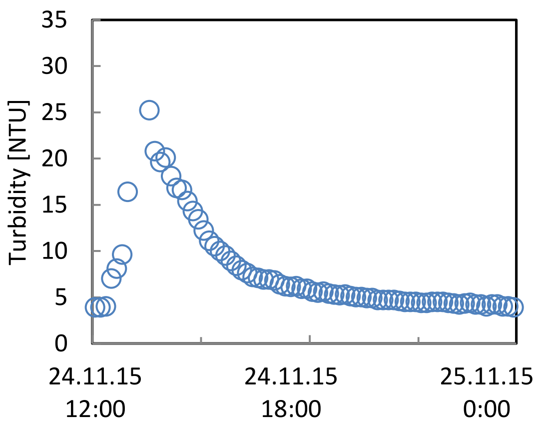



***Figure 75 Typical 12h HRF cross flushing turbidity peak to be bypassed [DD/MM/YY HH:MM]***

In order to keep the continuous flow in the SSF system during the diversion time, the HRFs need to be cross-flushed on different days, so that water of the cross-flushed HRF can be discarded and the water from the not yet cross-flushed HRF can continue to be fed into the SSFs.

## 8.3 OPTIMISATION FOR BEST BACTERIA REMOVAL

The strength of the MSF system against conventional RSF systems is the higher performance in removal of pathogens. Experiences show that enteric bacteria can be removed up to 3 logs [909579](compare chapter 4.2). Thus SSFs are a modest mode of disinfection and can be the only treatment step in case input bacteria levels are low (below $10^2$) and the SSF works at its optimum removal of 2 to 3 log for E.coli. The measurements at the project site though seldom reach these conditions. Firstly the input water quality regarding bacteriological contamination is rather poor, partly with more than $10^3$ E.coli and the removal efficiency tends to average around only 1 to 2 logs. The aim of having no CFU in 100ml can thus not be reached only by the SSF. Still the amount of chemical disinfection might be less than in a conventional treatment due to the reduction of bacteria loads. As measurement of bacteria is time consuming and expensive, a correlation of final turbidity and turbidity removal against E.coli and total coliform is analysed. Finally the optimal dosing of disinfectant is looked into including challenges of chlorine dosing due to high pH values.

### 8.3.1 OUTPUT WQ AND BACTERIA

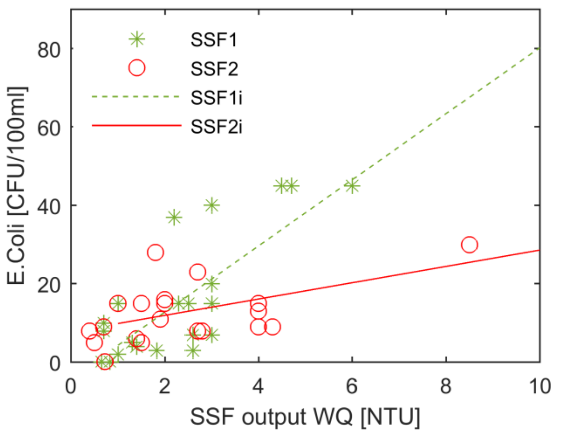



*Figure 76 Final output Water Quality (Turbidity) and remaining E.coli*

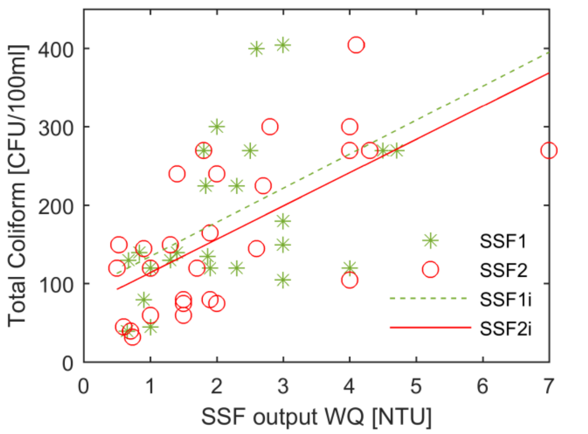



*Figure 77 Final output Water Quality and remaining total coliform*

Although E.coli correlation differs in SSF1 and SSF2 in its positive magnitude when considering the linear fitting curves, Figure 76 still shows the importance of low turbidity for reducing bacteriological load of E.coli. The acceptable turbidity limit of 1 NTU correlates to E.coli concentration around 1 to 10 CFU/100ml for SSF 1 and SSF2 whereas the permissible limit of 5NTU rather indicates levels around 20 to 40 CFU/100ml for SSF2 and SSF1.

Figure 77 shows that lowering turbidity has a similar strong impact on total coliform bacteria reduction. Complying with the permissible limit of 5NTU would lead to 250 to 300 CFU/100ml whereas compliance with the acceptable limit of 1NTU would reduce the bacteria to 100 to 150 CFU/100ml for SSF1 and SSF2 respectively thus reducing them by more than 50%.

It can thus be concluded that there are good indications that lowering the final turbidity will also lead to an optimised bacteria removal. On the other side it can also be concluded that even when achieving WQ better than 1NTU the treated water will still have bacteriological contamination and needs post-disinfection.

### 8.3.2 TURBIDITY REMOVAL AND BACTERIA REMOVAL

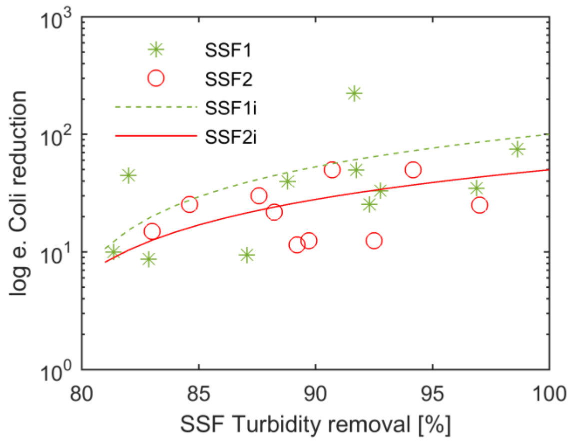



*Figure 78 Turbidity removal in SSFs and E.coli reduction*

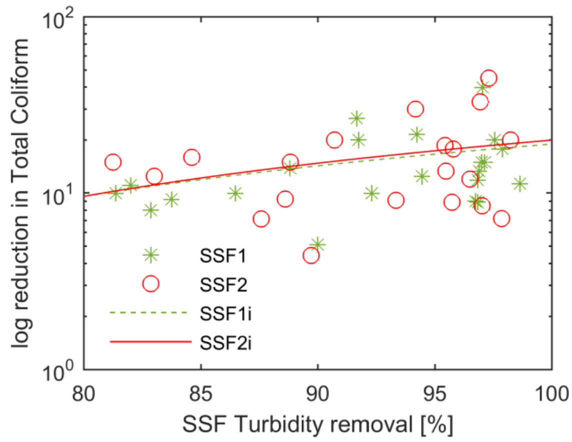



*Figure 79 Turbidity removal in SSFs and total coliform reduction*

Going one step further and looking at turbidity removal efficiency of the SSFs and their correlation with the bacteria removal efficiency, positive correlations can be made out for E.coli as well as for total coliform. The average SSF removal efficiency in the performance period of 91.7 and 91% would lead to a log 1.5 and log 1.2 reduction of E.coli for SSF1 and SSF2 respectively (Figure 78). Total coliform reduction would possibly range around 1.05 for SSF1 and SSF2 (Figure 79). It can be concluded that higher turbidity removal efficiencies will have a positive impact on the reduction of bacteria while the impact on E.coli is stronger than on total coliform.

### 8.3.3 BACTERIA REMOVAL OF EACH TREATMENT STEP

Looking at the E.coli concentration frequency distribution of each of the treatment steps over the entire monitoring period including the ripening phase it can be seen that more than 60% of all raw water samples have more than 100 E.coli CFU/100ml, while less than 5% have more than 500. In total a log 3 to 4 removal thus has to be applied. While HRF 1 achieves less than 100 CFU/100ml for 90% of the samples HRF2 achieves less than 60 CFU/100ml in 90% of the sampling cases. Similarly 10% of HRF1 samples achieve 5 CFU/100ml, while 10% of HRF2 samples achieve 2 CFU/ 100ml. SSF 1 and SSF2 achieve less than 50 and 30 CFU/100ml in 90% and less than 1 and 2 CFU/100ml in 10% of cases respectively. The OHT water, which has not been disinfected during the ripening period, shows that only in 33% of the samples taken less than 1 E.coli CFU/100ml occurs(Figure 80).
As plotted in Figure 81 total coliform bacteria in raw water are more than 1000 CFU/100ml in 80% and in less than 10% more than 5000 CFU/100ml. HRF 1 and 2 provide quite similar removal patterns: 90% of samples are below 600 CFU/100ml. 10% of samples achieve less than 80 and less than 60 CFU/100ml for HRF1 and HRF2 respectively. SSF1 and SSF2 achieve less than 200 and 150 CFU/100 ml in 90% and less than 80 and 40 CFU /100ml in 10% respectively. The OHT achieves 0 CFU/100ml in 15% of all cases during the entire monitoring period and in 28% of all cases during the performance period.

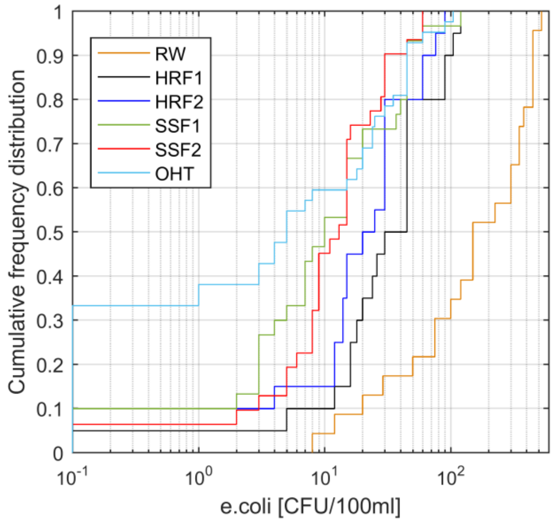



*Figure 80 Cumulative frequency distribution of E.coli for all treatment steps*

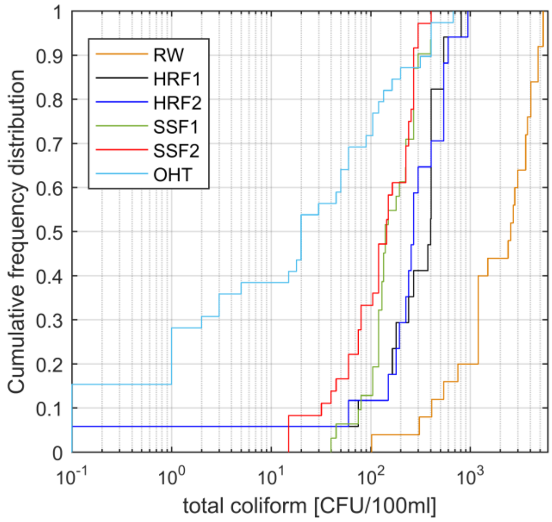



*Figure 81 Cumulative frequency distribution of total coliform for all treatment steps*

The CFD plots of E.coli and total coliform further show that the HRFs play a major role in the removal of the bacteria. For the E.coli removal the HRFs mainly remove around 1 log while the SSFs only remove 0.2 to 0.5 log in the higher range around 300 E.coli CFU/100ml RW input. In the lower contamination regions below 100 E.coli CFU/100ml RW input the SSFs also perform well in removing around 1 log whereas the HRFs stay between 0.1 to 0.8 log. Overall it can be said that the HRFs play the major role of bacteria removal in over 50% of the cases (Figure 80). The picture for total coliform removal is slightly different: the HRFs have a major contribution to the bacteria removal of around 1 log almost throughout the entire frequency distribution, the SSFs stay between 0.3 to 0.6 log removal (Figure 81). Thus both cases show that the pre-treatment plays the more important role considering the overall bacteria removal.

### 8.3.4 FAC LEVEL

Disinfection at the site proves to be more complicated than initially expected. As per IS10500 0.2, 0.5 and 1.0 mg/l of residual FAC are tested but do not lead to 0 CFU/100ml E.coli or total coliform. Slowly increasing the dose shows that FAC level at the point of dosing has to be higher than 4mg/l in order to achieve bacteria free water in the tank on the next day (residual chlorine at the next day (after 24h) has to be higher than 0.5mg/l). While IS10500 suggests a CT level of only 30 min mg/l for virus inactivation, bacteria monitoring shows that at this level bacteria is still present. 1.8 mg/l FAC after 30 min (CT = 54), or 0.7 mg/l after 24h (CT = 1008) can achieve bacteria free water, this can be ensured only with dosing around 4.7mg/l. The high amount of chlorine needed can be explained with the high pH value of the treated water, pH in the overhead tank has an average value of 7.9 but sometimes increases up 8.7 (compare chapter 0). Prior to chlorine dosing the pH should thus always be measured and EPA CT tables which are pH dependent referred to.

Offline tests with variation of dosing are repeated 7 times in two different periods, one in June and one in November. As a result 1ml/l sodium hypochlorite dosing leads to FAC levels above 4 mg/l and residual chlorine around above 0.5 mg/l on the next day. This dosing is concluded to be a safe way of disinfection considering a pH level between 7.4 and 8.6, and temperature between 20 and 30°C.

Interpolating the online FAC level measured in the distribution line with the E.coli measurements of the OHT water shows that FAC levels above 1 mg/l are required to reach 0 CFU / 100ml (Figure 82). The FAC measurements are taken approximately 12 hour after dosing into the CWT, thus the CT value calculates to >720.

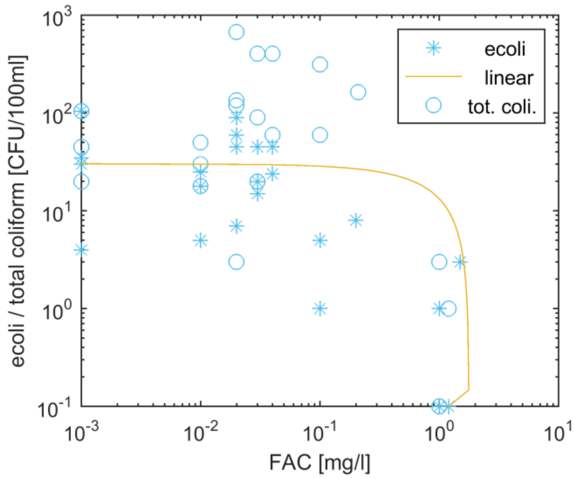



*Figure 82 online monitoring of FAC level*

## 8.4 OPTIMIZATION OF FLOWRATE

The main process parameter which the operator can influence in the MSF is the flowrate. Different treatment steps might have their optima at different flowrates. Although the flowrate can be adjusted for each filter bed individually, all the water passing through the HRFs finally reaches the SSFs if no water is to be lost during any treatment steps. The flowrates can still be distributed for the individual filter lines for each of the filter steps. While the SSF filters are very similar regarding the filter media (chapter 6.3.4) and it is not expected that there are major differences in their performance and operation requirements, varying flowrates might make sense for the two HRF - one filled with gravel and the other one with stone chips - as these have different characteristic regarding hydraulic and quality related performance (chapter 7.1 and 7.2).

### 8.4.1 FLOWRATES AND WATER QUALITY

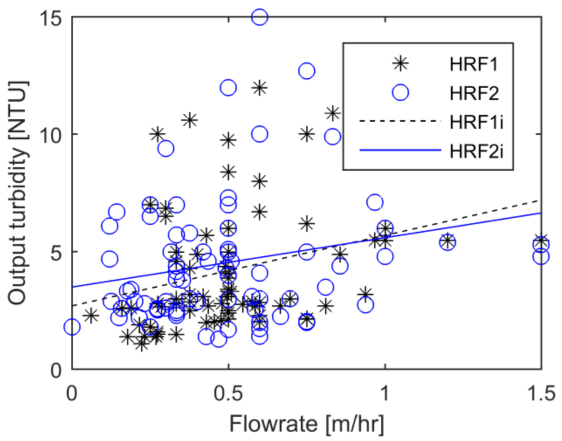



*Figure 83 Flowrate and Output Turbidity of HRFs during performance period*

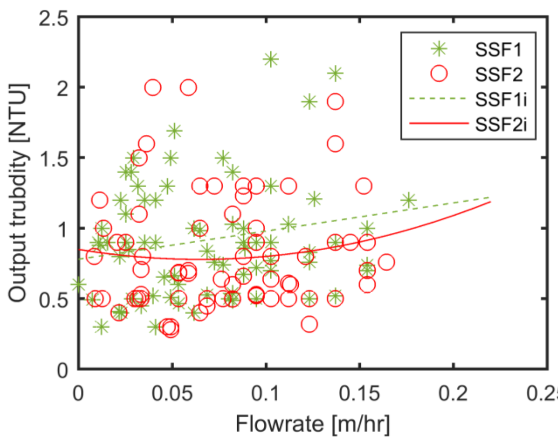



*Figure 84 Flowrate and Output Turbidity of SSFs during the performance period*

The final treated water quality of the HRF system as well as the SSF system is a main criterion for the operation conditions. The SSF treated water has to comply with the IS10500 criteria and the HRF has to pre-treat the water to a level which enables the SSF to perform better in regards to quality and

scraping period length. While it is suggested to always aim for the best possible quality, the maximum possible flowrate of the filter system is of interest in regards to the production capacity.
In the performance period it can be observed that the linear fitting curves for HRFs final treatment WQ regarding turbidity value against flowrate correlate positively. It can thus be concluded that the slowest possible flowrate leads to the best result. Regarding the cut off WQ the performance period shows good results. Even at double the design flowrate of 1m/hr the final WQ could stay around 5 NTU which is still well in the limits of the desired SSF input of around 8NTU (Figure 83).
SSF1 also shows a linear fitting curve with positive correlation. The fitting curves passes 1 NTU at 0.12m/hr and thus suggests to keep the filtration velocity below this level while generally suggesting to keep the flowrate as low as possible. At the design flowrate of 0.1m/hr it would have a turbidity of 0.98 NTU, while 0.2m/hr would lead to 1.18 NTU.
SSF2 shows a slightly different behaviour. The interpolated quadratic fitting curve of SSF2 has a minimum at 0.066m/hr which leads to an average turbidity of 0.78 NTU. The design flowrate of 0.1m/hr would lead to an average turbidity of 0.8 while 0.2m/hr would lead to 1.1 NTU, while the curve passes 1 NTU at 0.18m/hr. Conclusions for the operation of the SSFs are that 0.2m/hr flowrate should be avoided if possible. 0.1m/hr seems feasible in regards to complying with the acceptable IS10500 value of 1NTU. If possible the filters should be run at a lower filtration velocity of only 0.07m/hr which could lead to even better results. This would suite the HRFs anyway as they perform better the slower they are run. The reduced flowrate of 0.7m/hr would lead to a production of around 10 KLD instead of 14 KLD.

### 8.4.2 FLOWRATES AND REMOVAL EFFICIENCY OF HRF AND SSF

Although the final WQ is the most important objective of the treatment, it is also interesting to look at the influence of the flowrate on the removal efficiency and verify the results concluded from the WQ observations. Looking at a typical HRF cross-flushing cycle (Figure 85), it can be observed that HRF removal efficiencies do not seem to correlate with the flowrate. While the removal efficiencies firstly drop together with the flowrate around 03/06, they soon recover to their original or even higher efficiencies although the flowrate remains low.
A typical scraping interval of SSF1 shows that a correlation between flowrate and SSF filter seems to exist, but the overall MSF removal efficiency seems to remain stable. These observations led to the idea of plotting flowrates against removal efficiencies to analyse their dependencies in more detail.

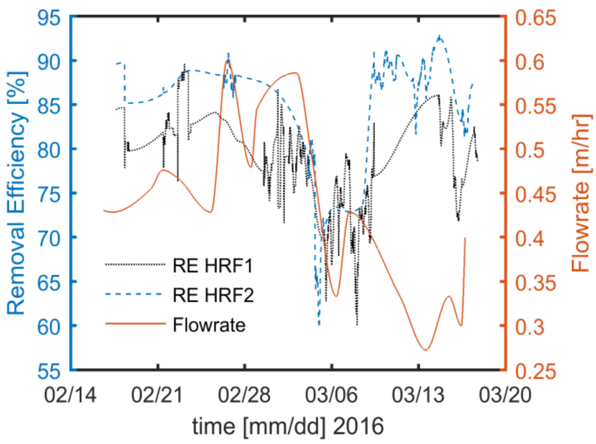



*Figure 85 Removal efficiency and flowrate of HRFs in a typical cross-flushing period*

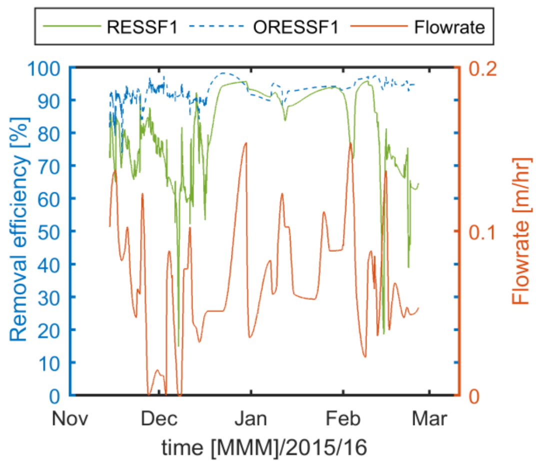



*Figure 86 Removal Efficiency (RESSF1) and Overall Removal Efficiency of SFF1 (ORESSF1) in 4th scraping period*

It can be assumed that removal efficiencies of filters should be higher with lower flowrates when sedimentation, interception and hydrodynamic forces work better. This is also the case for the HRFs, it can be observed that flowrate and removal efficiency correlate negatively, with a very similar gradient for both HRFs (Figure 87). At design flowrate of 0.5m/hr the removal efficiency is around 70%, while at 1m/hr removal efficiency is only 65.4%. In order to treat 90% of the influent raw water quality during the entire monitoring period to the minimum level of 20NTU, the HRFs would need to bring down 50 from 70NTU (Figure 69), which leads to a removal requirement of 71.4%. This could only be achieved with a flowrate of 0.3 and 0.21m/hr for HRF1 and HRF2 respectively. Bringing down 90% of the influent water to 8NTU would require a removal efficiency of 89% which seems not to be possible with the current setup. These observations provide a strong hint to requiring more efficient pre-treatment in order to cope with higher input turbidity.

In the SSF, being a vertical gravity filter, removal by sedimentation and hydrodynamic forces don't seem to be dominant. It seems that primarily screening - which is independent of the flowrate - is dominant, as well as biological activity in the biomass layer on top of the filter. Correlations in the area of the flowrates relevant for these processes are positive. SSF1 values fit best with a linear interpolation while SSF2 values have a quadratic fitting and thus a maximum (Figure 88). At design flowrate of 0.1m/hr removal efficiencies are 79% for both SSFs. At 0.2m/hr removal efficiencies are 80.3 and 79.8% for SSF1 and SSF2 respectively. At lower flowrates e.g. 0.05m/hr removal efficiencies go down to 78.1 and 76.1% for SSF1 and SSF2. The maximum removal efficiency of 80.5% for SSF2 is reached at a flowrate between 0.15 and 0.16m/hr. SSF1 has a removal efficiency of 79.9% at this filtration velocity.

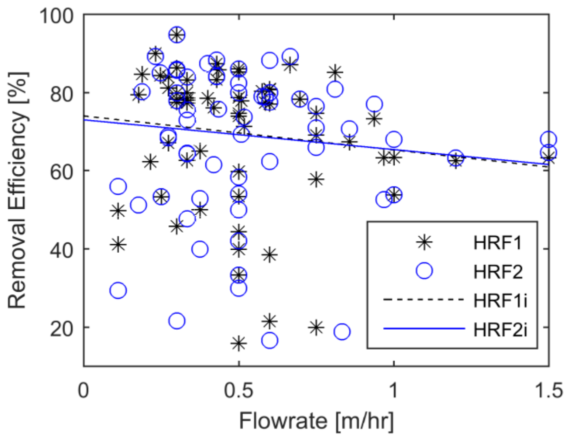



*Figure 87 Flowrate and Removal Efficiency of HRFs*

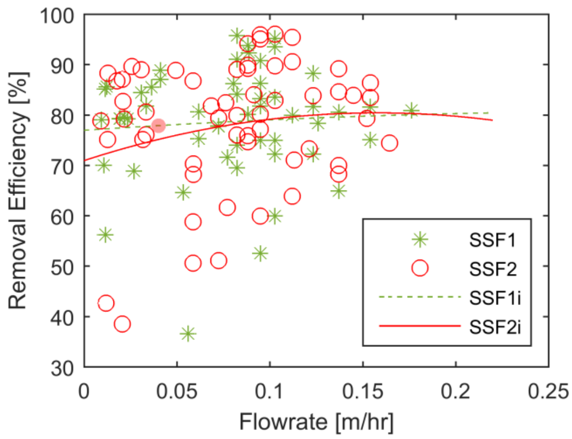



*Figure 88 Flowrate and Removal Efficiency of SSFs*

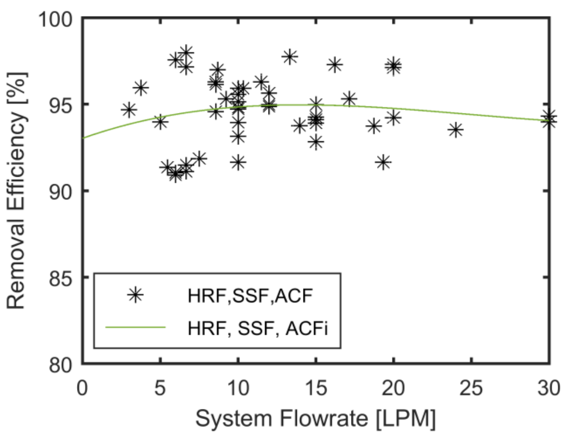



*Figure 89 Overall System Flowrate and Removal Efficiency*

Looking at the overall removal efficiency of the system, for the MSF process the optimal system flowrate is around 14 LPM, which translates to approx. 0.14m/hr flowrate for the SSF and 0.7m/hr for the HRF, and 30min contact time for ACF slightly higher than the original design flowrate of 0.1 and 0.5m/hr for SSF and HRF, and shorter than 48min for ACF. This supports the theory that higher flowrates are more preferential in tropical climates like in West Bengal in comparison to temperate zones like Europe and USA [167].

## 8.5 IMPACT OF AERATION DURING FILTER PROCESS

Each of the 3 filters in the MSF system have biological activity, whereby the SSF is attributed the most important biological role. The biological performance of the Slow Sand Filtration (SSF) process is influenced by aerobic conditions in the filter media. The level of DO activates biodegradation in the filter bed. Oxygen levels below 3mg/l might have a negative impact on the filtration efficiency while anaerobic conditions in the filter bed might lead to decomposition and production of hydrogen sulphide, ammonia, dissolved iron and manganese and other taste and odour producing substances [79].

Oxygen can be provided by algae which can grow on uncovered filters [168],however uncovered filters in tropical regions can also lead to intense algae grow which can clog the filter quickly and the algae can consume oxygen in the night time. Furthermore, uncovered filters which are exposed to direct sunlight tend to heat up and increase the water temperature, which is not desirable for the consumers. In covered filters not only dissolved oxygen (DO) levels of the raw water but also continuous filtration rates are necessary for achieving constant aerobic conditions [72]. The project plant in Jyot Sujan is shaded by the photovoltaic cells and can be considered as semi-covered. Even if the raw water from the pond has been measured to have a DO level between of 3.3 and 7 mg/l according to climatic season and time of the day, the challenge for a solar-based system lies in the continuous filtration rate. The PV system provides energy output during a limited daily time period which in addition changes according to varying climatic conditions and yearly seasons. Thus in order to ensure aerobic conditions in the slow sand filter bed, various process modifications and additional plant equipment have to be set up related to prolonging the availability of the power source as well as increasing the tank capacity for the raw water storage at an elevated location (compare 6.4) [169].

### 8.5.1 DISSOLVED OXYGEN AND WATER QUALITY

For achieving aerobic treatment in the SSF the construction of the treatment plant has the provision of aeration cascades in form of v-notches at entrance and exit of the HRF, and another two cascades between HRF and SSF of 30cm height together.

It can be observed that the oxygen level on the SSF has an impact on the final achieved WQ. As expected, the linear fitting curve based on all measured values throughout the entire monitoring period shows a negative correlation. Although the curve indicates that DO levels above 1 already tend to correlate with a turbidity of below 1NTU, Figure 90 shows that there are many exceptions and to ensure a turbidity below 1NTU DO levels have to be higher than 5mg/l.

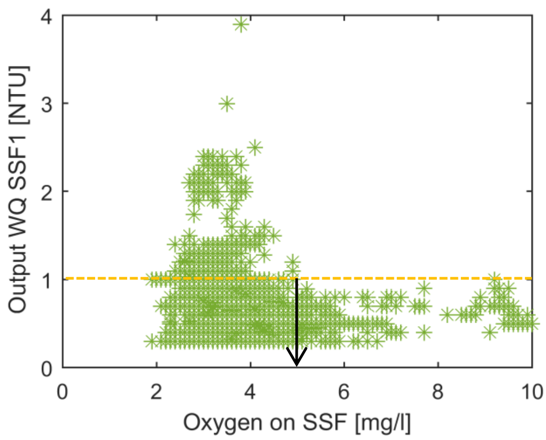



*Figure 90 Output water quality of SSF1 in dependency of dissolved oxygen on the filter bed*

### 8.5.2 DISSOLVED OXYGEN AND REMOVAL EFFICIENCY

Observing the removal efficiency against the DO level on the SSF a positive correlation can be read from the best fitting linear interpolation in Figure 91, showing that average removal efficiencies are predicted to be only 77.4% with DO of 2.5mg/l on the SSF filter whereas an DO level of 6mg/l would lead to a removal efficiency of 83.1%.

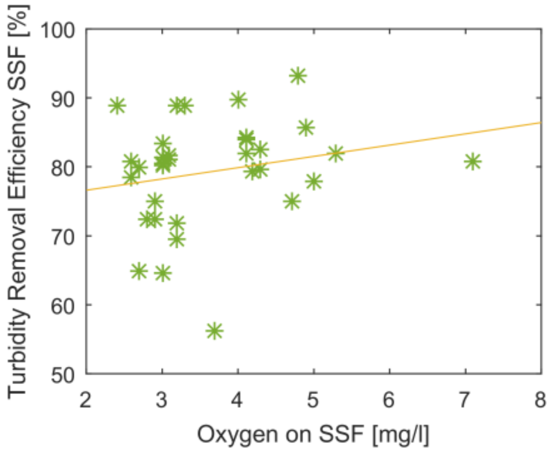



***Figure 91 Turbidity Removal Efficiency of SSF1 against DO of the influent***

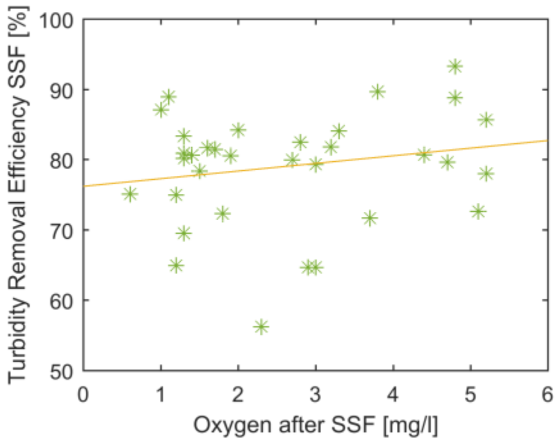



***Figure 92 Turbidity Removal Efficiency of SSF1 against DO of the effluent***

Similarly the oxygen after the SSF also correlates positively with 77.3 and 81.6% for DO levels of 1 and 5 mg/l respectively. The oxygen depletion representing the consumed oxygen or oxygen demand when passing through the filter correlates negatively with the efficiency, with 79.4 and 76.5% for 1 and 4 mg/l DO depletion.

It thus makes sense to have more oxygen in the feed water of the SSF as well as to create conditions in which the water which exits the SSF has a higher oxygen level, or less oxygen is consumed during the filtration process. This could be achieved by a higher flowrate and thus less filter bed contact time.

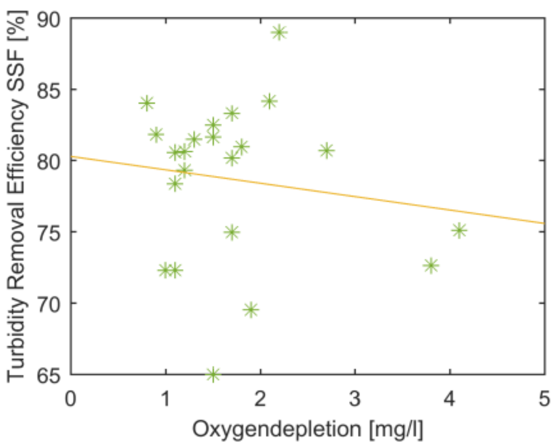



***Figure 93 Turbidity Removal Efficiency of SSF1 against DO demand during the filtration***

### 8.5.3 DISSOLVED OXYGEN AND FLOWRATE

The dependency of flowrate and oxygen level is thus analysed to ensure this hypothesis. Looking at the oxygen level on the SSF against the flowrate in Figure 94, the best fitting linear interpolation curve shows a negative correlation with a gradient of -0.11 mgl/l per LPM, whereas the DO level at the SSF output against the flowrate in Figure 95 shows a slighter negative correlation with a gradient of only -0.081 mg/l per LPM thus resulting in an overall negative correlation of DO consumption with flowrate. The negative correlation of flowrate and oxygen depletion (Figure 96) as well as the negative correlation between oxygen depletion and removal efficiency (Figure 93) can thus provide an explanation for the observed positive correlation between lower flowrate and removal efficiency of the SSF in Figure 88.

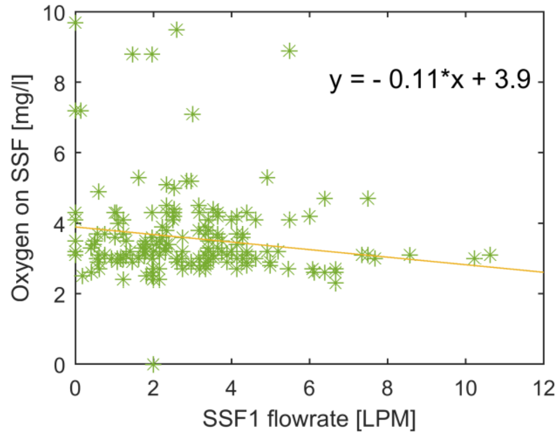



*Figure 94 DO level of influent against flowrate of SSF1*

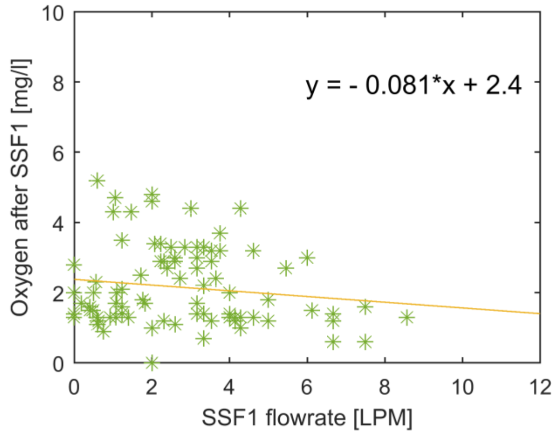



*Figure 95 DO level of effluent against flowrate of SSF1*

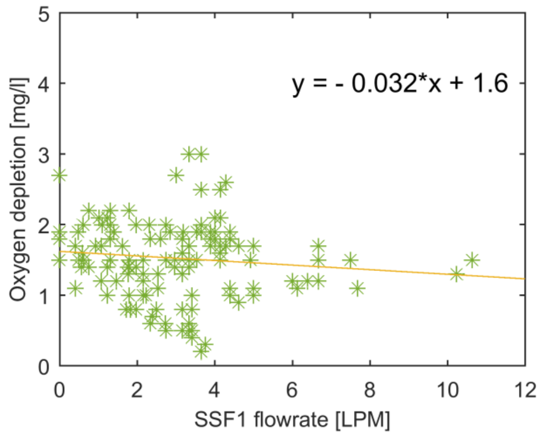



*Figure 96 DO consumption during the filtration process against flowrate of SSF1*

It seems that a certain flowrate has to be achieved for the SSF in order for the oxygen to reach into the sand layer and to the microorganisms so that these can be active in reducing turbidity and with it the bacteria. Although the increase of flowrate at a lower level seems to have a positive effect on the removal efficiency of the SSF, it still has a negative impact on the removal efficiency as well as the final water quality of the HRF, and from a certain flowrate onwards also a negative impact on the water quality of the SSF (Figure 84). From the point of view of minimum oxygen level of 3mg/l on the SSF, in order to avoid negative impacts on the removal efficiency, the maximum flowrate, when considering the interpolated fitting curve in Figure 94, would be 8.2 LPM which translates to 0.16 m/hr. This coincides with the observations on flowrate and removal efficiency in Figure 88.

# 9 SUSTAINABILITY OF OVERALL SETUP IN COMPARISON WITH OTHER SOLUTIONS

In a final overall assessment of the deployed technologies, the long-term project sustainability is addressed and elaborated based on certain criteria.

The term sustainability is used in a variety of contexts. The structure of this chapter as such gives an answer to the definition of “sustainability” in the context of a community-based water supply. In general the long-term viability of the operation of a water supply providing safe water by its own consumers is meant when speaking of sustainability of the technology solution, including the soft measures for its introduction. The aspects considered when assessing the long-term viability are its technical performance and reliability, its social and environmental impacts to the direct beneficiaries as well as the wider society, and its economic implications, affordability and efficiency in producing benefits (compare chapter 3.4.4). In the analysis of the sustainability focusses on two implemented solutions at the project site, the alternative which is being elaborated in this thesis and the advanced (compare 4.3), which are compared to the status quo, the current setup (compare chapter 5.1.4) and a possible conventional setup (compare chapter 4.1).

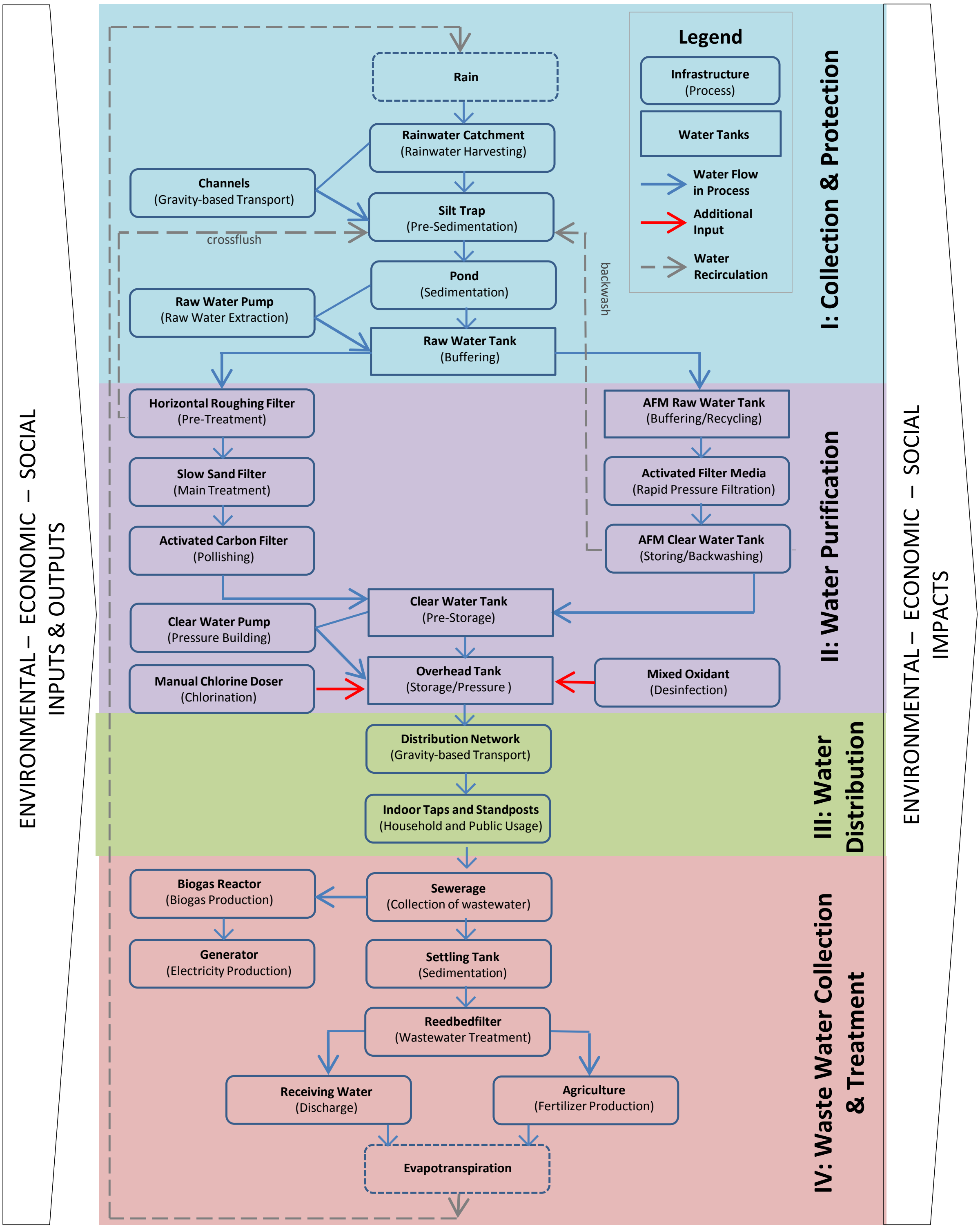



*Figure 97 Processes considered in the SELCA and CBA grouped into the 4 stages showing the options of alternative and advanced setup in the stage II*

Regarding the system boundaries considered in the evaluation, the alternative setup covers 4 phases of the water cycle from collecting the water to purifying and distributing to treating the resulting wastewater (all four water life cycle stages as shown in Figure 97. The advanced setup is embedded into (and dependent on) the alternative setup in the way that it constitutes an additional option next to the purification of the collected raw water (life cycle stage II).

Apart from the varying comprehensiveness of the two compared setups, the focus of this study lies on the evaluation of the alternative system rather than the advanced system. The alternative system is designed with the objective of achieving technical, socio-economic and environmental sustainability and thus has been analysed in detail.

The design of the advanced system instead aims at being pre-manufactured ready-made deployable technology which only needs to be installed on-site. This aspect is only partly realised as the advanced setup is integrated into the alternative setup and builds on catchment area management, setup of a trained water committee as well as an uninterrupted power supply for some components which are sourced from the alternative setup.

Both systems are prototypes setup with components solely integrated to enable performance monitoring and cannot be considered as final “market ready” products. This aspect is addressed in the final MCA evaluation by also considering a potential scenario for the two innovative solutions.

## 9.2 TECHNICAL PERFORMANCE

The technical performance related to the achieved water quality of the alternative system is analysed in-depth in chapter 8. In the evaluation further performance aspects are considered related to the practical construction and operation of the system.

### 9.2.1 FINAL RESULTS RELATED TO TREATED WATER QUALITY

Water quality results of a monitoring programme with parallel samples taken at the same time for both systems are compared, so that performance for the same raw water can be compared. Bacteria values are not compared as the disinfection is done jointly for both treatment paths.

The alternative and advanced setup show only slight differences in water quality (Table 42, Appendix O). Both have better results in 3 of 10 parameters whilst having comparable results in 2 parameters. Bacteria parameters exceed permissible limits for both filtration systems, with better results for the SSFs. Turbidity - which is the most important indicator parameter for surface water treatment - is removed best by the advanced system, which can remove turbidity up to 0.18 NTU. Regarding the scoring for the MCA, the alternative systems installed on-site achieves drinking water quality to the acceptable limits during the entire monitoring period only in 58% of all cases, while it has the proven potential to do so in 93% of all cases, as shown in the performance period (considering turbidity as indicator parameter (Figure 69). The advanced technology scores 25% higher with 68,5% for the implemented and 94,75% for the potential setup as per the comparison of 0.6 NTU to 0.75 NTU average of the SSFs. In comparison, the current water supply with tube wells can only supply acceptable water to 35% (compare chapter 5.1.4), while for the conventional setups it is assumed that in 70% of all cases acceptable water can be provided.

For the MCA the alternative system as implemented at the pilot plant and its potential score 5.8 and 9.3 out of 10 points respectively, whereas the implemented advanced system and its potential score higher with 6.9 and 9.5 respectively as its performance related to the main indicator parameter turbidity is superior. The current system scores 3.5 and the conventional 7.

### 9.2.2 RELIABILITY OF WORKING STATUS AND PROVISION OF SAFE WATER

The alternative system showed to work reliable in the sense of filtering water in 100% of the time, whereas the advanced system had less than 30% uptime during the monitoring period. The current tube well setup was said to provide water in average 75% of the time, whereas the conventional setup would be regarded similarly with 75% uptime due to similar management of the water resource as the current setup.

For the provision of safe water the disinfection performance is analysed. The Trustwater unit, as part of the advanced technology, does not perform as per expectations. During its implementation at the pilot site, not only does the mixed-oxidant generation unit prove to be unreliable, but the disinfectant Ecasol shows to be highly ineffective in comparison to more conventional chlorination means such as Sodium Hypochlorite. To attain the same Free Available Chlorine (FAC) residual of 0.2mg/L in the overhead tank (OHT), 2ml of a 0.07ml/L liquid chlorine stock needed to be dosed in comparison with 20ml of a 6ml/l Ecasol stock, making the Ecasol almost 1000 times less effective than conventional Sodium hypochlorite. A second test came to the conclusion that in order to disinfect the treated water with a daily flowrate of 14kl/d, 70 litres of Ecasol would be required each day. Although the factor here is only 50 as compared to 1.4 L of sodium Hypochlorite, this amount is still unpractical to be dosed and exceeds realistic daily production capacities of Ecasol. The manual disinfection however was also not always working to the full satisfaction as even high doses of above 1mg/L FAC did not lead to bacteria free water. Finally a very high initial dose of over 4mg/L FAC was applied in order to achieve bacteria free water and a residual FAC above 0.2mg/L on the next day (compare 8.3.4).

MCA scoring results in 7 due to the difficulties in the chlorination for the alternative system as implemented at the pilot plant, whereas its potential scores 9 out of 10 points as reliability is achievable, but still depending on correct operation. The implemented advanced system scores 3 considering the technical problems and downtime at the pilot site but having a potential score of 10 when everything works fully automatically. The current system scores 7.5 and the conventional 7.5 as per their expected uptime.

### 9.2.3 AVAILABILITY OF CONSTRUCTION AND INSTALLATION MATERIAL

*Table 23 Requirement for the construction of alternative and advanced setup*

| Structure | Alternative Setup | Advanced Setup |
|---|---|---|
| Catchment engineering | Earthwork, RCC hume pipes | Uses alternative setup |
| Pond renovation | Earth Work | Uses alternative setup |
| Silt trap | Brickwork, partly with PCC lining | Uses alternative setup |
| Treatment system | Filter system HRF/SSF/ACF: RCC construction with GI pipes, filled with gravel, stone chips and sand | Imported AFM filter system including GRP tanks to be setup at site, Steel pressure filter tank, pressure pump, activated filter media, programmable logical controller, coagulation dosing pump, coagulant |
| Tank system RWT, OHT, CWT and pump house | RCC construction with GI pipes | Uses OHT and pump house of alternative setup |
| Disinfection | Manual disinfection with bucket and plastic valves | Imported mixed oxidant generator system including, pressure and dosing pump, softener, Ecasol device, brine and Ecasol plastic tanks |
| Power provision | Local solar PV cells, Inverter, Batteries | Grid connection with transformer and battery backup |
| Pumps and piping | Local pump and PVC pipes | Uses alternative setup |
| Water quality monitoring | Local field test kit with colour comparator tests | Imported online monitoring system including sensors, programmable logical controller, computer, cellular router |
| Space requirement | Land: 100 m² | Standard shipping container |

The main work required for the construction of the alternative treatment plant are civil works such as excavation, foundations, shuttering work, concrete mixing, bar-bending, casting, plastering, curing, etc. Machines like mixture machine for concrete mixing, vibrator, levelling machine, etc. are needed for these types of construction. Two solar pumps are purchased from local suppliers and connected to the filters by local plumbers. Field Test Kits for monitoring of the water quality are locally procured. For the overall setup 100m² of land are required (Table 23). As the aim of using local construction material readily available is accomplished, the system as implemented on/site as well as its potential receive 10 points.

Ground work to set up the AFM is required. Materials and labour for construction can be found locally. Civil work includes the construction of concrete pads for each corner of the containers. The complete system is supplied in a container, including sufficient chemical products to operate the system for a period of at least one year. Fittings and spare parts are not available in the local market and have to be imported.

The Trustwater device is pre-installed in the container and requires plumbing and electrical connections for installation by technical experts with remote guidance by the manufacturer. Plumbing fittings are not available on the local market and have to be produced with workarounds.

The online monitoring system reaches the site pre-assembled. Sensors have to be installed on the field and connected to the system; only the electrical connections have to be made, which can be done by a local electrician with remote guidance.

Considering that the implemented advanced system is completely imported it scores only 1, whereas it has the potential to use local parts and produce some components locally so that half of the components can be sourced locally achieving 5. The current tube well setup is locally available, thus scores 10, just as well as the conventional system which is current practice.

### 9.2.4 LABOUR EFFORTS FOR THE SETUP OF THE PLANT

The advanced system is a ready-made pre-manufactured system imported from overseas which needs very little civil work on-site, but does need to be assembled locally by technical experts with remote guidance from the manufacturer. The setup could take only a few weeks - which would be a score of 10 - but took over one year due to technical complications, which scores only 1.

The time required for complete construction as well as installation of the whole alternative setup could be 6 months to one year. Trained civil works labourer can construct it without any difficulties, if guided by an experienced lead worker. In the case of the pilot project it took more than one year due to the resignation of two contractors from their jobs. The alternative system as implemented at the pilot plant and its potential score 1 and 5 respectively. As it is intended to be set up locally, which by nature of the activity takes time and involves local human resource, this can be viewed negatively from a technical point but positively regarding the socio-economic impact (which is dealt with in the other aspects).

It takes several days to install one tube well. Considering 140 or 280 tubewells, this would lead to several years of time adding up for setting up all of them, thus scoring only 1 whereas a conventional system is similar to setup as the alternative system though having smaller structures which would reduce the construction time thus receiving 6 points.

### 9.2.5 ENERGY AND CONSUMABLE REQUIREMENTS FOR OPERATION

The alternative setup does not require external energy as it is solar driven. Due to the semi-optimal performance of the implemented setup, high chlorine dosing is required. Spare parts, such as water pumps and water quality field test kits, are low-tech and thus locally available. Filter materials can also be sourced locally. Due to the high chlorine requirements, the implemented setup scores only 7 but the system has the potential to achieve 9.

The advanced setup requires around 42 kWh per day for the entire setup, as well as PAC coagulant and highly purified salt, which is not locally available but can be sourced in India. Spare parts are high-tech imported equipment. Furthermore the main setup has a lifetime of only 10 years and needs to be replaced thereafter (Table 24). This leads to a scoring of only 3 with a potential of 6, when economising on energy consumption by substituting the aeration as well as adapting the design to make use of local available spares.
The tube well setup requires locally available spare parts and no energy or chemicals, thus achieving 10. The conventional setup would require energy as well as a higher amount of chlorine for the disinfection as compared to the alternative system while having no issues with the availability of spare parts, thus scoring 5.

*Table 24 Requirements for operation of the alternative and the advanced system*

| Consumable | Alternative Setup | Advanced Setup |
|---|---|---|
| Labour | One full-time local operator for all operation and maintenance activities | 1/4 time local operator for operation, experts for maintenance |
| Energy | Aeration: Solar power pump induced cascading | Aeration: 26.4 kWh/day |
| | Pumps: Solar power 6 – 13.5 kWh/day | Blower and pumps: 7.2 + 2.25 kWh/day |
| | No external energy needed | Disinfection: Ecasol Generator 4kWh/day, Dosing pump 0,5 kWh/day |
| | | Water quality online monitoring 1.5 kWh/d |
| | | (Total energy input of 41.85 kWh/day) |
| Water | Cross-flush: 2000 L / week or month | Backwash: 5000L/day |
| Chemicals | Disinfection: Sodium Hypochlorite Solution 1.4 - 2.8L/day | - 6L APF/PAC coag./ month for AFM |
| | | - 4.5kg salt / month for the mixed oxidants |
| Spare parts | Pumps: every 5 years | Pump: every 5 years |
| | Filter media – Sand : every 3-4 years | Dosing pump: every 5 years |
| | Filter media – Activated carbon: when exhausted (1-2 years) | Peristaltic dosing pump tube: every 6-12 months. |
| | Structural repairs (RCC structure, plumbing) | M.O. system: every 10 years |
| | Water quality monitoring: field test kit consumables | M.O. peristaltic pump tube: every 2 years |
| | | Online monitoring: every 10 years |
| | | Spare parts need to be provided by specific Producer companies and are not available locally |

### 9.2.6 SKILLS AND QUALIFICATION REQUIREMENTS FOR OPERATORS

One full time operator is required to run the alternative setup. The operator does not need to have special skills and can be trained in a few hands-on workshops. The procedures have been taken up well in the implemented pilot. Water quality monitoring has also been taken up well by the water committee members, who learned the processes while accompanying the project team several times. New unforeseen issues could be solved by the local operator by phone. The implemented solution scoring 8 can however still be further optimised regarding the operational steps, as well as further simplified regarding the monitoring setup, then achieving 9.
The advanced setup requires less labour operation with a potential of a quarter-time operator only, in case the systems run smoothly. In case of maintenance technical experts have to be contracted. Support by the manufacturer is necessary for addressing operational issues. The local water

committee was not able to solve problems with the control system, so that the system had repeated periods of down time. The project partners had to visit the site again to suggest solutions. The online monitoring does not require much maintenance and it can be partly remotely maintained as long as the internet connection works, although any hardware maintenance has to be taken up by external experts. Score is thus just 2 which could however be improved to 6 with a simplified redesign based on gravity flow, as has been announced by the manufacturer.
Tube wells can be operated by any member of the community scoring 10. The conventional system is more complicated than the alternative setup due to the dosing of the coagulant and maintenance of a frequent backwashing program, in this way scoring only 5.

## 9.3 SOCIO-ECONOMIC ENVIRONMENTAL LIFE CYCLE ASSESSMENT (SELCA)

The technologies are analysed throughout their life cycle from construction through operation and final disposal of the systems.

### 9.3.1 INVENTORY ANALYSIS

The Inventory Analysis consists of identification of inventory indicators, which are inputs required and outputs generated during the life cycle of the treatment plant and assessment of the quantitative inventory data for each indicator. Inventory indicators related to the construction of the systems are mentioned in Table 23 and show that the alternative system, covering all life water cycle phases, comprises more inputs required for its construction than the advanced system which is limited to the purification phase. Indicators and the assessed data for the operation are provided in Table 24.
The detailed inventory analysis with all assessed indicators and data is provided in Appendix V. The inventory data is used to derive the impacts of the systems.

### 9.3.2 IMPACT ASSESSMENT

Identified impacts are assessed on the basis of the inventory analysis to have a positive (+), negative (-) or neutral (o) effect on the stakeholder level in comparison to the current tube well setup, which is the baseline for the valuation of the impacts. The alternative and advanced solutions are assessed as implemented in the field, with the problems pilots have, and their potential when implemented at large scale in a more mature version. The beneficiaries of the impacts are grouped into general public society, community and individual consumer level. The individual impacts are described in in Appendix W.

*Table 25 Assessment of impacts of the different technology solutions, differentiating between the implemented pilot and the potential the technologies have when implemented at large scale*

| Category | Impact | Conventional | Implemented Alternative / potential | Implemented Advanced / potential |
|---|---|---|---|---|
| **General Public Society Level** | | | | |
| **Socio-Economic** | Increased grassroots development | 0 | +/+ | 0/+ |
| | Enhance overall economic development | + | +/+ | +/+ |
| | Human resources development | 0 | +/+ | 0/+ |
| | Business opportunities for regional companies | + | +/+ | 0/+ |
| | Decline of bottle sales business | 0 | -/- | -/- |
| | **Subtotal Socio-Economic** | **2** | **3/3** | **0/3** |
| **Environ-mental** | Greenhouse gases | - | +/+ | -/- |
| | Exploitation of non-renewable materials | - | -/- | +/+ |
| | Use of renewable energy | 0 | +/+ | 0/0 |
| | Increased evapotranspiration | 0 | +/+ | 0/0 |
| | **Subtotal Environmental** | **-2** | **2/2** | **0/0** |
| **Subtotal Socio-Economic and Environmental** | | **0** | **5/5** | **0/3** |
| **Local Community Level** | | | | |
| **Socio-Ecomonic** | Increase in property value | + | +/+ | +/+ |
| | Sludge-based fertilizer production | 0 | 0/+ | 0/0 |
| | Wastewater reclamation for agriculture | 0 | 0/+ | 0/0 |
| | Cost savings for leisure activities | 0 | +/+ | 0/0 |
| | Strengthened community integrity | 0 | +/+ | 0/0 |
| | Strengthened relationships with external stakeholders | + | +/+ | +/+ |
| | Employment | + | +/+ | +/+ |
| | Skills development | + | +/+ | +/+ |
| | Increased well-being due to cleaner environment | 0 | 0/+ | 0/0 |
| | Awareness on WASH-issues | 0 | +/+ | 0/0 |
| | Independent maintenance | 0 | +/+ | -/0 |
| | Increased community resilience | 0 | +/+ | 0/0 |
| | Noise attenuation | + | +/+ | +/+ |
| | Refunds for land use | - | -/0 | -/- |
| | Decline of income from aquaculture | 0 | -/0 | 0/0 |
| | Increase of domestic water filter purchases | 0 | -/0 | -/0 |
| | Lowered harvests in organic farming | 0 | -/- | 0/0 |
| | **Subtotal Socio-Economic** | **4** | **6/12** | **2/4** |
| **Environ-mental** | Reduced trashing of plastic bottles | + | +/+ | +/+ |
| | Improved environmental quality | 0 | +/+ | 0/0 |
| | Benefits for biodiversity | 0 | +/+ | 0/0 |
| | Improvement of groundwater | + | +/+ | +/+ |
| | Soil erosion | 0 | +/+ | 0/0 |
| | Less arsenic contamination in the immediate surroundings | + | +/+ | +/+ |
| | Disposal of sludge | - | +/+ | -/- |
| | Disposal of system and spare parts | - | -/- | -/- |
| | Land use change | 0 | -/+ | 0/0 |
| | **Subtotal Environmental** | **1** | **5/7** | **1/1** |

| | | | | |
|---|---|---|---|---|
| **Subtotal Socio-Economic and Environmental** | | **5** | **11/19** | **3/5** |
| **Individual Consumer Level** | | | | |
| **Socio-Economic** | Time surplus for economic activities | + | +/+ | +/+ |
| | Reduced costs from purchasing bottled water | + | +/+ | +/+ |
| | Health-related work productivity | + | +/+ | +/+ |
| | Costs savings from reduced medicine purchases and hospital visits | + | +/+ | +/+ |
| | Averted waterborne diseases | + | +/+ | +/+ |
| | Timed surplus for social activities | + | +/+ | +/+ |
| | Lowered consumption of medicines | + | +/+ | +/+ |
| | Increased privacy and intimacy for hygiene practices | 0 | 0/+ | 0/+ |
| | Higher comfort due to indoor facilities | 0 | 0/+ | 0/+ |
| | Sufficient and safe water for hygiene/cooking | + | +/+ | +/+ |
| | Gender equality advocacy | 0 | +/+ | 0/0 |
| | Equality enhancement | + | +/+ | +/+ |
| | Reduced anxiety of falling ill | + | +/+ | +/+ |
| | **Subtotal Socio-Economic** | **10** | **11/13** | **10/12** |
| **Environ-mental** | Increased well-being due to a cleaner environment | 0 | +/+ | 0/0 |
| **Subtotal Socio-Economic and Environmental** | | **10** | **12/14** | **10/12** |
| **Overall Socio Economic** | | **16** | **20/28** | **12/19** |
| **Overall Environmental** | | **-1** | **8/10** | **1/1** |
| **Overall Total** | | **15** | **28/38** | **13/20** |

### 9.3.3 INTERPRETATION

All three technologies have impacts on all stakeholder levels. While the impacts on the community are more numerous, most socio-economic impacts are related to the achieved water quality of the drinking water treatment system, the organisation of the project, as well as the construction and operation activities of the overall system. Environmental impacts are rather related to the catchment area management and waste water treatment. Overall the positive impacts outweigh the negative impacts by far for all solutions. The alternative system considering all the phases of the water cycle has most positive impacts with 36 and 42 against 8 and 4 negative impacts leading to ta final score of 28 and 38 for implemented and potential respectively.  The conventional has 20 positive against 5 negative impacts and the implemented advanced and potential advanced system have 20 and 25 positive against 7 and 5 negative impacts respectively.

#### 9.3.3.1 SOCIO-ECONOMIC IMPACTS

Health issues and their economic implication relate mainly to providing drinking water which again relates to the technical performance evaluation of achieving drinking water quality. In this regard the alternative and advanced system can score higher against the current setup and also the conventional systems. Organisational improvements on the grassroots level are related to the overall involvement of the local population at the various stages of the project, which is mainly achieved by the alternative system. Overall, the alternative system as implemented at the pilot plant and its potential score 7.8 and 10 respectively, the implemented advanced system and its potential score 3.1 and 6.4 respectively, whereas the conventional scores 5.9.

#### 9.3.3.2 LEVEL OF ENVIRONMENTAL IMPACTS

Pollution is related to any human activity and can thus only be compared as to the minimisation and in relation to the other positive impacts that interventions have. Notably, the minimisation of transport, use of energy (solar) and chemicals (biological treatment) is more on the side of the alternative system than the advanced system. An advantage of the advanced system is the usage of recyclable materials in contrast to RCC structures used in the alternative system. The approach of catchment area management, house connections, reed bed filters and biogas production can rather be related to the alternative approach. Overall the alternative system as implemented at the pilot plant and its potential score 9.1 and 10 points respectively whereas the implemented advanced system and its potential both score 0.5. The conventional scores 0.

## 9.4 FINANCIAL VIABILITY

Financial viability is analysed for the alternative, advanced, conventional and current setup on the level of the water price with and without investment, the private profit and loss for an operator as well as by calculating the ratio of benefits to cost considering external effects.

### 9.4.1 ADEQUACY OF WATER PRICE

The water price is calculated for various types of setups, differing in the size and the extent of infrastructure and concluding services (Table 26). The lower design size of the alternative solution of 14KLD supply, which leads to a supply to 140 households with 20LPCD, is compared to the maximum possible supply of the alternative system with double the flowrate and a capacity of 280 households. The current setup, which is scalable on an individual level, is also compared with the same capacities. The Conventional setup does not have a variable flowrate and reaches to only 70% of the design households due to a non-participatory approach. The advanced setup is compared with the basic design capacity of the alternative system of 14KLD and the maximum possible capacity of the advanced system of 60KLD. It must however be mentioned that the calculations have limited meaning for the higher capacities, as the pond has only be assessed for providing sustainable water quantities for up to a maximum of 20KLD, and this only if the maximum catchment area of 35.000m² is well managed.
The different capacities however show whether an option has a beneficial scaling up effect or not. A beneficial scaling up effect occurs when the costs do not increase linearly with the capacity. This is the case for both alternative and advanced setup, but not for the current setup. Here an increased capacity only translates into the no. of tube wells, which are not cheaper if procured in a higher no. of units, and the water price stays 20 or 30 Paise per L considering only O&M or also investment respectively. The scaling effect also differs between alternative and advanced setup as the O&M expenses for the alternative setup only rise for the chemicals as well as the spare parts, whereas the advanced setup has additional expenses for the energy consumption, which contributes with 24% to the overall O&M expenses of the 60KLD treatment system. The price of the water, considering investment and O&M, for the alternative system almost halves from 6 to 3.7 Paise when doubling the capacity from 14 to 28KLD. At the same time increasing the capacity of the advanced system with the factor 4.29, from 14 to 60KLD, only reduces the price with the factor of 2.4 from 15.5 to 6.4 Paise. The advanced system is also compared with a lifetime of 30 years and 10 years as major part of the equipment have to be replaced after 10 years increasing the expenses for O&M in the form of spare parts. The O&M based water price of the one time use advanced setup with 10 years lifetime is thus only 3.2 Paise per L if 60KLD are produced. Still the alternative system is more competitive and produces water for 2.9 and 4.5 Paise with 28 and 14KLD considering the 30 year setup and only O&M.

The investment for the sewerage system constitutes to 64% of the alternative setup and 49% of the advanced setup. The water price for the setups including all infrastructure is thus much higher than for the water production only. All water prices including investment and monthly O&M costs are given in Table 26,details for all cost calculations are given in the Appendix 0.

*Table 26 Calculation of water price for various types of setups with and without investment costs*

| Type of Setup | Supply Capacity [KLD] | Lifetime [years] | Investment Cost [INR] | total O&M [INR per month] | Water price including only O&M costs [Paise/Liter] | Water price including investment cost [Paise/Liter] | Water fee for O&M cost [INR/household] | Water fee for O&M and investment [INR/household] |
|---|---|---|---|---|---|---|---|---|
| Current Setup | 14 | 10 | 4,913,192 | 86,097 | 20.5 | 30.2 | 615 | 907 |
| Current Setup big | 28 | 10 | 9,826,384 | 172,193 | 20.5 | 30.2 | 615 | 907 |
| Conventional Setup | 14 | 30 | 2,157,162 | 27,553 | 6.6 | 8.0 | 197 | 240 |
| Alternative Setup including all | 14 | 30 | 7,770,278 | 48,000 | 11.4 | 16.6 | 343 | 497 |
| Alternative Setup with catchment | 14 | 30 | 2,795,000 | 22,270 | 5.3 | 7.2 | 159 | 215 |
| Alternative Setup only water production | 14 | 30 | 2,280,000 | 18,874 | 4.5 | 6.0 | 135 | 180 |
| Alternative including all | 28 | 30 | 10,472,917 | 67,802 | 8.1 | 11.5 | 242 | 346 |
| Alternative Setup with catchment | 28 | 30 | 3,010,000 | 29,207 | 3.5 | 4.5 | 104 | 134 |
| Alternative Setup only water production | 28 | 30 | 2,470,000 | 24,457 | 2.9 | 3.7 | 87 | 112 |
| Advanced Setup including all | 14 | 30 | 10,191,691 | 81,052 | 19.3 | 26.0 | 579 | 781 |
| Advanced Setup with catchment | 14 | 30 | 5,216,413 | 55,322 | 13.2 | 16.6 | 395 | 499 |
| Advanced Setup only water production | 14 | 30 | 4,701,413 | 51,926 | 12.4 | 15.5 | 371 | 464 |
| Advanced Setup including all | 60 | 30 | 22,306,521 | 188,116 | 10.5 | 13.9 | 314 | 417 |
| Advanced Setup with catchment | 60 | 30 | 6,314,556 | 111,483 | 6.2 | 7.2 | 186 | 215 |
| Advanced Setup only water production | 60 | 30 | 5,157,413 | 101,661 | 5.6 | 6.4 | 169 | 193 |
| Advanced Setup including all | 14 | 10 | 10,191,691 | 60,352 | 14.4 | 34.6 | 431 | 1038 |
| Advanced Setup with catchment | 14 | 10 | 5,216,413 | 34,622 | 8.2 | 18.6 | 247 | 558 |
| Advanced Setup only water production | 14 | 10 | 4,701,413 | 31,226 | 7.4 | 16.8 | 223 | 503 |
| Advanced Setup including all | 60 | 10 | 22,306,521 | 143,428 | 8.0 | 18.3 | 239 | 549 |
| Advanced Setup with catchment | 60 | 10 | 6,314,556 | 66,795 | 3.7 | 6.6 | 111 | 199 |
| Advanced Setup only water production | 60 | 10 | 5,157,413 | 56,974 | 3.2 | 5.6 | 95 | 167 |

The scorings for the individual constellations are averaged for each setup, while potential economisation is considered to be 20% for the alternative and 50% for the advanced setup as per statements from the manufacturers.
The adequacy of the water price considering only expenditures for O&M for the alternative system, as implemented at the pilot plant and its potential, score 6.1 and 7.3. The implemented advanced system and its potential score 4.1 and 6.1 respectively. The current system scores 1.4 and the conventional 4.7.
Adequacy of water price considering investment and O&M for the alternative system as implemented at the pilot plant and its potential score 5.9 and 7.0. The implemented advanced system and its potential score 3.3 and 4.9 respectively. The current system scores 1.2 and the conventional 4.7.

### 9.4.2 PRIVATE BENEFIT TO COST RATIO

The selection of benefits is based on the positive impacts identified in the SELCA for which monetization methodologies are available. As the benefits depend on the extent of infrastructure considered, each benefit is attributed to the correlating infrastructure investment.

In a first step, the internal benefits are assessed for the microeconomic analysis. Essentially, a water service fee can be seen as one of the main revenues to a drinking water supply system. The Panchayat further has the governmental provision of sourcing 50% for the O&M expenses.

The benefits or incomes are compared to the running O&M expenses without taking into account the investment in order to see, whether any of the supply systems can be run in a profitable way by only providing the water to the villagers.

Even collecting 50 INR (compare 5.2.3) from each household and receiving the 50% O&M support from the government would not lead to any of the solution to run on profit when distributing via a piped supply. Least losses would be encountered with the alternative system at double design flowrate reaching 280 households with the catchment area management. Yearly losses amount to 49,241 INR. The conventional setup would create 98,115 INR losses while reaching 112 households whereas the advanced setup has least losses when reaching 140 households and including the catchment area management of 268,931 INR. The catchment area management is profitable, or reduces the losses as it is assessed that it generates a higher willingness to pay by the villagers because they have more faith in the quality of the water. Details for the profit loss calculations are given in the Appendix U.

A profitable way of running the water treatment plant would require the operator to sell the treated water in bottles to the market price. With an average profit of 4 INR per 20L bottle the operator would need to sell more than 35 bottles or 0.7KLD each day in order to reach breakeven in case of the most economical alternative setup. Considering a production of 28KLD, 0.7KLD seems to be a small part of the overall supply. In case of the design flowrate of only 14KLD, 50 bottles or 1KLD would need to be sold to reach breakeven.

A private operator will want to maximise his profit and thus only sell bottled water, instead of supplying it to the villagers by pipe. He would then not expect to receive the plant as granted and would also not receive government support for the O&M. For the 14KLD alternative plant including the catchment area management he could have a BCR of 3.4 and make a maximum profit of 5,840,954 INR in 30 years if he sells all water it bottles. He has a payback period of 3 years, from when on he would start making profit.

As the aim of this study is not to calculate the business case of a water bottling factory, this case is not further elaborated, but mentioned as it seems the only market economic viable way for running the treatment plant.

The scoring is given in regards to the loss percentage of investment thereby taking averages of the different alternative and advanced setup options, also including the 10 year advanced option. The 10 year advanced scenario is profitable (or better creating the least losses) in the short run as O&M expenses are comparably cheaper while being able to achieve full benefits. Again the potential alternative is considered to have 20% less costs and the potential advanced to have 50% less costs. With these assumptions the potential advanced 10 year setup has the least losses with 1.34% scoring 10 and the average advanced potential scores 7.4, while the implemented advanced scores only 3.7, the potential and implemented alternative 6.81 and 5.45 with 1.96 and 2.46% while the conventional scores 2.94 with 4.55%.

### 9.4.3 PUBLIC BENEFIT TO COST RATIO

The public benefit to cost ratio on a macroeconomic level provides more positive picture for the piped water supply setup supplying water to the villagers. When internalising external effects [170] all options have a positive BCR. The highest BCR is achieved with the alternative system incl. catchment area management and supply of 28KLD with 22.1 producing benefits of 64.3 million INR. Due to the high no. of people reached with 60KLD a BCR of 20.3 is achieved with 132 million INR monetized benefits by the advanced technology incl. catchment area management. Although the water supply including distribution network, sewerage and waste water treatment achieve the highest benefits, 171 million of the advanced setup with 60KLD, the BCRs are lower as the costs are comparably higher (Figure 98).

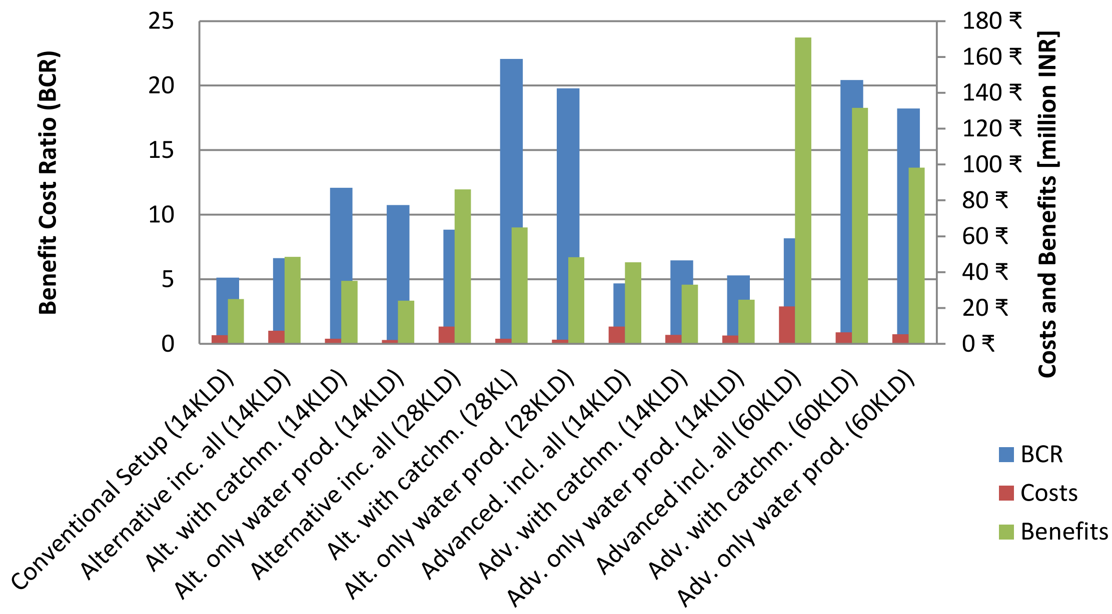



*Figure 98 Comparison of public benefit to cost ratio*

The alternative system as implemented at the pilot plant and its potential score 6.1 and 7.6 whereas the implemented advanced system and its potential score 4.7 and 9.5. The conventional scores 2.5 with a BCR of 5.6.

## 9.5 STAKEHOLDER VIEWS ON THE SUSTAINABILITY CRITERIA

Considering the sum of the unweighted scores, the potential alternative technology sores 100 followed by the potential advanced with 81, the alternative pilot with 79, conventional with 61, current with 49 and the advanced as implemented with 36. While the alternative scores high in socio-economic and environmental impacts as well as availability of construction material and water price, the advanced scores high in water quality, reliability, quick setup and private as well as public benefits (Figure 99).

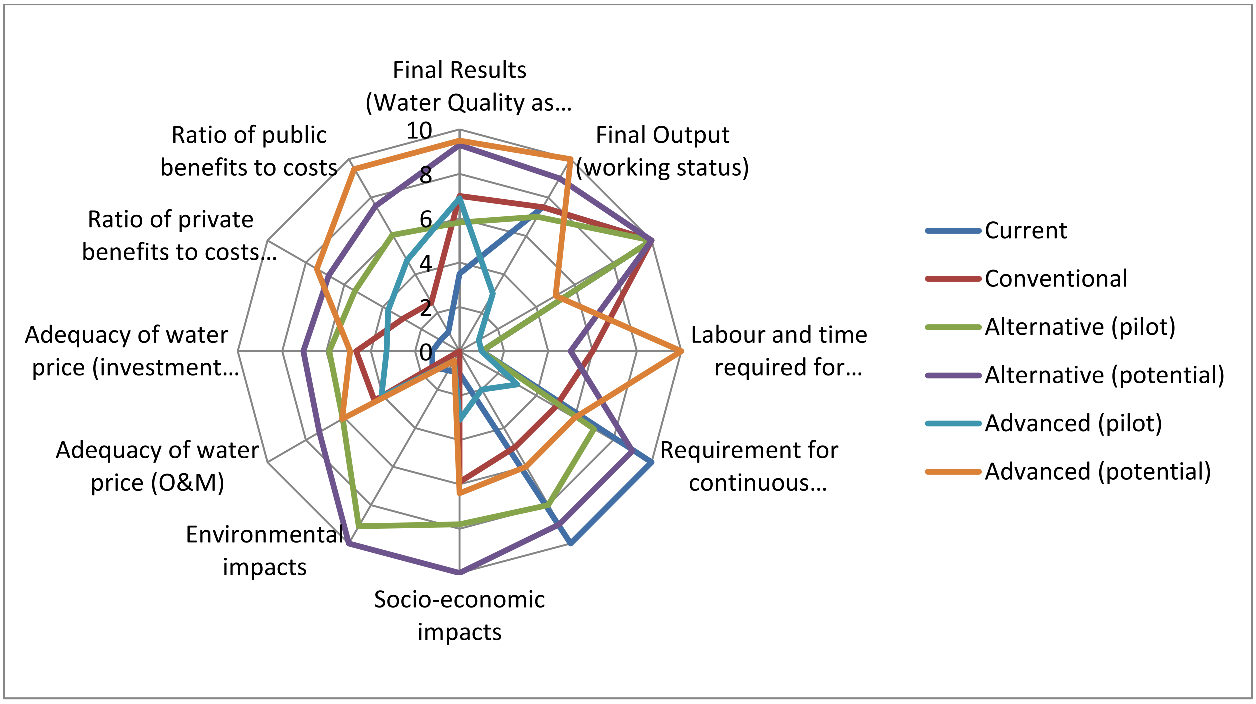



*Figure 99 Achieved unweighted scores for each of the technologies*

In a weighting range of 0-3 for each criteria it can be seen that the accumulated weighting by all stakeholders is highest for the adequacy of the water price based on O&M and the reliability of the plant as well as the final water quality. The time for construction is the least important criteria followed by the qualification requirements for the operator (Figure 100).

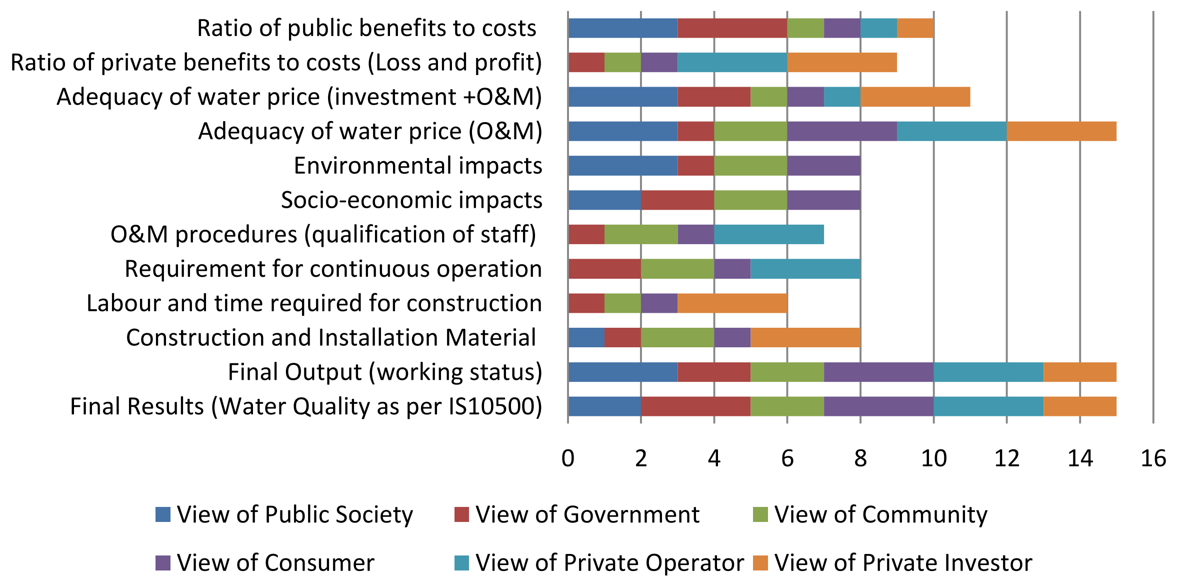



*Figure 100 Accumulated Weighting of the criteria by the stakeholders*

In a final multi-criteria rating it can be seen that the different weightage of the criteria across the stakeholders changes the order of preference for the technologies between the stakeholders. In contrast to all other stakeholders preferring the potential alternative technology, the private investor prefers the advanced potential technology, as he is mostly interested in a smooth construction process and the final water price, as well as the private BCR. The potential advanced also scores well for the private operator, who is interested in the water quality and the reliability as well as the operation, pricing of the water based on O&M and the private BCR. Nonetheless, all stakeholders - except the private investor - would prefer the alternative potential technology which also scores the highest overall score. Comparing the actually implemented solutions, the alternative pilot is preferred by all stakeholders. The private investor though would also consider the conventional system as a close second, while the private operator sees no difference between conventional and the current tube well setup, which the public society views as the least preferable. Still in the view of the government, community, consumer and private operator, the current tube well setup is preferred over the implemented advanced pilot, mainly because of the difficulties in construction, operation and maintenance of the advanced system.

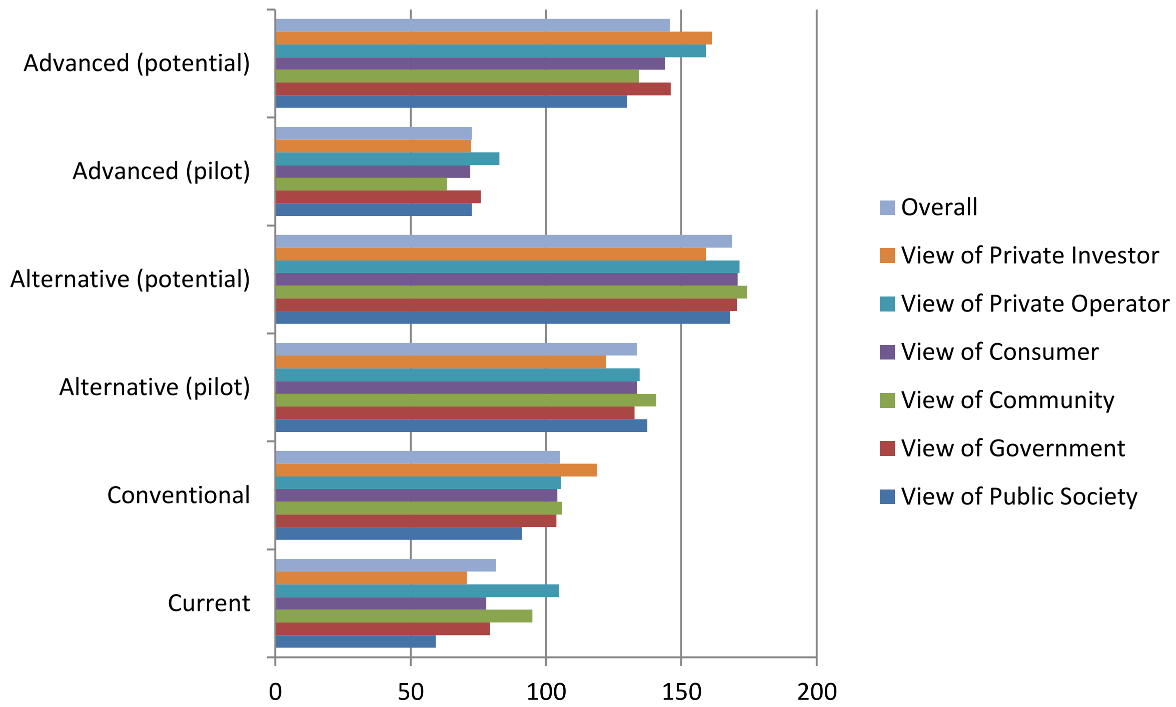



*Figure 101 Rating of the solutions by the stakeholders in [Sum of weighting x score]*

Overall the potential alternative system leads with 167 points followed by the potential advanced with 141, the alternative pilot with 131, the conventional with 104, current with 79 and then then advanced pilot with 68.

At the implementation level, the alternative system seems the most sustainable considering its robust performance, actual socio-economic impact and comparably more affordable price for water. As the potentials are assumed, the future advanced system might become more preferential showing scope regarding impeccable water quality, reliability and its private and public BCR.

# 10 OUTLOOK, LESSONS LEARNED AND CONCLUSIONS

The sustainability assessment provides the outlook that the integrated ecological surface water treatment system – consisting of rainwater harvesting and catchment area management, filtration by roughing filters, slow sand filters and activated carbon, disinfection with manually dosed sodium hypochlorite and usage of solar photovoltaic cells with a battery backup as energy source - is regarded as the most sustainable solution, even in comparison with an advanced high tech setup. Many of the socio-economic impacts are related to the safe distribution and comfort of having a water source at home, but environmental impacts relate to a cleaner environment due to a sewerage system and sanitation setup. These components have not been described when elaborating the water treatment part of the water supply, as they were not essential for the technological performance evaluation of the drinking water production, but also because they were not implemented in the field and still remain an outlook. They are still foreseen to be set up by the Indian project team in the future development of the water supply. Developed concepts and designs are briefly outlined.

The outlook further contains recommendations for the replication scope of the developed solution and concludes on the main technological and socioeconomic outcomes of the study including the identified limitations of the elaborated results and further scope for research.

## 10.1 FURTHER COMPONENTS OF A SUSTAINABLE WATER SUPPLY

The final construction step of the study could only be taken up partly in the project period as the third and final disbursement of project funds for the construction activities was not disbursed in time by the funding agency. These construction activities covered the integrated distribution scheme with stand posts, house connections, sanitation structures, sewerage and waste water treatment plant, as well as the integration of existing biogas plants for the usage of the waste water sludge. These parts of the water supply scheme are essential for its overall sustainability concerning the distribution of safe water and handling of additionally generated waste water by the water supply.

### 10.1.1 DISTRIBUTION NETWORK

In order to provide the water safely and conveniently to the consumers, a distribution network is foreseen. The treated water is being pumped to a 6.4m elevated 12KL OHT, which can develop a maximum head of 7.6 meter when completely filled. For the standard design flowrate 14KLD is intended to be distributed by pipes to 85 households with stand posts and 15 households with house connection. The locations have an elevation of up to 2.3m from the project site, thus having minimum head of 5.1m not considering pressure loss in the pipelines (compare chapter 6.2.1.2). According to calculation with EPAnet[v] and Watergems[w] the main line leading to the village is designed to have a diameter of 50mm for 320m. 40mm pipes for 850m would suffice for the two lines dividing from the village entrance towards Malpara and Jyot Sujan. The house connection and stand posts can be connected to the main with 15mm pipes, of which approx. 370m would be required (compare Map 5). This setup would guarantee sufficient pressure at every point of the network under normal usage.

### 10.1.2 SANITATION UNITS

The households still not equipped with sanitation units to date need them in order to avoid open defecation, and in this way protect the catchment area. Especially the poorer households in Malpara require sanitation units. Houses which are not connected to the sewer system would require dual pit latrines, which work reliably in rural areas. Households receiving piped water supply and connected to the sewer system can have flushed toilets [171]. This intervention would also lead to the reduction of waterborne diseases. In the course of the project the GOI Swach Bharat programme has implemented numerous sanitation units in the village so that the current requirement is lower than the originally planned 50 households.

***v https://www.epa.gov/water-research/epanet***

***w https://www.bentley.com/en/products/product-line/hydraulics-and-hydrology-software/watergems***

### 10.1.3 SEWERAGE

A sewer network is more expensive than a drinking water distribution network. Sewer lines have a bigger diameter and also need to be laid more sophisticated, as they need a constant free-fall gradient maintained throughout the network. The gradients should have a minimum inclination of 1% in order to allow the sewage to flow by gravity. The topography of the village and the possible location for the waste water treatment plant allows only for a head of 3.5 meters which translates to a maximum length of 350m. The location for the pilot sewerage has thus been chosen just adjacent to the location of the waste water treatment plant (compare Map 2). The main line of the sewerage needs a diameter of 150mm, while the individual house connection leading to the main can have 100mm diameter pipes. While GI pipes are preferred for the drinking water distribution due to their sturdiness, the sewerage pipes can be made of PVC or concrete.

### 10.1.4 WASTE WATER TREATMENT

A waste water treatment process using minimal amounts of external energy and space in comparison with a simple waste water pond system is the reed bed filter process. The first step in this process is the settlement or sedimentation tank in which organic substances settle. Its operation capacity depends on the retention time of the sewage, surface loading and flow velocity. The tanks are designed so that even at maximum inflow a good sedimentation efficiency is achieved. The retention time in this case is about 1.5 days. The sludge accumulates in the funnel shaped bottom of the sedimentation tank, where it can be collected for further use in a biogas digester.

The settlement tank is followed by a horizontal reed bed filter which mainly contributes to reduce TSS, BOD and COD. Further treatment is done by a vertical reed bed filter which can also contribute in reducing nutrients in the water. Helophyte types of plants like Phragmites Karka and Communis, Canna Indica, Typha Latifolia or Angustifolia could be used which support phosphate and ammonia binding and denitrification.[172,173] The pilot sewerage would discharge waste water from around a 100 people for which a total plant area of 204 m² is required. Two parallel treatment rows would have settlement tanks with two compartments of 5 and 2.5m² and a depth of 1m, rectangular horizontal reed bed filter sized 49.5m²m with a depth of 0.4m and two 25m² circular vertical reed bed filters with 0.7 m depth. This kind of setup would be able to take care of 5 to a maximum of 10 KLD with COD and nitrogen concentrations up to 20 and 4 g/l respectively. A rough design sketch is given in Figure 141, Appendix K.

### 10.1.5 BIOGAS PRODUCTION

Waste water sludge is collected in the settlement tank and can be extracted regularly and used for biogas production. It is even more effective to mix the sludge with biomass like cow manure, rice shells, rice stems and parts of banana plants which are cut after harvesting. The assessed overall potential of methane, that can be produced by waste water and biomass available in the villages, is 622 MWh per year. One optimised low tech reactor in the village could make use of 27.9 tons wastewater, 2.22 tons of cow manure, 0.31 and 0.33 tons of rice shells and stems as well as 1.38 tons of banana plants per year. The entire available waste water sludge and biomass available could be yielded with 98 of the 5m³ low tech reactors and could altogether generate between 150 to 220 MWh per year [146]. Compared to an energy demand for the multi stage surface water scheme of 2 to 5 MWh/y, the solar energy provision of the 2.4 KWpeak system of 4.5 MWh/y or the demand for the entire water supply including waste water pumping of around 30 MWh per year, the potential of biogas in the village is very high and could also cover a major part of the energy demand of the individual households.

## 10.2 REPLICATION POTENTIAL

Technically the developed solution is applicable to many target areas. As described in chapter 1.2, worldwide numerous rural areas suffer from contaminated groundwater sources and have options for rainwater harvesting or direct surface water usage. From a geographical point of view prerequisites relate to the availability of a perennial surface water source or the option to create a reservoir and catchment which can harvest sufficient water; furthermore it has to be possible to manage the catchment in a way that the harvested water is not contaminated by pollutants which are not removable with the biological treatment. For setting up a solar-based treatment system, the solar irradiation has to be sufficient. Requirements for technological framework conditions and infrastructure are at a very low level: Basic civil construction, including the capacities of building water proof tanks!, and plumbing capacities have to be available; sand, pebbles, gravels or stone chips as well as chemicals for disinfection should be available.

### 10.2.1 FIRST REPLICATION CASES

Several adjoining community representatives visit the pilot plant and intimate their interest of having a similar plant setup in their community. Investment costs though are a big hurdle for community-based organisation and Panchayats to implement a water supply.
PHED has taken interest in the setup, and so have various politicians in the region who visited the project site and stated their support for further replication.
Replication initiatives have been taken up by a partner organisation of the solar company Onergy, which supplied the solar pumping setup for the pilot. The NGO Switch On implemented a multi-stage filtration system as part of a solar-based irrigation scheme in Joka village near Bagnan in the Howrah district of West Bengal. The system consists of an upflow roughing filter and a slow sand filter and provides around 1000 LPD to the farmers and field workers.
Another replication has been taken up by the German NGO Indienhilfe. The community-based approach together with the Panchayat in the village Chatra in North 24 Parganas, West Bengal started with a site visit of Panchayat representatives to the pilot site in Jyot Sujan and a discussion with the Jyot Sujan Water Committee about their experiences and mode of project development. In May 2016 Indienhilfe performed a baseline assessment in the village as a first step of the project development. A water committee is set up and takes first steps in elaborating project concepts.
During the project period Sulabh international has setup a few surface water based community-sized treatment plants, though with a slightly different technological concept (compare 4.1.2).

### 10.2.2 ECONOMICAL CONDITIONS FOR LARGE SCALE IMPLEMENTATION

As derived in chapter 9.4 a private investment in a rural water supply project is not financially viable in the assessed economic context in the region, thus replication options here are limited to public programmes or donor organisations. As it is generally not even viable to source sufficient funds for operation and maintenance, a permanent funding source is required to keep the supply scheme working. The existing Indian national government scheme for Panchayats covering 100% of the investment and 50% of the O&M[174] would need to cover an even higher share of the O&M expenses in order to make rural water supply possible.
With the current government policies the system is only economically feasible with community initiative if the average household income is high enough to allow people to spend sufficient fees for the O&M. While the salary of the operator requires on average 100 paying consumers - considering a water fee of 1% of the average salary - the remaining O&M expenses for spare parts, repair and chemicals would be lower in overall share of the overall O&M costs in economies with higher salaries and less costs for material. In Jyot Sujan the O&M expenses apart from the salary contribute

to around 83% of total costs. This thus requires another 490 paying consumers and thus in total 590 paying customers, which is not possible for the size of the setup in the Jyot Sujan. In a region where the salary might contribute to 50% of the O&M expenses only 200 paying customers would be required to cover the O&M. Assuming the prices for the material and spare parts to stay constant, a community with an average monthly salary of 25,000 INR could source sufficient fees for covering O&M in a private setup. The other option would of course be that at least 83% of the O&M would be covered by public sources.

## 10.3 CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

Conclusions can be drawn on several levels and on various topics, some of the conclusion lead to new questions and research topics. The conclusions are grouped in technical and socio-economic conclusions which include environmental aspects.

### 10.3.1 TECHNICAL ASPECTS

Main outcomes and lessons learned are concluded along the treatment process of the alternative setup, beginning with the catchment area and ending with distribution of the treated water. A main focus is laid on the performance optimisation of the multi-stage filtration process.

The engineered catchment area performed as required, but it could be observed that the bunds and channels needed to be repaired very often as they were dug through by mice or other animals, especially in channels close to a water body. This led to losses of water during rainwater harvesting especially in the beginning of the rainy season when the ponds in the catchment were empty. The solution of constructing cemented or other permanent channels would cause problems with the agricultural usage, as the channels need to be changed regularly. Research could thus look into ways of preventing these animals to dig in the channels, possibly by planting some species which drives the diggers away. A further conclusion related to the catchment area management is that the diversion of catchment water is required when stakeholders apply harmful pesticides, as the application of harmless pesticides was unfeasible (compare 10.3.2.2). The simple way of constructing the diversion with a temporary soil bunds works effectively.

Excavation of the pond proved to be very challenging and resource intensive; even with four simultaneous pumps it was not possible to dry the pond so that a JCB could be used for excavation. Manual excavation was required and led to an increase of costs for the preparation of the pond reservoir. It can be concluded that perennial ponds have a reason for being perennial, which is that they are connected to a constantly feeding water source and thus are not easy to dry up for excavation purpose; wet excavation is then required.

Another challenge during the construction is the leak-proofing of the RCC structures and especially at the connections with the pipes, two local contractors resigned as they were technically not capable to leak-proof the filter units. Finally usage of complete epoxy coating of the structure was required, as repeated time consuming attempts to repair the RCC leakages with cement mixed with various SICA chemicals did not lead to satisfactory results. It can be concluded that RCC water tanks have to be either built by specialists or ready fabricated structures have to be used.

When looking at the technical performance of the treatment plant, conclusions for the optimal mode of operation can be made for the following three input parameters: flowrate, required pre-treatment by roughing filters and oxygen levels for the SSF inlet. Aims of the optimisation are removal efficiency, and final treated water quality related to turbidity and consequently bacteriological concentrations while producing the maximum possible amount of water (flowrate). The three input parameters have interdependencies. Higher flowrates might work well with low input turbidity. On the other hand oxygen levels are lower with high flowrates, which is not preferable for the treatment performance.

### 10.3.1.1 PRE-TREATMENT AND FLOWRATE

As analysed in chapter 8.2 the required SSF input water quality needs to be below 8 NTU, which can only be achieved by the HRF with a raw water quality of a maximum of 25 NTU. This is only the case in 82% of all monitored cases throughout the year (Figure 69).
As the treatment performance not only depends on the input water quality but also the flowrate as shown in chapter 8.4, the flowrate would need to be reduced in the HRFs when the input raw water has high turbidity in order to increase their treatment result. The rate of decrease cannot be concluded from the monitoring data, as with the decrease of up to 3LPM sufficient quality was not achieved (Figure 102, compare also Figure 83). Further research would thus need to be conducted in order to find the verified flowrates at input turbidity higher than 25 NTU.

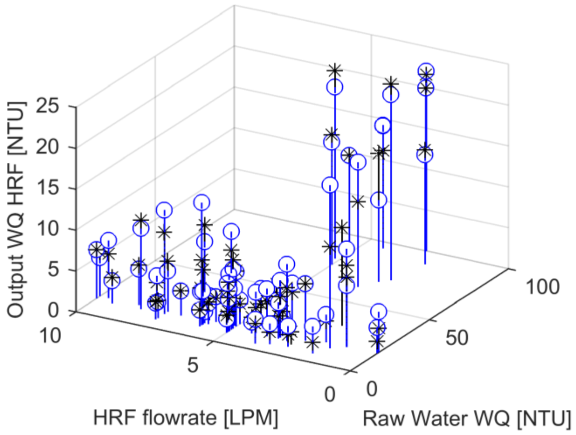



*Figure 102 Output water turbidity of HRFs in dependency of flowrate and raw water quality*

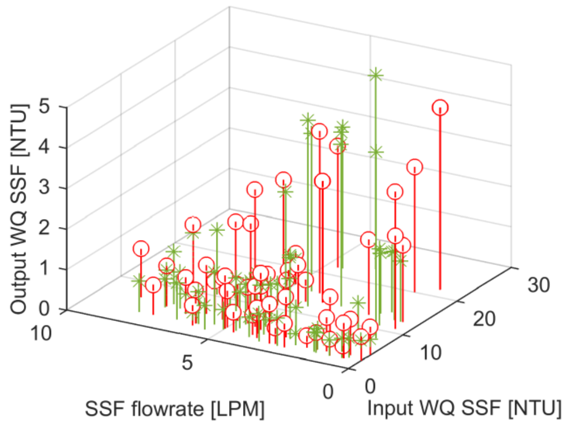



*Figure 103 Treated water turbidity of SSFs in dependency of flowrate and input water quality*

While the SSF is rather constant in output WQ in regards to the flowrate (even worse at lower flowrates (Figure 84)) it is very sensible towards input water quality (Figure 103). As a conclusion for the current setup it could be considered to run only one SSF during high turbidity peak loads, when the two HRFs are running on a low filtration rate, so that the one SSF receives water from both and thus runs on its optimal filtration velocity. Another option would be to recycle parts of the SSF treated water so that both SSFs receive sufficient flow.
When looking at structural improvements one option could be to increase the size of the HRFs. Either the cross-sectional area could be increased, this would reduce the flowrate which would lead to better performance, but also the length of the HRF chambers could be increased, or another chamber, possibly one with finer gravel could be added. Another option could be the inclusion of a dynamic roughing filter prior to the HRF [101].

### 10.3.1.2 OXYGEN LEVEL AND FLOWRATE

It can be shown that the treatment performance increases when the SSF receives more oxygen (Figure 90). Measures for increasing the oxygen level are also described in 8.5. Initial assumptions of achieving higher oxygen rates with higher flowrates and this being the reason for the better performance of the SSF could not be confirmed. Contrarily increased flowrates reduced the DO levels on the SSF (Figure 94). Possibly algae on the SSF produce oxygen, which generates higher DO concentrations, when the detention time on the SSF is increased. It can thus be concluded that from the point of view of pre-treatment as well as regarding the oxygen level, both core parameters for an overall better performance, lower flowrates are more preferential.

Interestingly the overall removal efficiency increases up to a certain level with the flowrate independent of the DO level. Partly high removal efficiencies are observed at high flowrates up to 20 LPM even at low DO levels of 2-3mg/l. The SSF removal efficiency increases, while oxygen on the SSF decreases as well as the HRF performance decreases. One explanation is the observation of the oxygen depletion in the SSF. Less oxygen depletion increases the removal efficiency of the SSF and higher flowrates reduce oxygen depletion. Another explanation is that too slow flowrates bring too little nutrients or even total amount of oxygen to the organisms in the Schmutzdecke, which might be less active. This leads to the conclusion of the optimal flowrate, being high enough to cause little oxygen depletion and nutrient provision and sufficiently low to allow enough oxygen increase on the filter bed. This optimal flowrate is observed to be 14 LPM or 0.14m/h at the SSF (Figure 89).
It has to be mentioned though that the first years monsoon season with high turbidity waters could not be analysed representatively as the filters had not yet acclimated and ripened. Long-time analysis with ripened SSFs and longer test of higher flowrates under higher oxygen conditions would be interesting to further fine-tune optimisation options regarding flowrate and aeration.
As the treatment seems to be depending on DO levels on the SSF setting up an aeration device on the SSF for increasing the oxygen and testing under various conditions could be interesting for looking at the optimisation of cascading between HRF and SSF.
In general the conducted tests can only provide limited conclusions as a range of parameters are changing and the dependency of single parameters can only be observed in a limited way. Although 3D dependencies provide a little more insight, for clearer dependencies it would be important to have longer periods with constant parameters and variation of only one parameter.

#### 10.3.1.3 FURTHER TECHNICAL OBSERVATIONS LEADING TO CONCLUSIONS

The comparison of filter media for the roughing filter shows very similar results, while it can be observed that the stone chips performed better in the first period and the gravel performed better in the second period (chapter 8.2.2). Conclusions related to ripening of the gravel and initial surface charge of the stone chips could be further looked into and longer observations made in order to come to a final conclusion of giving preference to the stone chips due to their local availability and thus cheaper price.
High chlorination dosing requirements are explained due to the high pH value, but chlorine demand could also be caused by high organic matter content of water. DOC and TOC testing along the treatment process could be looked into and conclusively its removal during the MSF in which the ACF should remove DOC and TOC effectively.
Another area of further research would be to find ways of pH regulation at the site prior to disinfection in order to reduce disinfectant dosage requirement.
While the maximum loading of the SSFs has been observed to be 1.95 kg/m² in a scraping interval of 147 days, the maximum loading prior to breakthrough was not derived for the HRF, which could be looked into as a future research work.

### 10.3.2 SOCIO-ECONOMIC AND ENVIRONMENTAL ASPECTS

The general conclusion from the study is that it makes sense to decide for the tedious long-lasting participatory approach when it comes to development of a water supply in a community. The comparison of the high tech advanced “black box” delivery solution to the low tech solution, which was constructed on-site, shows that the users and local operators have more acceptance towards the solution which they consider their own solution in regards to technology knowledge ownership. The willingness to deal with a technology which is not understood and for which operation confidence is lacking is lower, even though objective measurements can show its superior performance.

The full scale pilot setup in the village Jyot Sujan and adjoining Malpara have certainly created positive socio-economic impacts for the individual beneficiaries receiving water, as well as the local government representatives having exposure to the entire process of development of a community based water supply. Most of the positive impacts are firstly related to the availability of safe water as derived in chapter 9.3.2. The organisation of the community and potentials for improved environmental conditions are important for the general public.

#### 10.3.2.1 ENVIRONMENTAL POTENTIALS

Positive environmental impacts are mainly related to the catchment area management and the waste water collection and treatment. The research on less toxic or harmless pesticides and the workshops with the pesticide and fertiliser suppliers led to discouraging results. The harmless pesticides are 3 to 5 times more expensive. Although organic fertilizers are understood to be more sustainable in the long run they do not provide the same amount of harvest in the first year; farmers living from seasonal incomes cannot afford to plan ahead and fertilize sustainably. The sewerage and waste water treatment plant are expected to provide benefits which are to be evaluated in future studies. Climate change adaptation in regards to source diversification and improved management can be considered accomplished just as the greenhouse gas emission mitigation with the successful setup of the photovoltaic system. The grid energy substituted by the PV system equals to 1.8 to 4 tons of $CO_2$ per year. Generating electricity from the biogas production could substitute grid electricity with 123 to 180 tons of $CO_2$ emissions.

#### 10.3.2.2 ECONOMIC REALITIES

A serious conclusion is that awareness, ownership and confidence cannot change economic realities. The operation and maintenance of an infrastructure cannot be done only by good will, but also needs funding. The profit loss calculations in chapter 9.4.2 show why private entrepreneurs are not taking up rural water supply as a business. It also shows that under the current economic conditions of the rural population and their willingness to pay, which is comparable to higher income economies in regards to the percentage of income (compare 4.4.2), public subsidies are required if safe drinking water is to be provided to the entire population. Without subsidies the market forces would only be able to provide bottled drinking water to a few well off people in the villagers, who have exceptionally high paid jobs in the cities or are owners of large estates. As provision of drinking water is one way of empowerment and aid in increasing the household income, initial subsidies might lead to the economic development of the consumers and thus their ability to pay for the service in the long run.

A concluding research question for this topic is twofold, firstly how can the costs for the system be brought down further, and secondly how can the public benefit be internalised in the economic budget and thus require a public entity to fund the water supply.

Calculations in chapter 9.4.1 have shown that treatment plants are more cost-efficient when dimensioned on a bigger scale. Although this is a generally known fact, it has to be seen that the small plant size has been especially selected in order to have decentral community based systems and not centrally operated systems with long distribution systems.

#### 10.3.2.3 POLICY RECOMMENDATIONS

Plenty of recommendations for various governance levels can be derived, at this point only three are mentioned briefly: The new GOI strategy of transferring the responsibility for planning and O&M of rural water supplies from state departments like the PHED to the Panchayats is to be advocated from the point of providing the democratic basis with more competency. Reality on the ground, as observed in the case in Jyot Sujan, is that these local bodies are neither aware of their new

responsibility, nor capable of implementing it. More resources for staffing and capacity building at the local level have to be allocated, and the availability of support of the PHED clearly communicated in order to enable the Panchayats to take up their new task.
International Donor organisations and governmental development cooperation focussing on the strengthening of SMEs, privatisation of public services or initiation of public private partnerships should rethink their approach, especially - but not only - when it comes to rural water supply. Focus should be on capacity development in the public sector and provision of grants for the operation and maintenance rather than the construction of yet another pilot which is doomed to fail due to unavailable O&M resources.
Finally, a general political problem has to be addressed which is that politicians tend to implement new projects instead of maintaining already set up projects due to populist vote advantages. The necessity of research on the most effective way of awareness creation on sustainable allocation of public budget and the convincing conveyance of its long-term political advantage is probably the most important conclusion to be taken from the field work in this study.

The author is always open to cooperation in any of the above mentioned future research topics and also very happy to receive comments, feedback or requests for clarification.

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# APPENDICES

## A. ABBREVIATIONS

| | |
|---|---|
| ACF | Activated Carbon Filtration |
| AFM | Activated Filter Media |
| AOC | Assimilable Organic Carbon |
| ARP | Arsenic Removal Plant |
| ARU | Arsenic Removal Unit |
| ATU | Arsenic Treatment Unit |
| AWWA | American Water Works Association |
| BAC | Biological Activated Carbon |
| BCR | Benefit Cost Ratio |
| BDO | Block Development Officer |
| BOD | Biological Oxygen Demand |
| BPL | Below Poverty Level |
| CBA | Cost Benefit Analysis |
| CFU | Colony Forming Units |
| Cinara | Instituto de Investigación y Desarollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico |
| COD | Chemical Oxygen Demand |
| CPHEEO | Central Public Health and Environmental Engineering Organisation |
| CT | Concentration * Time (of FAC contact) |
| CWP | Clear Water Pump |
| CWT | Clear Water Tank |
| DO | Dissolved Oxygen |
| DOC | Dissolved Organic Carbon |
| DST | Department of Science and Technology, Government of India |
| DW | Drinking Water |
| EAWAG SANDEC | Water and Sanitation in Developing Countries |
| EBCT | Empty Bed Contact Time |
| EC | European Commission |
| ECO-India | "Energy-efficient, community-based water- and wastewater-treatment systems for deployment to India", Project No. 308467 funded by EC under FP7 and GOI under DST |
| EU | European Union |
| FAC | Free Available Chlorine |
| FLAIR | Facilitating of Learning, Action, Implementation and Reflection |
| FNU | Formazine Nephelometric Unit |
| FP7 | 7$^{th}$ Framework Pogramme for Research and Technological Development of the European Commission |
| GAC | Granulated Activated Carbon |
| GHG | Green House Gases |
| GOI | Government Of India |
| GP | Gram Panchayat |
| HP | Horse Power |
| HRF | Horizontal Roughing Filter |
| INR | Indian Rupees, 1€ = 75 INR (June 2016) |
| int | interpolated |
| IRC | International Reference Centre for Community Water Supply and Sanitation |

| | |
|---|---|
| IS10500 | Indian Standard for Drinking Water Quality |
| IWRM | Integrated Water Resource Management |
| JU | Jadavpur University |
| KLD | Kilo liter per day |
| LCA | Life Cycle Assessment |
| LPCD | Liter Per Capita and Day |
| LPM | Liter Per Minute |
| MASL | Meters Above Sea Level |
| MCA | Multi Criteria Analysis |
| MSF | Multi Stage Filtration |
| N | Number of samples |
| NA | Needs Assessment |
| NGO | Non Governmental Organisation |
| NTU | Nephelometric Turbidity Units |
| O&M | Operation and Maintenance |
| OHT | Over Head Tank |
| PAC | Poly Aluminium Chloride |
| pH | Power of Hydrogen, numerical scale for measurement acidity or alkalinity |
| PHC | Primary Health Center |
| PHED | Public Health Engineering Department |
| PPP | Public Private Partnership |
| PRA | Participatory Rural Appraisal |
| PSF | Pond Sand Filter |
| RCC | Reinforced Cement Concrete |
| RIDA | Resource, Infrastructure, Demand and Access |
| RMP | Rural Medical Practitioner |
| RSF | Rapid Sand Filter |
| RWP | Raw Water Pump |
| RWT | Raw Water Tank |
| SEBSSF | Solar Energy Based Slow Sand Filtration |
| SELCA | Socio-economic and Environmental Life Cycle Assessment |
| SCADA | Supervisory Control and Data Acquisition |
| SD | Standard Deviation |
| SHG | Self Help Group |
| SISSO | Sulabh Social Service Organisation |
| SS | Suspended Solids |
| SSF | Slow Sand Filter |
| TDS | Total Dissolved Solids |
| TOC | Total Organic Carbon |
| TOR | Terms of Reference |
| ToT | Training of Trainers |
| TS | Total Solids |
| USEPA | United States Environment Protection Agency |
| VS | Volatile Solids |
| VWSC | Village Water and Sanitation Committee |
| WQ | Water quality |
| WQ | Water Quality |
| WWTP | Waste Water Treatment Plant |

## B. LIST OF FIGURES

# C. LIST OF TABLES

## D. AREA MAPS SHOWING EXTEND OF ARSENIC CONTAMINATION AND LOCATION OF PROJECT SITE

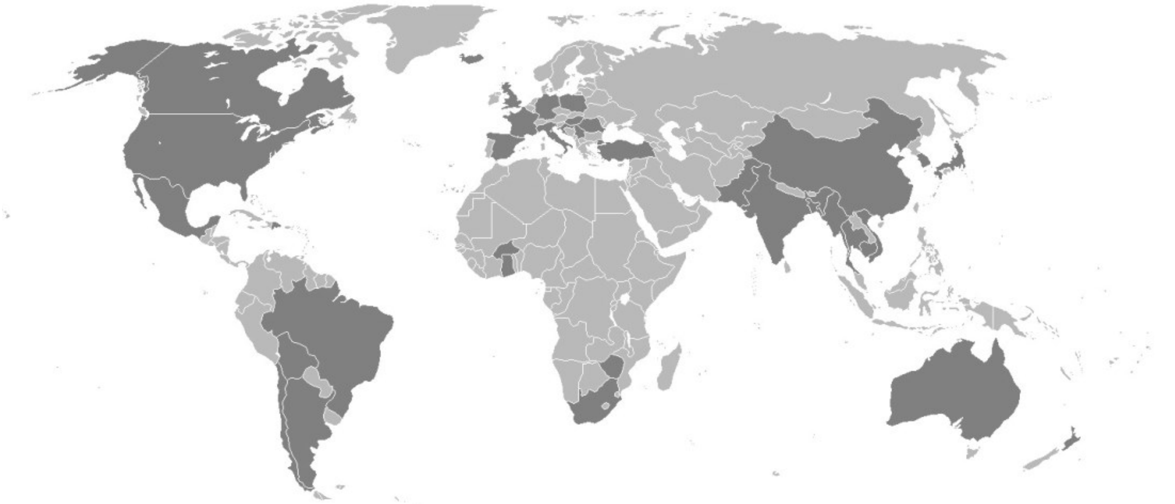

*Figure 104 Arsenic occurrence worldwide* [175]

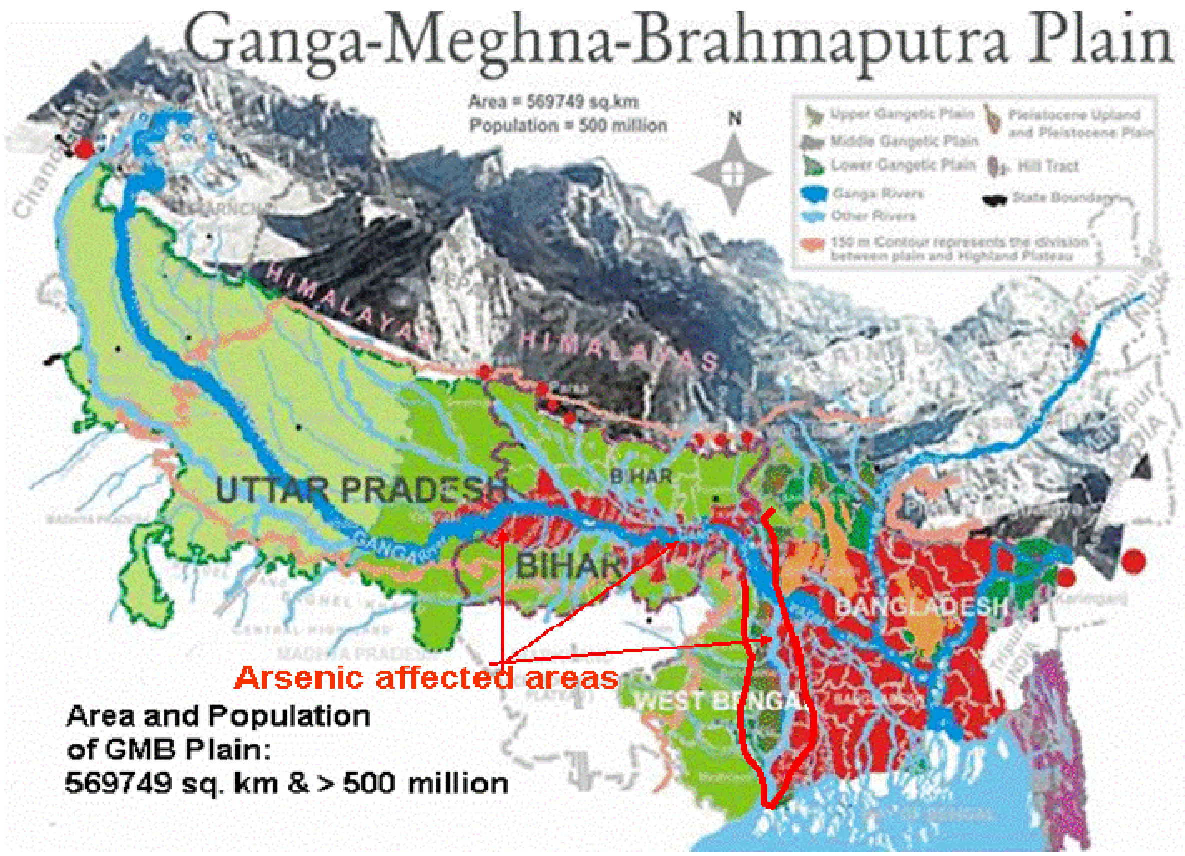


*Figure 105 Extend of Arsenic Contamination in GMB Plain* [30]

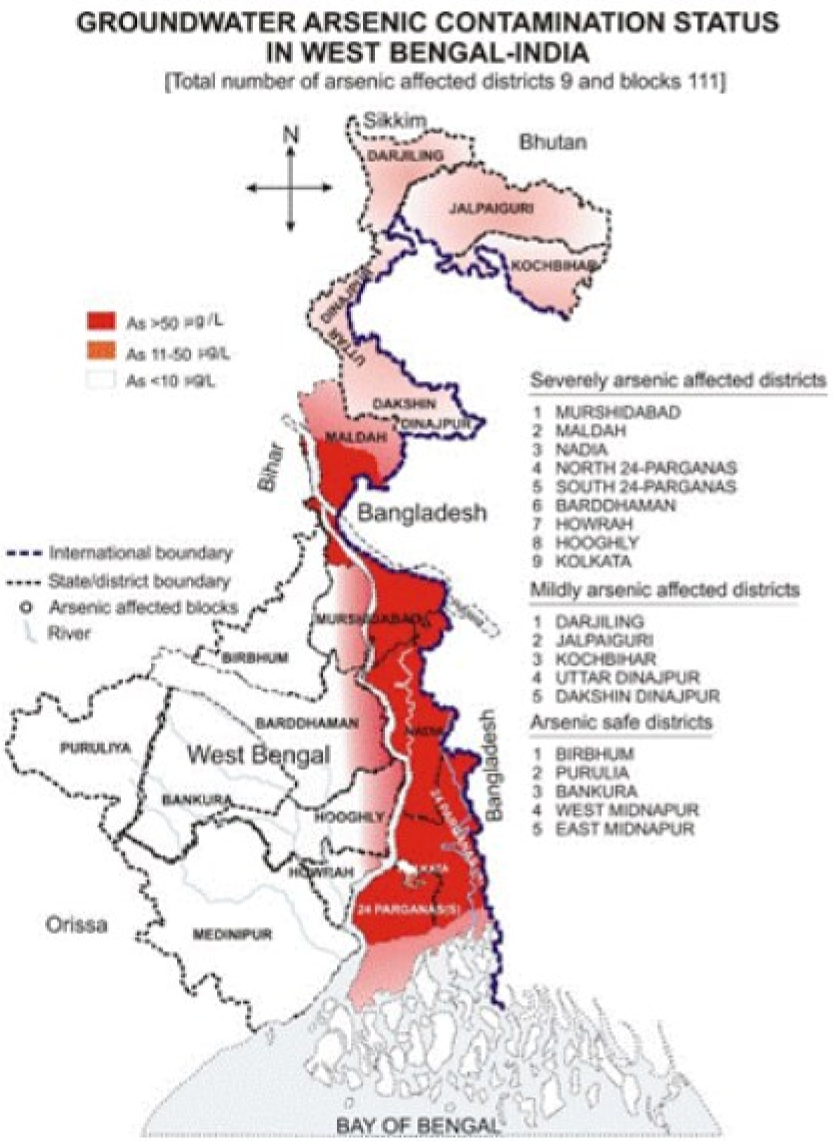


*Figure 106 Arsenic Contamination in WB*[30]

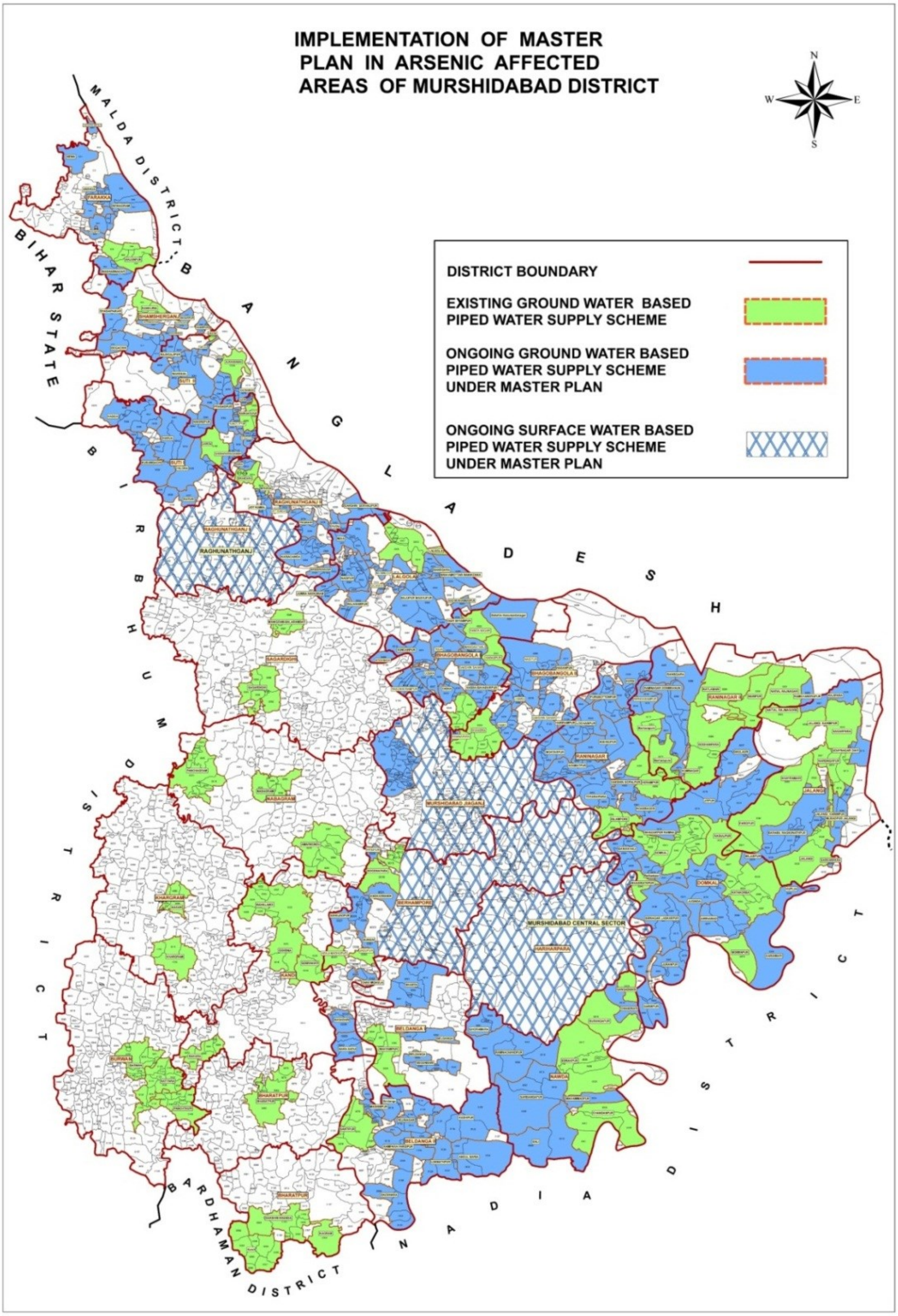


*Figure 107 Coverage as per PHED Master Plan*[14]

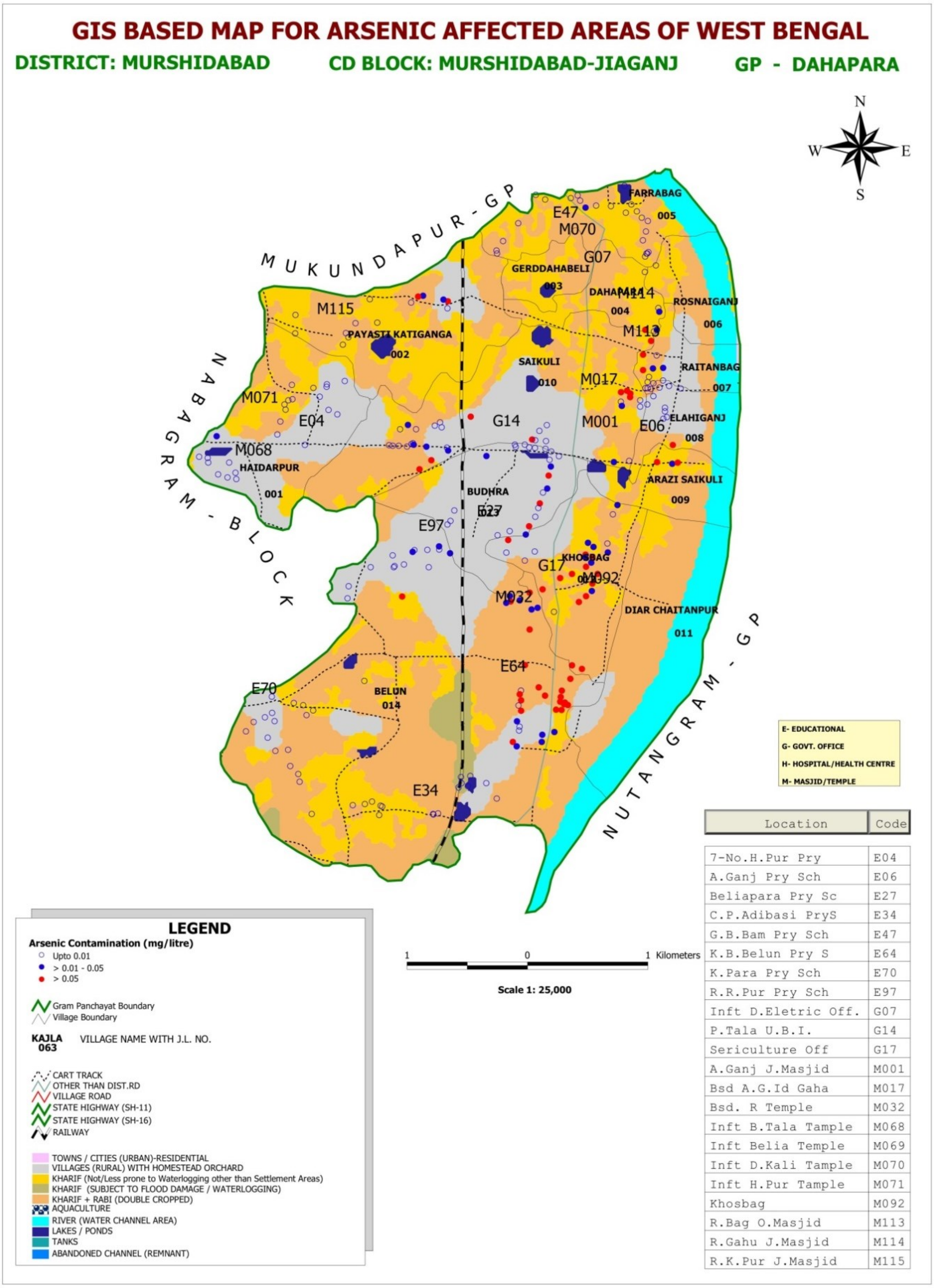


*Figure 108 Arsenic Tube wells in Jyot Sujan* [141]

MURSHIDABAD

| JL No. | Village | ARSENIC CONCENTRATION <= 0.01 ppm No. | % | > 0.01 & <=0.05 ppm No. | % | > 0.05 No. | % | Max. ppm | Total No. of Tube Wells |
|---|---|---|---|---|---|---|---|---|---|
| Block: (015) MURSHIDABAD-JIAGUNJ | | | | | | | | | |
| Panchayat 001 DAHAPARA | | | | | | | | | |
| 009 | ARAJI SAIKULI | 2 | 33.33 | 1 | 16.67 | 3 | 50.00 | 0.10 | 6 |
| 014 | BELUN | 52 | 80.00 | 7 | 10.77 | 6 | 9.23 | 0.21 | 65 |
| 013 | BUDHRA | 1 | 16.67 | 3 | 50.00 | 2 | 33.33 | 0.08 | 6 |
| 004 | DAHAPARA | 8 | 100.00 | 0 | 0.00 | 0 | 0.00 | 0.01 | 8 |
| 002 | DHAMUA | 12 | 75.00 | 2 | 12.50 | 2 | 12.50 | 0.08 | 16 |
| 011 | DIAR CHAITANYA PUR | 2 | 9.52 | 5 | 23.81 | 14 | 66.67 | 0.27 | 21 |
| 008 | ELAHIGANJ | 10 | 66.67 | 1 | 6.67 | 4 | 26.67 | 0.89 | 15 |
| 005 | FARRABAG | 11 | 91.67 | 1 | 8.33 | 0 | 0.00 | 0.02 | 12 |
| 001 | HAIDARPUR | 22 | 95.65 | 1 | 4.35 | 0 | 0.00 | 0.02 | 23 |
| 012 | KHOSBAG | 10 | 27.03 | 11 | 29.73 | 16 | 43.24 | 0.22 | 37 |
| 007 | RAITANBAG | 4 | 33.33 | 4 | 33.33 | 4 | 33.33 | 0.12 | 12 |
| 006 | ROSNAIGANJ | 6 | 100.00 | 0 | 0.00 | 0 | 0.00 | 0.01 | 6 |
| 010 | SAIKULI | 31 | 86.11 | 3 | 8.33 | 2 | 5.56 | 0.06 | 36 |
| | **Panchayat Total** | **171** | **65.02** | **39** | **14.83** | **53** | **20.15** | | **263** |

*Figure 109 Village(Mouza) wise arsenic concentration of Dhapara GP from PHED website*[141]

## E. PICTURES OF EXISTING INITIATIVES

### SULABH RSF PLANT IN MADHUSUDANKATI

*Figure 110 Source pond for Sulabh's Treatment plant*

*Figure 111 Microfiltration and disinfection after RSF*

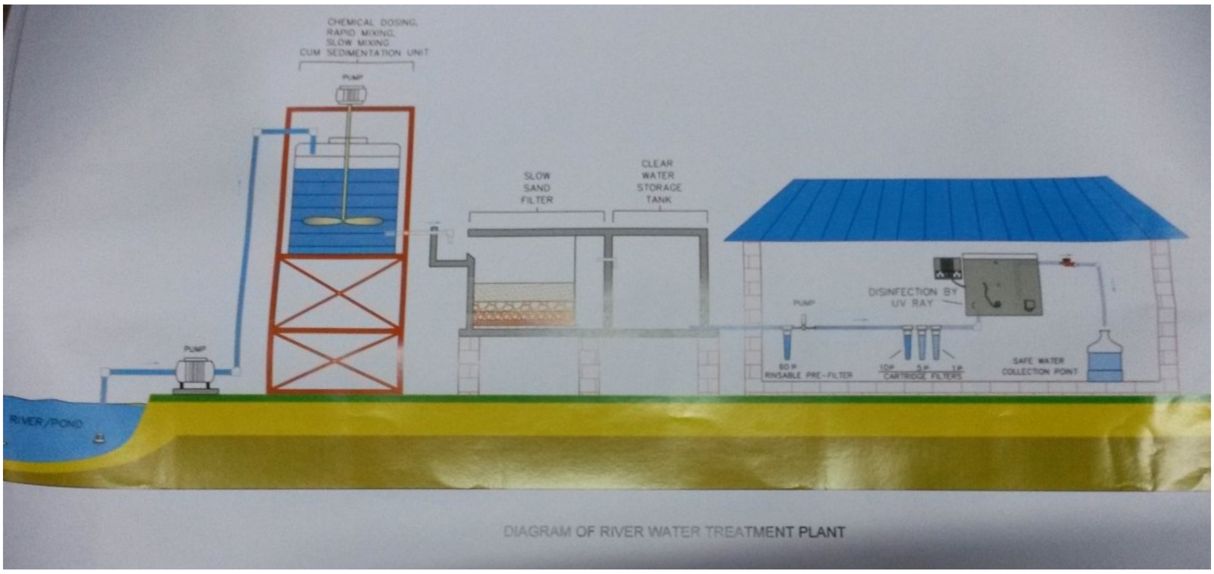


***Figure 112 Treatment process diagram of Sulabh's RSF process (labelled as SSF)***

## MSF IN DESARAJUPALI

***Figure 113 elevated MSF filter with integrated pump house***

***Figure 114 location of filter unit next to irrigation pond***


*Figure 115 Layout of the water supply for Desarajupalli*

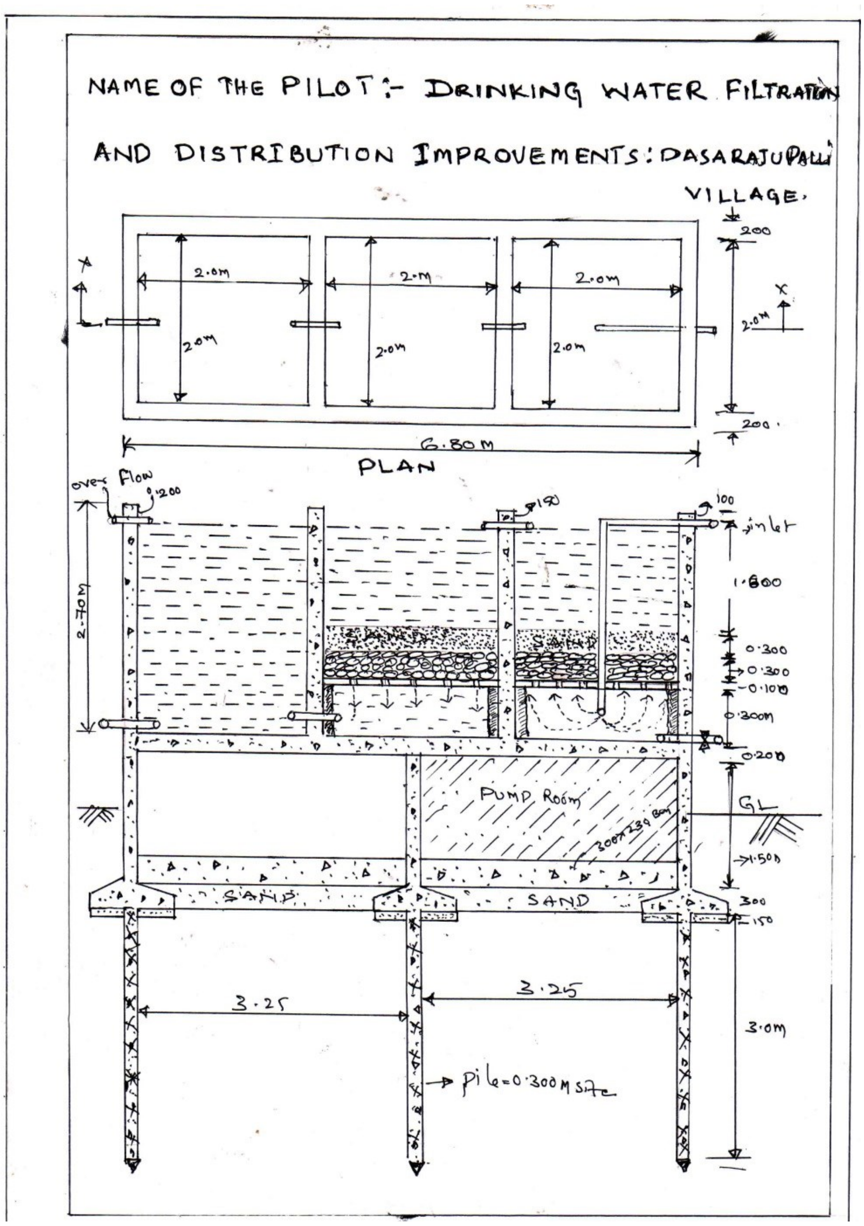


*Figure 116 Draft design by the local engineer Mr. Pardhasaradhi, which was later changed to 6m² SSF and 3m² Upflow RF*

## F. QUALITATIVE ASSESSMENT QUESTIONAIRE

*Table 27 General information on the community collected in the needs assessment*[37]

| | Parameters to be evaluated | Assessed Information |
|---|---|---|
| 1 | Population | 2000 with children and 1500 above 18 years. 250 households |
| 2 | General needs and important aspects of the village | Provision of safe drinking water, improvement of sanitation facilities, increase of awareness on hygienic practices regarding water contaminations |
| 3 | Main income (Key livelihoods/sectors, source of income, agricultural and other technologies/processes used) | Agriculture, pond aquaculture and animal husbandry are the main sources of income. There is substantial use of chemicals fertilizer, pesticides and insecticides in the agricultural (paddy, vegetable, fruits (Mango orchards)) and usage of medicines and food for the aquaculture in the ponds. |
| 4 | Soil type | sandy and sandy alluvial soil (mix of sand and clay), partly clay (used for brick manufacture) |
| 5 | Soil texture (infiltration) | Top soil is sandy alluvial (mix of sand and clay) and in different strata sand and clay layers. Partly clay patches. |
| 6 | Hydraulic conductivity of soil | for soil mixture of sand, silt and clay, the hydraulic conductivity is assumed to be 0.1 m/day |
| 7 | Types of land and use | Plains with grass lands for animal husbandry, agricultural field: rice fields, vegetable, mango orchards, ponds for aquaculture |
| 8 | Mainly applied irrigation techniques and fate of agricultural runoff | Flood irrigation fed by water from the river Bhagirathi and shallow or deep tubewells partly canalized to the fields. The agricultural runoff goes to the river Bhagirathi. |
| 9 | Averge annual rainfall, monthly precipitation distribution | 1400 mm, |
| | min, max monthly temperature distribution | Min 8 to Max 43 (Degree Celsius) |
| 10 | Average annual Pot Evapotranspiration and monthly distribution | given in Figure 13 |
| 11 | Solar Intensity, monthly distribution | 4.58 Kwh/m2/day |
| 12 | Longest dry period during last years (months) | dry periods occurred in 2009 and this year 2012 (November to June) |
| 13 | Rainy season | June, July, August, September are the rainy seasons. In case of extreme rainfall, there is a standing water of 6 inches which flows to Bhagirathi or seeps into the soil, the next days |

| | | |
|---|---|---|
| 14 | Wind speed and distribution | Average 2.64 m/s |
| 15 | Flood information (highest flood water level) | Flood in 2000, 3 feet flood water level in village center |
| 16 | Socio-economic condition, average income | Average monthly income for each family ranges from 1500 to 4500 INR |
| 17 | Competing uses of Water with drinking water supply | Agriculture, fishery and animal husbandry |
| 18 | Current water consumption (irrigation, animal husbandry, domestic and drinking) | Domestic and drinking water – approx 40 L/ p/ day |
| 19 | Ground water availability and fluctuation of ground water levels | February, March and April, the ground water availability decreases with 8 feet lowering of the ground water table. / from 2.73 to 5.35 m post and pre monsoon |
| 20 | Transport system to the village and of villagers | Boat and motor or man driven carts are the transport systems needed to reach the village. The people in the village mostly use bicycles, and some motor bikes |
| 21 | Energy information: how many hours grid connected current per day, max. possible load, other sources of energy (gas, wood, fuels) | Electricity unavailable only 1 hour a day in average. Single and three phase supply available. 200 to 220 volts. 440V for mill. 11000 V transformer in village. For cooking wood, cow dung and residue of agricultural harvest is use. Diesel and petrol is used for pumps, motors etc. Permission for electric load connections has to be obtained from Azimganj electric office |
| 22 | Mobile network (1G, 2G, 3G), which provider has which network (speedtest kb/s) | 2G is available (vodafone, reliance and airtel, mts, uninor around 15 kb/s), partly 3G is also available from Vodafone |

*Table 28 Specific needs assessment questions related to the current situation of the water supply in the community*[37]

| No. | Question/Topic | Response and Description |
|---|---|---|
| **Water Sources** | | |
| 1 | What are the main sources of water for the community? | River, Ponds and Tube wells |
| | a) River | Bhagirati River flows paralle to the village in 300m to 500m distance appr. Flowrate appr. 40000 CuSec |
| | b) Ponds | numerous ponds are located in and around the village most of them are used for pisciculture |
| | c) Dug wells | Not used |
| | d) Tube wells | almost all households have individual tubewells which are used for drinking water purpose |
| | e) Rainwater collection | Collected in ponds |
| | f) Other | Bottled water is bought by some villageers |
| | g) Don't know | |
| | | |
| 2 | What is the distance between the main water sources and the community? | 500 m to the river, ponds are in the village and others are in a radius of several hundred meters around the village almost every family has its own tubewell. |
| 3 | How reliable are these main water sources? | |
| | a) Water is available all year | tubewell, groundwater level fluctuates by approx.. 3 m sometimes tubewells go dry |
| | b) Water is available except in the dry season | Some ponds tend to dry up in the dry season |
| | c) Water is available only when it rains | |
| | d) Other | |
| | Don't know | |
| 4 | What potential new sources are possible for a community water supply? | |
| | a) River | people are interested in using this source |
| | b) Ponds | will be used preferentially in this project |
| | c) Dug wells | |
| | d) Tube wells | will be used for GWS |
| | e) Rainwater collection | limited scope of rooftop runoff collection, surface runoff will be used for pond recharge |
| | f) Other | |
| | g) Don't know | |
| 5 | How many people take their drinking water from each of the sources listed above? | |
| | a) The entire community | |
| | b) Most of the community | from tubewells |
| | c) Only a few households | buy water in water cans or treat the groundwater with domestic filter |

| | | |
|---|---|---|
| | d) Don't know | |
| 6 | What is the condition of the land around the main water sources? | |
| | a) Forested | |
| | b) Grassland with some trees | around some ponds |
| | c) Cultivated land | around some ponds |
| | d) Barren land | next to the Upopradhan pond |
| | e) Mountainous | |
| | f) Rolling hills | Only a few meters elevation difference |
| | g) Flat | The region is generally flat |
| | h) Other | tubewells in habitation often very close to sanitary units and it`s soak pits |
| | i) Don't know | |
| 7 | What is the quality of water in the main sources? | |
| | a) Safe for drinking | some tubewells might be safe for drinking |
| | b) Not safe but is being used for drinking and other purposes | as per PHED maps arsenic levels are elevated in all tubewells |
| | c) Not used except in emergencies | |
| | d) Other | water quality yet to be assessed compare chapter 7.2 |
| | e) Don't know | |
| 8 | What is the cause of pollution in the water sources? | Human excreta and trash, Animal excreta, Agricultural activities, Erosion/deforestation, Minerals in the underground water |
| | a) Water is not polluted | might be for some tubewells sources |
| | b) Human excreta and trash | ponds, river as well as tubewells could be affected |
| | c) Animal excreta | ponds, river as well as tubewells could be affected |
| | d) Agricultural activities | ponds, river as well as tubewells could be affected |
| | e) Erosion/deforestation | ponds, river as well as tubewells could be affected |
| | f) Drainage from mines and factories | |
| | g) Minerals in the underground water | tubewells could be affected |
| | h) Other villages | river water is affected by upstream waste water discharges |
| | i) Other | |
| | j) Don't know | |
| 9 | Who is responsible for maintaining the operation of the water sources? | |
| | a) No one | |
| | b) Community water operator | |
| | c) Community volunteers | |
| | d) Other | Panchayat for its tubewells and individual for its tubewells and pond, river is not managed by anybody locally. |
| | e) Don't know | |
| Water Transport | | |

| | | |
|---|---|---|
| 10 | How is water transported from the source to the household? | No need to transport, most have own tubewell and some use their neighbours tubewells. |
| | a) Carry water on head or back | bought water containers |
| | b) Bicycle | bought water containers |
| | c) Animal | |
| | d) Open channel | |
| | e) Other | No need to transport, most have own tubewell and some use their neighbours tubewells. |
| | f) Don't know | |
| 11 | Who is responsible for transporting water to the households? | Women, Young girls, Boys and Men |
| | a) Women | Mostly |
| | b) Young girls | Also |
| | c) Boys | Also |
| | d) Men | Also |
| | e) Other | |
| | f) Don't know | |
| 12 | How many return trips per day does each household make to the water sources? | |
| | a) None | Tube wells are on primises |
| | b) 1 to 2 | |
| | c) 3 to 5 | |
| | d) 6 to 10 | |
| | e) More than 10 | |
| | f) Other | |
| | g) Don't know | |
| 13 | Are there any problems with transporting water to the household? | |
| | a) No problems | no |
| | b) Seasonal (rainy/dry season) | |
| | c) Seasonal (planting/harvesting season) | |
| | d) Land or water source ownership | |
| | e) conflict and lack of security | |
| | f) Others | |
| | g) Don't know | |
| Storage | | |
| 14 | How does the community store its water? | |
| | a) No water storage occurs | |
| | b) Community water storage tank | |
| | c) Household water storage tanks | Household water storage tanks and |
| | d) small containers inside the households | small containers inside the households of size 10 to 15 lits |
| | e) open pond or reservoir | |
| | f) open well | |
| | g) Others | |
| | i) don't know | |
| 15 | Who is responsible for maintaining the water storage facilities? | |
| | a) No one | |
| | b) someone from household | X |

| | | |
|---|---|---|
| | c) community water operator | |
| | d) community volunteers | |
| | e) Others | |
| | f) don't know | |
| Uses | | |
| 16 | What are the main uses of water at the household? | |
| | a) Drinking | X |
| | b) Cooking | X |
| | c) Cleaning | X |
| | d) Bathing | X |
| | e) Clothes washing | X |
| | f) sanitation | X |
| | g) Animals | X |
| | h) Home vegetable gardens | X |
| | i) Brick making | |
| | j) Handicrafts | |
| | k) Other | |
| | l) Don't know | |
| 17 | How many litres per day does the average household use in each of the above uses? | 200 litres/ household/day |
| | a) Drinking | 20 |
| | b) Cooking | 20 |
| | c) Cleaning | 10 |
| | d) Bathing | 50 |
| | e) Clothes washing | 40 |
| | f) sanitation | 30 |
| | g) Animals | 30 |
| | h) Home vegetable gardens | 0 |
| | i) Brick making | 0 |
| | j) Handicrafts | |
| | k) Other | |
| | l) Don't know | |
| | | |
| 18 | Which of the main water uses does the community want to increase? | better quality for drinking water, more water usage on household level and for sanitation purpose |
| 19 | Are there any special water and sanitation needs in the community? | 30 % of the community practice open defecation |
| | a) No special needs | |
| | b) Health centre | |
| | c) School | 200 pupil in primary school, ICDS integrated child development service 50 kids |
| | d) Market | |
| | e) Orphans and vulnerable children | |
| | f) Elderly | |
| | g) masjid | 100 people 5 times a day * 5l = 2500 L |
| | h) pisciculture | for filling the ponds in dry season |
| Water Treatment | | |

| | | |
|---|---|---|
| 20 | Does the community do anything to improve the quality of safety of the water at the source, during transport or during storage? | |
| | a) No treatment activities given | |
| | b) Improve the watershed | |
| | c) Fence the water source | |
| | d) Filter the water | |
| | e) Add chemicals to the water | The panchayat some times gives bleaching powder $Ca(ClO)_2$ (chlorine) tablets to the community |
| | f) Other | |
| | g) Don't know | |
| 21 | Do individual households do anything to improve the quality or safety of the water in the household? | |
| | a) No treatment | In general no treatment is done to the source water by individuals |
| | b) Cooling | |
| | c) Boiling | |
| | d) Filtering | Some households have domestic candle filters |
| | e) Add chemicals | |
| | f) Solar disinfection | |
| | g) Other | |
| | h) Don't know | |
| Sanitation—Latrines | | |
| 22 | What are the main methods of excreta disposal in the community? | Improved (sanitary) pit latrine - 10 % of community. Unimproved (unsanitary) pit latrine and Temporary shallow pits - 60 %, Defecation area in the brush - 30% |
| | a) Improved (sanitary) pit latrine | X |
| | b) Unimproved (unsanitary) pit latrine | X |
| | c) Disposal in sacs or containers | |
| | d) Defecation area in the brush | X |
| | e) Temporary shallow pits | X |
| | f) No special method | |
| | g) Other | |
| | h) Don't know | |
| 23 | What are the main problems in having a household latrine? | Cost of materials and Lack of knowledge are the main problems of having a household latrine |
| | a) No problems | |
| | b) Cost of materials | X |
| | c) Lack of knowledge | X |
| | d) Difficult lo keep clean | |
| | e) Soil or groundwater problems | |
| | f) Other | |
| | g) Don't know- | |
| Sanitation—Community Hygiene | | |
| 24 | Are there any hygiene or environmental sanitation problems in the community? | household waste, garbage and grey water are collected in a shallow pit near the tubewells |

| | | |
|---|---|---|
| | a) No problems | |
| | b) Household wastes/garbage | no waste management in the village, waste collection points would be welcome |
| | c) Drainage | drain from masjid tubewell, one storm water drain discharging water from low lying field near to primary school to river, connection of households to drains would be welcome |
| | d) Vector control | 20 years ago bleaching powder was used, today no more, mosquito net is used |
| | e) General community cleanliness | solid waste and waste water management would be welcome |
| | f) Other | |
| | g) Don't know | |
| Sanitation—Community Health | | |
| 25 | Are there any illnesses caused by water and sanitation in the community? | |
| | a) Diarrhoea | X |
| | b) Malaria | |
| | c) Skin diseases | X |
| | d) Eye diseases | X |
| | e) Worms | |
| | f) Bilharzia | |
| | g) Other | |
| | h) Don't know | |
| Hygiene Promotion | | |
| 26 | How often are water, sanitation or hygiene presentations given in the community? | Yearly from the panchyat, presentation on hygiene are given in schools and visiting individual households |
| | a) Never | |
| | b) Only once | |
| | c) Yearly | X |
| | d) Every six months | |
| | e) Monthly | |
| | f) Weekly | |
| | g) Other | |
| | h) Don't know | |
| community Involvement | | |
| 27 | What can the community contribute to a | The community has skilled labour for electrification, masonry and plumping |
| | water and sanitation project? | |
| | Nothing | |
| | Unskilled labour | X |
| | Skilled labour | X |
| | Local materials | X |
| | Cash | |
| | Support to outside technical advisors | |
| | Other | |
| | Don't know | |
| | | |
| 28 | What are the responsibilities of the community water and sanitation committee? | No committee for community water and sanitation exists but a committee for agricultural water exists. |

| | | |
|---|---|---|
| | No committee exists | x |
| | Responsibilities not defined | |
| | Control operation of water system | |
| | Collect user fees | |
| | Purchase spare parts | |
| | Employ system operator | |
| | Other | |
| | Don't know | |

## G. QUANTITATIVE SURVEY FORM

*Table 29 bilingual needs assessment questionnaire for the household level* [37]

| | Question | | প্রশ্ন | Possible Response | সম্বাব্য উত্তর | Response/ উত্তর |
|---|---|---|---|---|---|---|
| | | | **GENERAL / সাধারণ** | | | |
| 1 | How old are you? | ১ | আপনার বয়স কাত ? | Agegroup :- 00-18 | বয়স সীমা:- 00-১৮ | |
| | | | | Agegroup :- 18-45 | বয়স সীমা :- ১৮-৪৫ | |
| | | | | Agegroup :- 45-60 | বয়স সীমা :- ৪৫-৬০ | |
| 2 | Gender? | 2 | লিঙ্গ? | Male | পুরুষ | |
| | | | | Female | মহিলা | |
| 3 | What are the languages that you can read and write ? | ৩ | কি কি ভাষায় আপনি লিখতে পরতে জানেন ? | Y/N | হ্যাঁ/না | |
| 4 | Languages ? | ৪ | ভাষা ? | Bengali | বাংলা | |
| | | | | Hindi | হিন্দি | |
| | | | | English | ইংরেজী | |
| 5 | What is your occupation? | ৫ | আপনার জীবিকা কি? | Name | বিবরণ | |
| | | | **ASSESSMENT / মূল্যায়ণ** | | | |
| 6 | Where are you getting your drinking water from? | ৬ | কোথা থেকে আপনি পানীয় জল ব্যবহার করেন? | Tubewell | নলকূপ | |
| | | | | Bottled water | বোতলের জল | |
| | | | | Surface water | ভূপৃষ্ঠের জল | |
| | | | | Filtered water | পরিস্রুত | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | জল | |
| | | | | other | অন্যান্য | |
| 7 | Do you use any further measures for purification ? | ৭ | আপনি কি জল পরিসোধনের জন্য অন্য কোন উপায় ব্যবহার করেন? | Self build filter | ঘরোয়া ছাঁকনি | |
| | | | | Bought filter | কেনা ছাঁকনি | |
| | | | | Boiling of water | ফোটানো জল | |
| | | | | Chemical dosing | রাসায়ণিক পদার্থ | |
| | | | | Other | অন্যান্য | |
| 8 | What kind of sanitation facilities are you using? | ৮ | আপনাদের কি ধরনের শৌচালয় ব্যবস্থা আছে ? | Individual latrine | ব্যক্তিগত সৌচালয় | |
| | | | | Common latrine | সমষ্টিগত সৌচালয় | |
| | | | | Open defacation | প্রাকৃতিক (মাঠে) | |
| **WATER PROBLEMS / জল সংক্রান্ত সমস্যা** | | | | | | |
| 9 | Are there any water problems (quality and quantity) in your community ? | ৯ | আপনাদের জলসমস্যা আছে ?থাকলে কি কি?(গুনগত ও পরিমান গত) | Y/N and Name them | হ্যাঁ/না ,বিষদ বিবরণ | |
| 10 | Are there any sanitation related problems in your community ? | ১০ | শৌচালয় সংক্রান্ত সমস্যা আছে ? | Y/N and Name them | হ্যাঁ/না ,বিষদ বিবরণ | |
| 11 | Are you aware of arsenic contamination in the ground water reserves of your village ? | ১১ | আপনাদের গ্রামে ভূগর্ভস্থ জলে আরসেনিকের অস্তিত্য আছে? | Y/N | হ্যাঁ/না | |
| 12 | Did you or any of your family members suffer from any water borne diseases in last years ? | ১২ | আপনাদের পরিবারের কেউ আরসেনিক যুকত জল পান করে আক্রান্ত হয়েছেন? | Y/N | হ্যাঁ/না | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 13 | Were there any severe effects of water borne diseases in last years ? | ১৩ | এই গ্রামে অতীতে জল বাহিত রোগের প্রকোপ দেখা গেছে ? | Y/N and Name them | হ্যাঁ/না ,বিষদ বিবরণ | |
| **BENEFITS / লাভ/সুবিধা** | | | | | | |
| 14 | What could be the benefits of having a safe drinking water supply and improved sanitation facilities? | ১৪ | আপ্নার মতে পরিস্রুত জল ও সউছালই বাবস্থা পেলে আপনি কিভাবে উপক্রিত হবেন ? | Having a better standard of life | জীবন জাত্রার মান উন্নয়ণ | |
| | | | | Better health | সুসাসথ্য | |
| | | | | Earn more money | আর্থিক লাভ | |
| | | | | money saving due to substitution of bought water | পরিশোধিত জল ব্যবহারে আর্থিক সাস্রয় | |
| | | | | Better education | উন্নত শিক্ষা | |
| | | | | Higher life expectancy | গড় আয়ুবৃদ্ধি | |
| | | | | more water availability in dry season | ক্ষরার সময় পরযাপ্ত পরিমান জলের সংস্থান | |
| | | | | Cleaner environment | পরিস্কার পরিছান্ন পরিবেশ | |
| | | | | Higher social status | উচ্চ সামাজিক মরজাদা | |
| | | | | General social and economic development | সাধারন ভাবে সামাজিক ও | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | অর্থনৈতিক উন্নতি | |
| | | | | Peace and harmony | সামতি এবং সম্প্রিতি | |
| | | | | Other | অন্যান্য | |
| **SOLUTION and CONTRIBUTION / সমস্যার সমাধান এবং  আপনাদের ভুমিকা** | | | | | | |
| 15 | Do you think that the water borne diseases can be minimised with purification of water? | ১৫ | আপনি কি মনে করেন জল বাহিত রোগের প্রকোপ পরসোধিত জল পেলে কমবে? | Y/N | হ্যাঁ/না | |
| 16 | Regarding arsenic contamination do you think a surface water based piped water supply could be a solution ? | ১৬ | আপনি কি মনে করেন পাইপ লাইনের মাধ্যমে জল সরবরাহ করলে জলে আরসেনিকের সংক্রমন/মাত্রা কমবে? | Y/N | হ্যাঁ/না | |
| 17 | Do you think that the water borne diseases can be minimised with improved sanitation facilities ? | ১৭ | উন্নততর শৌচালয় বাবস্থা থাকলে জল বাহিত রগের প্রকোপ কমবে? | | হাঁ/না | |
| 18 | Would you be interested in having a piped drinking water house connection ? | ১৮ | আপনার বাড়িতে পাইপ লাইনের মাধ্যমে জল সরবরাহ করলে আপনি কি নিতে উৎসাহী? | Y/N | হ্যাঁ/না | |
| 19 | Would you be interested in having a flushed toilet? | ১৯ | আপনি কি  flushed toilet(নিষ্কাষিত শৌচালয়) পেতে আগ্রহি ? | Y/N | হ্যাঁ/না | |
| 20 | How much money per month would you be able to pay for the local operation and maintenance of the system ? | ২০ | আপনি  এই বাবস্থার রক্ষণা বেক্ষণের জন্য কতটা আর্থিক সহযোগিতা  করতে পারবেন? | Rs./month | টাকা./প্রতি মাসে | |
| 21 | Would you be interested in contributing to the implementation of a water supply and sanitation upgradation project ? | ২১ | আপনি কি উন্নততর জল সরবরাহ ও সৌচালয় বাবস্থা করতে আগ্রহী? | Y/N | হ্যাঁ/না | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 22 | Do you have land, water body or tubewell which could be used for the project? | ২২ | আপনার জমি,জলাশয়,নলকুপ আছে,যদি থাকে সেটি প্রকল্পে ব্যাবহার করতে দিতে আগ্রহি ? | Y/N | হ্যাঁ/না | |
| 23 | Can you contribute to the project in kind with labour, as electrician, plumber, masonry or any other labour? | ২৩ | আপনি কি এই প্রকল্পের জন্য শ্রমিক বা বৈদ্যতিক মিসত্রি বা পালমবার বা রাজমিসত্রি বা অন্যভাবে সাহায্য করতে পারবেন? | | | |
| 24 | If yes, Please specify : | ২৪ | যদি হ্যাঁ, বিষদে বিবরণ | | | |
| 25 | if yes please provide your contact details : | ২৫ | যদি হ্যাঁ, দয়া করে আপনার বিষয় বিষদে জানান | | | |
| 26 | Name | ২৬ | নাম | | | |
| 27 | Address | ২৭ | ঠিকানা | | | |
| 28 | Phone | ২৮ | ফোন নং | | | |

More details on the results of the needs assessment can be found in [50]

## H. AWARENESS POSTERS

# ECO-INDIA
# COMMUNITY BASED DRINKING WATER SUPPLY AND SANITATION
### 2ND FIELD VISIT:JOT SUJAN ASSESSMENT VISIT CUM WORKSHOP

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Jadavpur University together with its partners are conducting a survey and needs assessment for a drinking water and sanitation pilot project. This project is being supported by Indian and European government funds.

## WATER AND HEALTH , SOCIAL AND ECONOMICAL DEVELOPMENT

Clean Water is a vital source for the nutrition of us humans. Contaminated water can lead to diseases and cause serious health impacts. Unhealthy people are less productive and cannot contribute to the social and economic development of their family and community. Scarce safe water sources can lead to conflicts and fights. Contaminations in the water can have various sources. These can be from bacteriological contamination by e.g. open defecation or can have natural sources. According to the Public Health Engineering Department survey the village JodSujan in the DiarChaitanpur GP seems to be having a number of tubewells which might have arsenic contamination. Arsenic can be harmful to the health. It can cause skin diseases which can turn into cancer in serious cases. Having a safe water source and clean sanitation facilities will lead to better health and improve the quality of life. It can lead to better income higher life expectancy, higher social status, cleaner environment as well as peace and harmony.


## POSSIBLE SOLUTIONS


In order to have safe drinking water the contaminated sources have to be purified and the purified water has to be delivered to the consumer. Pollution of water sources has to be minimised and clean and hygienic practices adopted in the water supply and sanitation. The EcoIndia project is considering to setup water resource protection, a clean water reservoir and water treatment units for pond water as well as tubewell water. For a small selected pilot area piped house connections for drinking water, sanitation units, sewerage as well as a natural waste water treatment plant are planned.

## YOUR INVOLVEMENT

Planning and implementation will be done together with the community. The installations will also be handed over to be operated and maintained by the community. We need your kind cooperation in identifying the correct solution for your family and your community. For this purpose we invite you to come to our presentation and discussion meeting as well as participate in the assessment and planning workshop and support our information collection.

## DRAFT PROGRAM OF THE ECOINDIA TEAM IN THE NEXT 3 DAYS

31ST OCT (3PM TO 7PM) CENTRAL MEETING, PRESENTATION AND DISCUSSION
1ST NOV (10AM TO 4PM) WORKSHOP ON ASSESSMENT AND PLANNING WITH LUNCH
2NDNOV (8AM TO 2PM) ASSESSMENT AND WATER SAMPLE COLLECTION

**CONTACTS: GOURAB 9434197734 SOMNATH 8697029210 SANDEEP 8450874266 RONJON 8820744735**

## ইকো-ইন্ডিয়া - ECO-INDIA

### অঞ্চল ভিত্তিক পরিশুদ্ধ পানীয় জল সরবরাহ এবং নির্মলীকরণ প্রকল্প

পরিক্ষা মূলক জল সরবরাহ এবং নির্মলীকরণ প্রকল্পের জন্য যাদবপুর বিশ্ববিদ্যালয় এবং সহযোগী সংস্থাগুলির নির্বাচিত স্থানের পরিদর্শন (দ্বিতীয় দফা )। প্রকল্পটি ভারত সরকার ও ইউরপিও কমিশনের যুগ্ম আর্থীক আনুদান প্রাপ্ত ।

### জল স্বাস্থ্য এবং আর্থ সামাজিক উন্নয়ন

মানব শরীরে পুষ্টি সাধনে অন্যতম উৎস পরিস্রুত এবং বিশুদ্ধ জল। দূষিত জল বিভিন্ন রোগ এবং স্বাস্থ্য অবনতির কারন এবং অসুস্থ ও স্বাস্থহীন বেক্তি আর্থ সামাজিক উন্নয়নে যেমন কোন সাহায্য করতে পারে না তেমনই সমাজের খুদ্রতম অংশ হিসাবে তার পরিবার উন্নয়নের দিশারি হয়ে উঠতে পারে না । বিশুদ্ধ জলের অপ্রতুলতা পারস্পরিক দন্দ ও শত্রুতার কারন হয়ে উঠতে পারে । যেমন আমরা বিভিন্ন নোংরা জলের উৎস চাক্ষুষ করি তেমনি আবার প্রাকৃতিক উৎসেও জল যথেষ্ট দূষিত হতে পারে । দয়ার চইতন্যপুর গ্রাম পঞ্চায়েতের জোৎসুজান গ্রামের নলকূপ গুলি আরসেনিক মিশ্রিত জলের উৎসরূপে জনসাস্থ কারিগরী দপ্তরের পর্যবেক্ষণে পাওআ গেছে।আরসেনিক মিশ্রিত জলের ব্যাবহার বিভিন্ন চর্মরোগের এমন কি Cancer রোগেরও কারণ হয়ে উঠতে পারে।


অপরপক্ষে, বিশুদ্ধ পরিস্রুত জল এবং প্রত্যেক বাড়িতে নির্মলীকরণ ব্যবস্থা সুস্বাস্থের কারণ হয়; পরোক্ষভাবে আর্থসামাজিক উন্নতির অন্যতম দিশারী হয়ে ওঠে।

### এই সমস্যার কাঙ্খিত সমাধান


বিশুদ্ধ পানিও জল পেতে গেলে দুষিত জলের উৎস কে পরিস্রুত করতে হবে এবং সেই জল উপভোক্তাদের নিকট সরবরাহ করতে হবে । এই উদ্দেশ্য জল সরবরাহ এবং নিরমলিকরনের জন্য সাস্থ্যবিধি সম্মত প্রজুক্তি গ্রহণ করা প্রয়োজন । ECO-INDIA র এই প্রকল্পটির প্রধান উদ্দেশ্য এলাকার যে কোন বিশুদ্ধ জলের উৎস সংরক্ষণ, উন্নত প্রজুক্তির ব্যাবহারের মাধ্যমে পুকুর ও নলকূপের জল পরিশোধন এবং পরিস্রুত জলের ভাণ্ডার নির্মান করে, প্রতিটি ঘরে পাইপ-লাইনের সাহায্যে জল সরবরাহ করা।

### আপনাদের ভুমিকা

ECO-INDIA র উদ্দেশ্য আপনাদের এলাকার বাসিন্দাদের স্বতঃস্ফূর্ত অংশগ্রহনে উৎসাহিত করা; এই পদখ্যেপে আমরা তাঁদের সহযোগিতা পাওয়ার আশা রাখি। প্রকল্প রুপায়ন থেকে বাস্তোবায়েন অবধি আপনারা আমাদের উৎসাহিত রাখবেন সেই আশাও করি । কর্মকাণ্ডের শেষে আপনাদের এলাকার প্রকল্পটি আপনাদের প্রজত্নে রক্ষণাবেক্ষণের সঙ্গে ব্যাবহারের জন্য হস্তান্তরিত করা হবে। এই উদ্দেশ্য আপনাদের সুচিন্ত মতামত চ্যাঁই।

### খসরা অনুষ্ঠান সূচী

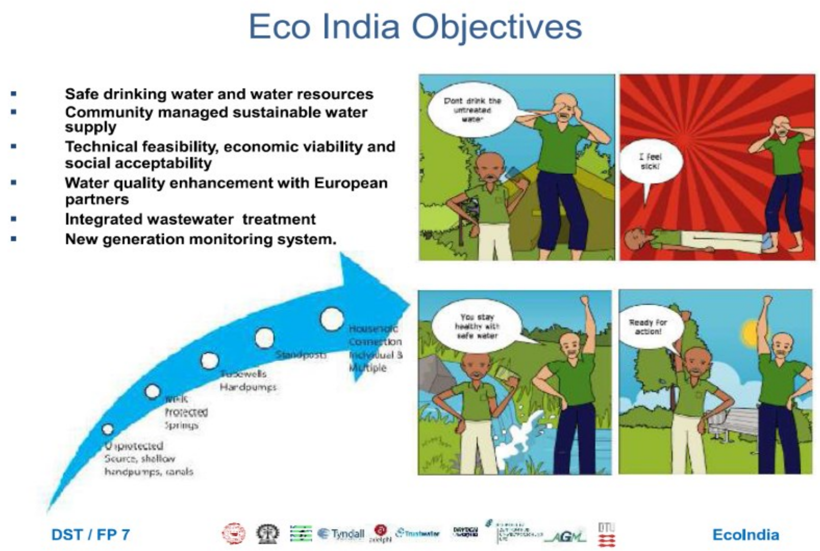
৩১ অকটোবারএ দুপুর ৩টা হইতে সন্ধ্যা ৭ টা অব্দি কেন্দ্রিয়সভা, উপস্থাপনা এবং আলোচনা।

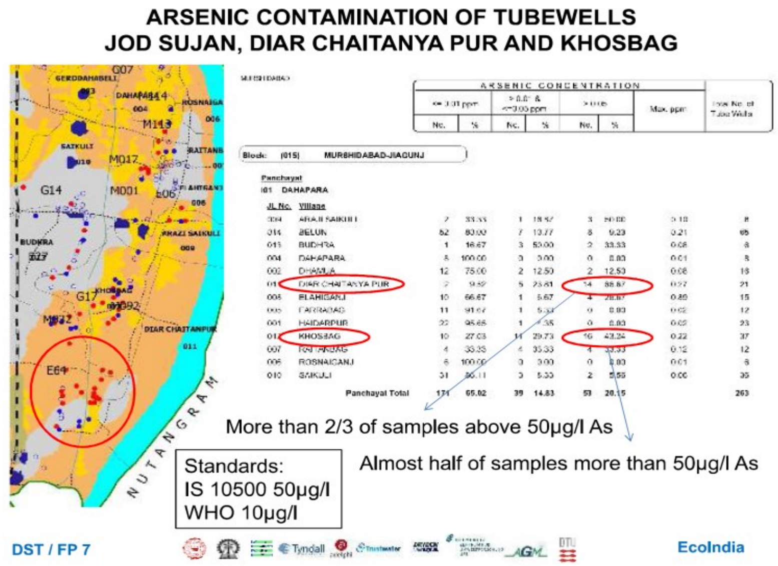
১লা নভেম্বর সকাল ১০ টা থেকে বিকাল ৪ টা অবধি পরিকল্পনার বিশ্লেষন ও মূল্যায়ন কর্মশালা(কর্মশালা প্রাঙ্গনে খাবার বাবস্থা থাকবে)।

২ রা নভেম্বর ৮ টা থেকে দুপুর ২ টা অবধি মূল্যায়ন এবং জলের নমুনা সংগ্রহ

*****যোগাযোগের নম্বর- গৌরব(৯৪৩৪১৯৭৭৩৪),সোমনাথ(৮৬৯৭০২৯২১০), সন্দীপ(৮৪৫০৮৭৪২৬৬), রঞ্জন(৮৮২০৭৪৪৭৩৫)**

*Figure 117: Eco-India needs assessment pamphlet for outreach activities in the local language Bengali.*





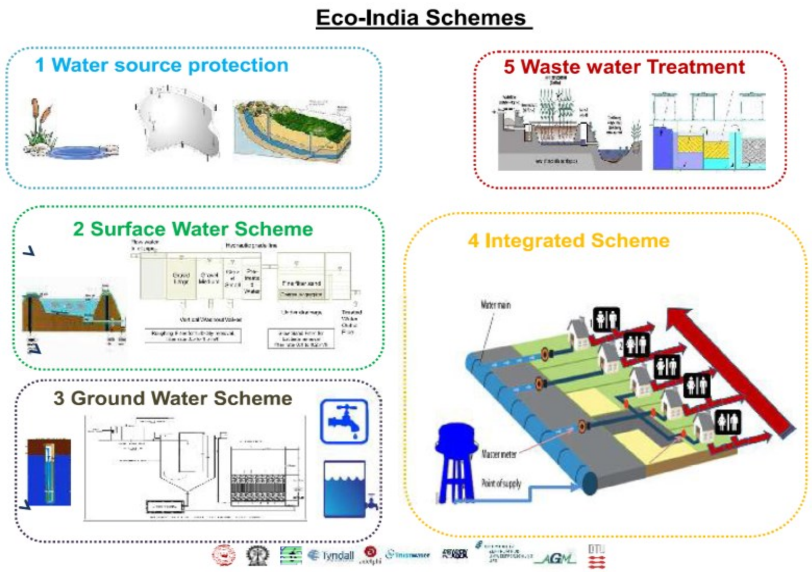



*Figure 118 Awareness Posters for a) general motivation on solution finding b) proof for arsenic poisoning in the project area c) pictures of visible health impacts from arsenic consumption and c) general solution approaches*


*Figure 119: Jyot Sujan scheme option 1*

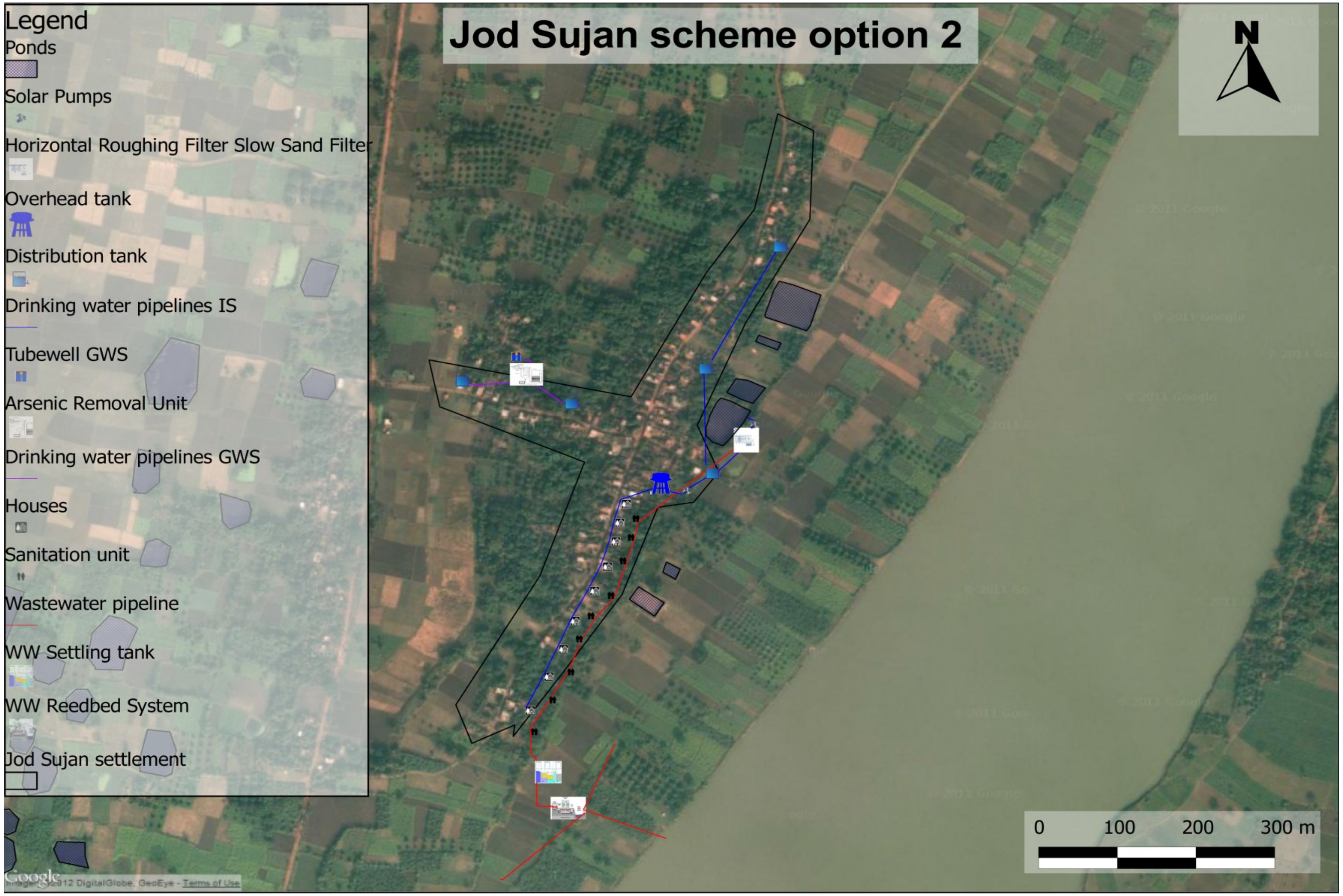



*Figure 120: Jyot Sujan scheme option 2*

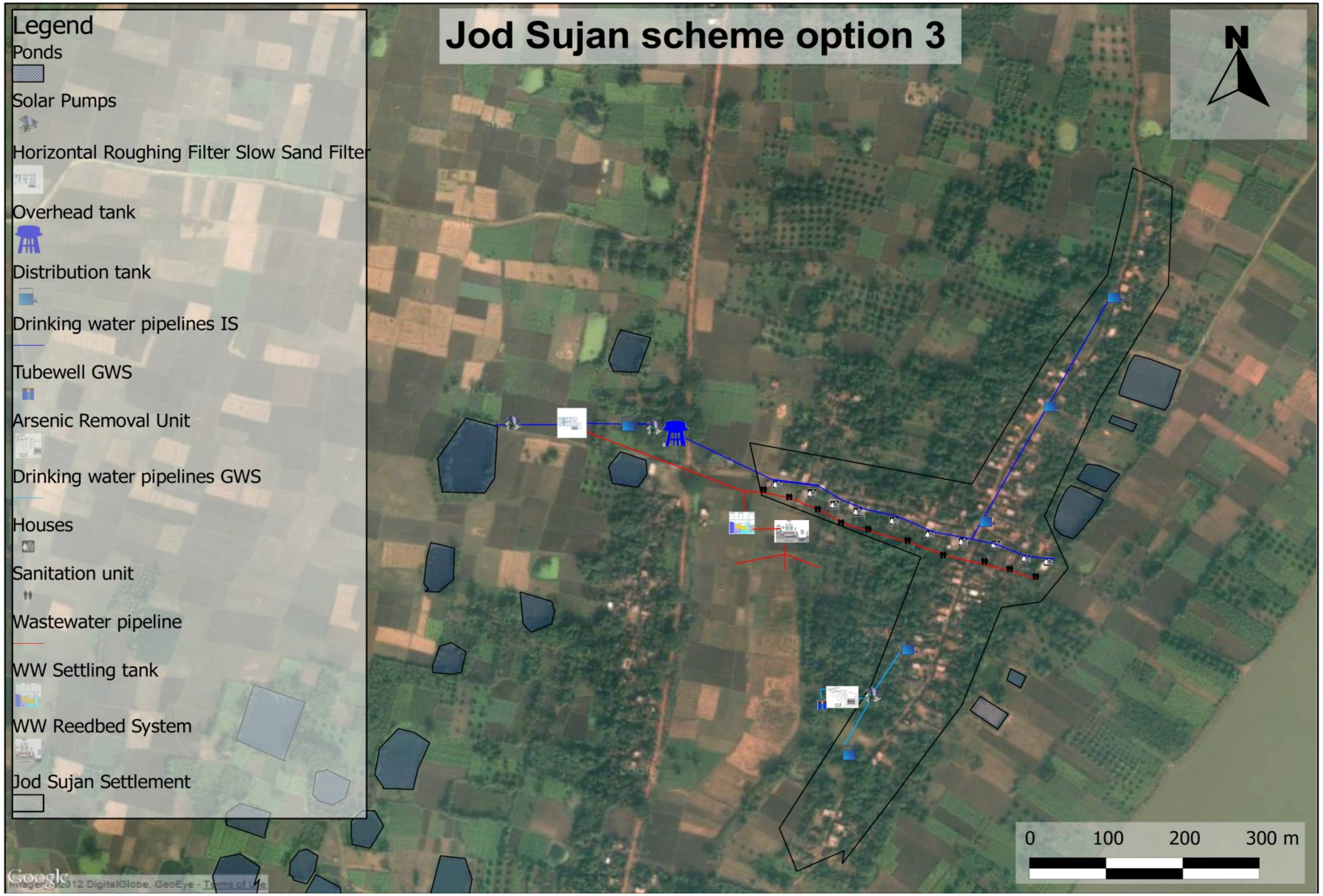



*Figure 121: Jyot Sujan scheme option 3*

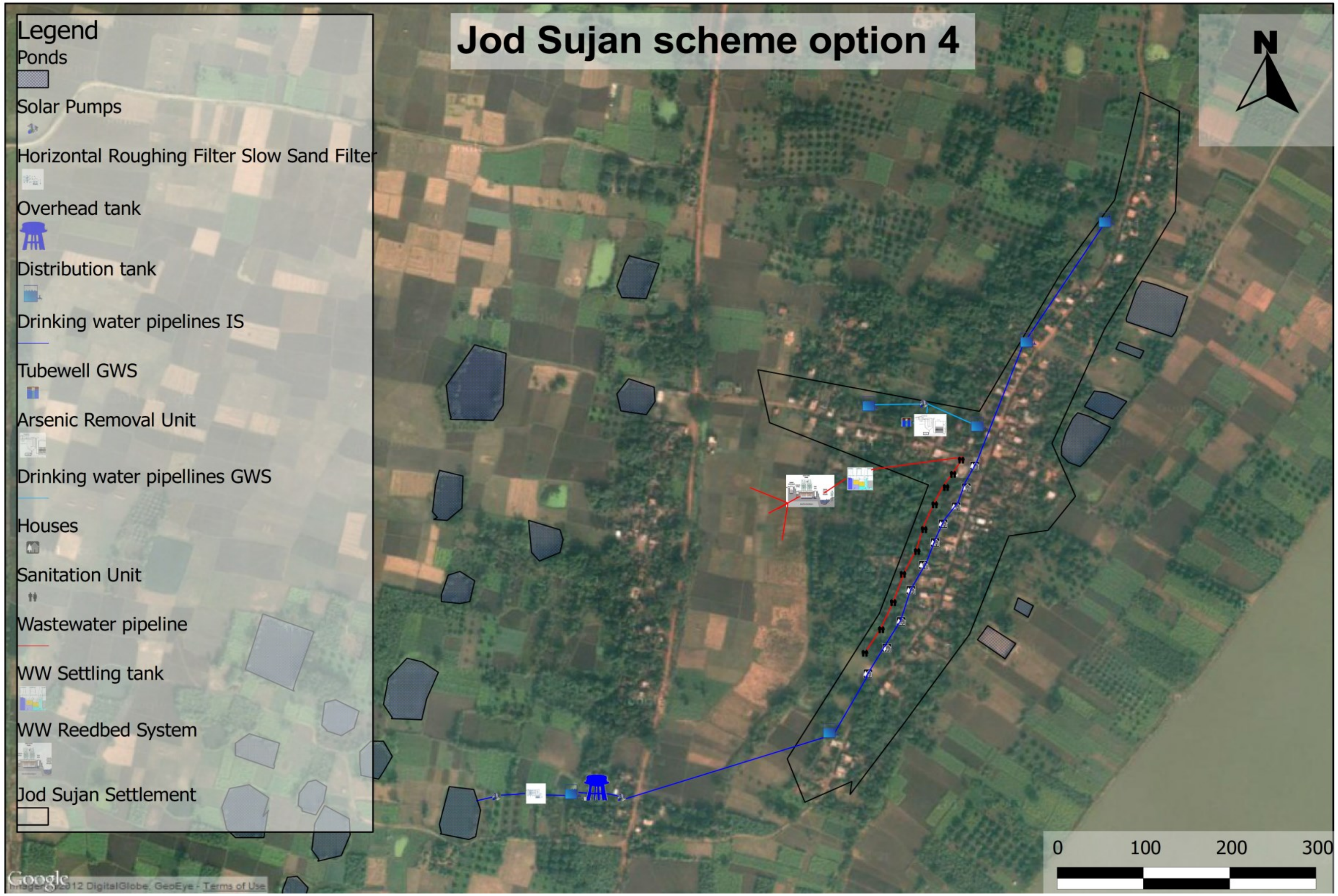



*Figure 122: Jyot Sujan scheme option 4*

## পানীয় জল সরবরাহার্থে জল সুরক্ষা এলাকা।

বন্ধুগণ,

এখানে একটি পানীয় জল শোধনাগার স্থাপিত হতে চলেছে। আপনাদের সামনে এটি একটি পানীয় জল শুদ্ধিকরণ ব্যবস্থা। এর জন্য পুকুর ও সংলগ্ন এলাকা যে কোন প্রকার দূষণ থেকে সুরক্ষিত রাখতে হবে। অনুগ্রহ করে আপনারা পুকুরের জল নির্মল রাখুন।

**- পুকুর ও সংলগ্ন এলাকায় প্রবেশ করবেন না।**
**( জল নেওয়া , স্নান করা ,অপরিস্কার বাসনপত্র , কাপড় ইত্যাদি ধোয়া থেকে sবিরত থাকুন।)**
**- পালিত পশুকে পুকুর ও সংলগ্ন এলাকায় আনবেন না।**
**- পুকুরের চারপাশের বাঁধে হাঁটাচলা করবেন না।**

যেহেতু পুকুরের জল নিকটবর্তী মাঠ ইত্যাদি থেকে নালির/ ড্রেনের মাধ্যমে জমা হয় , সেজন্য অনুগ্রহ করে নাব্য এলাকাগুলিকেও পরিচ্ছন্ন রাখুন। সেই হেতু এই অঞ্চলে নিম্নলিখিত সতর্কতাগুলি মেনে চলুন।

**- পশুচারণ বন্ধ রাখুন।**
**-পুকুর ও তার আশেপাশের জমির ২০০ মিটারের মধ্যে মল পরিত্যাগ করবেন না ।**
**- আবর্জনা ফেলা বন্ধ রাখুন।**
**- রাসায়নিক সার ও কীটনাশকের ব্যবহার বন্ধ করুন।**
**- নাব্য জমি ও বাঁধে খোঁড়াখুড়ি বা নির্মাণের কাজ থেকে বিরত থাকুন।**

মনে রাখবেন এভাবে আপনি নিজের পানীয় জলকেই বিষাক্ত করে তুলবেন। সাধ্যের মধ্যে কম খরচে পরিস্রুত শুদ্ধ জল সরবরাহ চালু রাখতে আপনাদের সক্রিয় সহযোগিতা একান্ত জরুরি। দূষণের ফলে জল শোধনের কাজ অনর্থক ব্যয়বহুল হয়ে পড়ে।
যে কোন বিষয়ে প্রশ্ন থাকলে বা দূষণ সম্পর্কিত যে কোন খবর দিতে এখানে যোগাযোগ করুন -

ইকো ইণ্ডিয়া ওয়াটার কমিটি। হবিবুল্লা সেখ - ৯৭৭৫৬৮৯৪৩৪ রইসুদ্দিন সেখ - ৯৬৪৭০৩২৫০৮।জেনারুল বাদ্সা-৯৭৭৫৫৪২৯১৪।আজাহার উদ্দিন-৯১৫৩৪৮৬৮২৯

ইকো ইণ্ডিয়া ওয়াটার কমিটি, ইকো ইণ্ডিয়া প্রকল্পের অধীন এই পুষ্করিণী নির্ভর জল সরবরাহ প্রকল্প স্থাপন করছেন। আর্থিক সহায়তায় - ইণ্ডিয়ান ডিপার্টমেন্ট অফ সায়েন্স এণ্ড টেকনলজির পক্ষে যাদবপুর বিশ্ববিদ্যালয়, কলকাতা ; আই আই টি খড়্গপুর এবং সুপার টেকনিসিয়ান্স এণ্ড দি ইউরোপীয়ান ডিরেক্টরেট জেনারেল রিসার্চ এণ্ড ইনোভেশনের পক্ষে টিণ্ডাল, অ্যাডেলফি, ড্রাইডেন অ্যাকোয়া, DTU,AGM,UFZ
ইকো ইণ্ডিয়া প্রকল্প সম্পর্কে বিস্তারিত তথ্য পাওয়া যাবে - www.eco-india.eu ওয়েবসাইটে।

**আপানাদের সহযোগিতা একান্তভাবে কামনা করি।**

## Water protection area for Drinking Water Supply

Dear friend,

A drinking water treatment supply is being implemented here. In front of you is a drinking water treatment plant. The pond and surrounding area have to be protected from any kind of pollution. Please protect the water quality of the pond:

- **do not enter the pond area**
- **(do not take water, wash or bath)**
- **do not let any animals enter the pond area**
- **do not walk on the bunds surrounding the pond**

As the water for the pond is collected from the surrounding field by channels please also protect the catchment area:

- **no animal grazing**
- **no open defecation within 200 meters.**
- **no waste disposal**
- **no application of pesticides and fertilizers**
- **no destruction of catchment channels and bunds**

Please consider that you may contaminate your own drinking water and your active participation is necessary for ensuring safe and affordable water supply. In case of pollution the water supply will be unnecessarily more expensive.

For any questions and reporting of pollution activities please contact

The ECO-India Water Committee: Habibulla Sekh: 9775689434, Roisuddin Sekh: 9647032508

Jenarul Badsha-9775542914,Azhar Uddin-9153486829

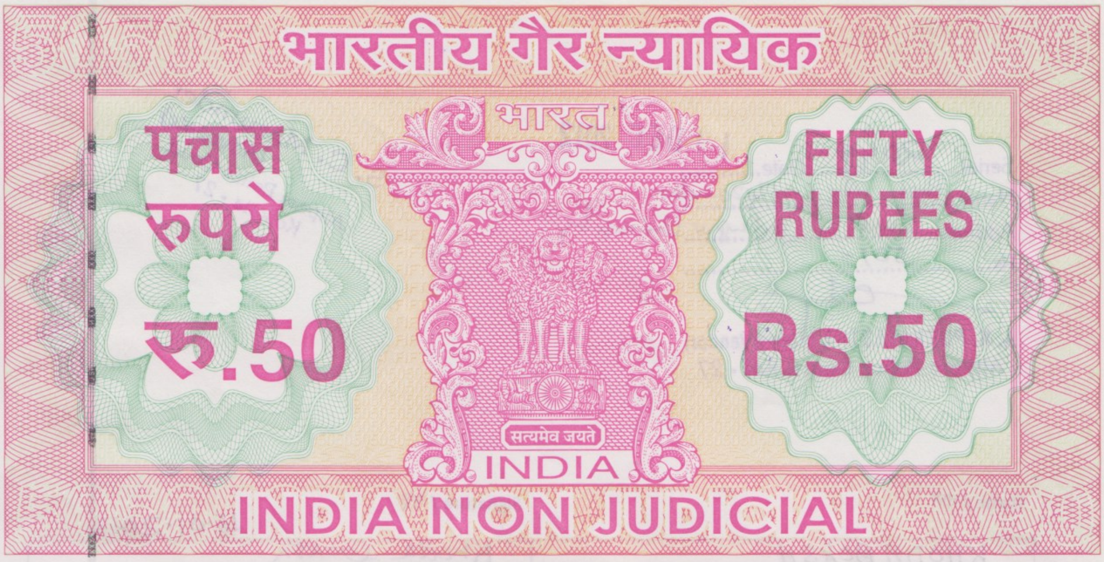
The ECO-India Water Committee is setting up this pond water based water supply scheme under the ECO-India project which is funded by the Indian Department of Science and Technology represented by Jadavpur University Kolkata, IIT Kharagpur and Super Technicians and the European Directorate General Research and Innovation represented by Tyndal, adelphi, Trustwater, Drydan Aqua, DTU, AGM and UFZ.

More information on the ECO-India project can be found on the website: www.eco-india.eu

**Your cooperation is highly appreciated!**

*Figure 123 Signboard for creating awareness on protection of the catchment area*

# I. AGREEMENT WITH WATER COMMITTEE




পশ্চিমবঙ্গ पश्चिम बंगाल WEST BENGAL

L 481688

English:

**<u>Agreement between Eco India Water Committee members from Jyot Sujan (permanent members) and DST / FP7 Eco India project partners (temporary members)</u>**

The DST / FP7 Eco India partners (temporary members) intend to support the Eco India water committee members (permanent members)in Jyot Sujan in setting up and operating the water supply in the Jyot Sujan village starting from the day of the signature of this agreement until the end of the project period lasting until 31.08.2015.

The permanent members of the Eco India Water committee residing in Jyot Sujan ensure to collect fees for maintenance of the system as well as for the payment of the annual compensation for the usage of the pond and land to the owners.

The water committee is aware that after the end of the project period no further support can be expected from the temporary members.

The English Version is the true translation of the Bengali Version

বাংলা

<u>চুক্তি পত্র **Eco INDIA Water Committee Jyot Sujan** গ্রামে অবস্থিত সদস্যের (স্থায়ী সদস্য) এবং **DST/FP7 ECO INDIA partners** (অস্থায়ী সদস্য) মধ্যে ।</u>

এই মর্মে জোৎ সুজান গ্রামের জল সরবরাহ প্রকল্পের সমস্ত সদস্যরা সমর্থনের জন্য মনস্থ করেছেন যে, DST/FP7 ECO INDIA অংশীদাররা জোৎসুজান গ্রামে, চুক্তিপত্রে সাক্ষরের দিন থেকে জল সরবরাহ প্রকল্পের অন্তিম সময়সীমা অর্থাৎ ৩১.০৮.২০১৫ পর্যন্ত এই গ্রামে জল সরবরাহ প্রকল্প স্থাপন এবং পরিচালনায় গ্রামবাসীকে সক্রিয় সাহায্য করবে ।

জোৎ সুজান গ্রামে বসবাসকারি ECO-INDIA জল সরবরাহ প্রকল্পের স্থায়ী সদস্যরা এই প্রকল্পের রক্ষনাবেক্ষনের জন্য পুকুর এবং তার পাশে আবস্থিত জমি ব্যবহারের জন্য বার্ষিক ক্ষতিপুরন পরিশোধের জন্য ফি (চাঁদা) সংগ্রহ নিশ্চিত করবে ।

এই গ্রামের জল সরবরাহ কমিটিকে এই ব্যপারে সচেতন থাকতে হবে যে, এই প্রকল্পের কার্যকারীতার সময় সীমা শেষ হওয়ার পরে DST/FP7 অংশীদারদের কাছে থেকে কোনোরূপ অতিরিক্ত সমর্থন আশা করা যাবে না ।

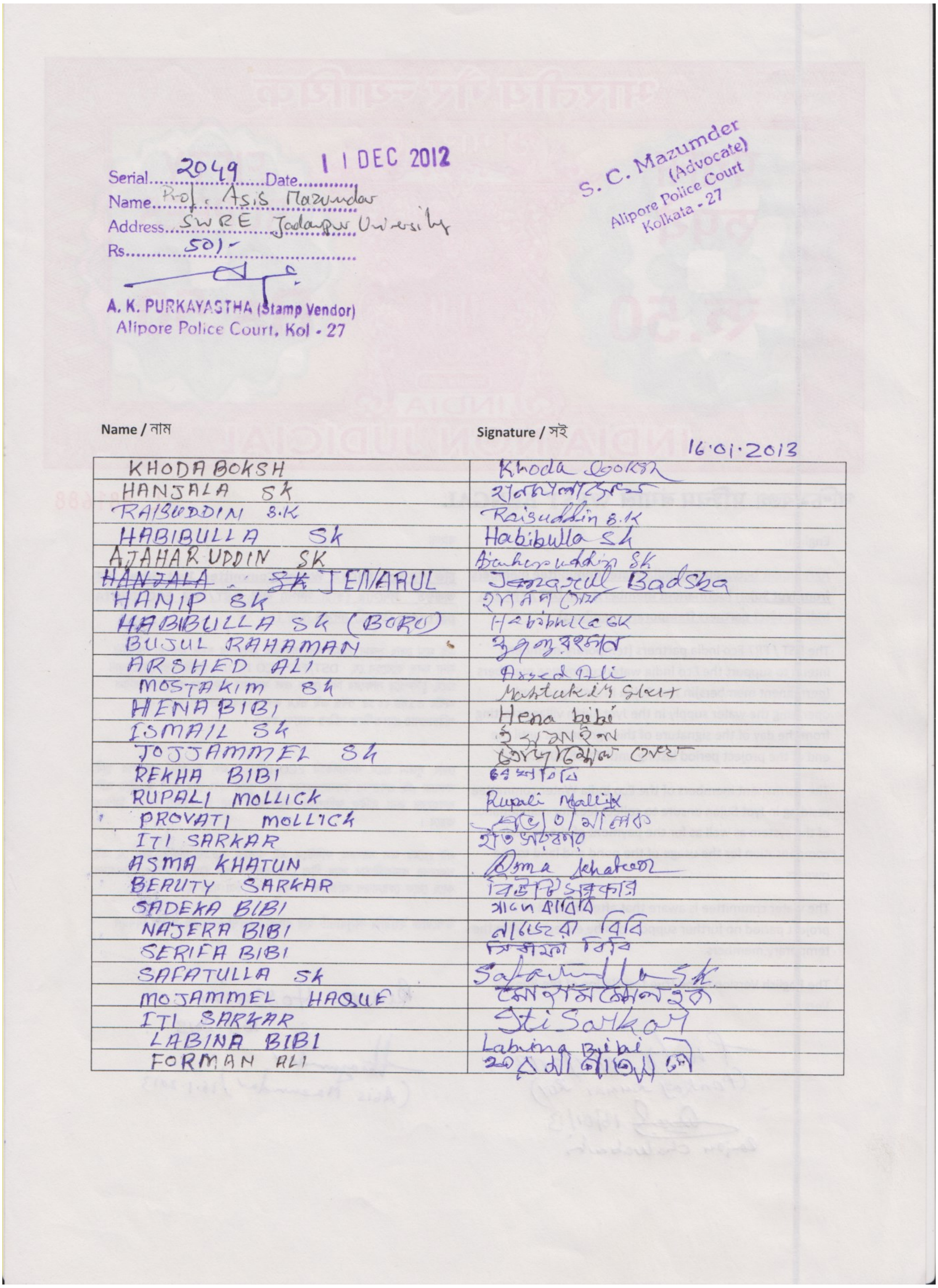
উপরোক্ত ইংরিজি অনুবাদটি হল বাংলায় লেখা চুক্তিটির সঠিক বিবরণ

Bedar Hossain
16.1.2013

(Asis Mazumdar) 16.1.2013

16/01/2013
(Pankoj Kumar Roy)

16/01/13
Ranjan Chakrabarti



Serial 2049 Date 11 DEC 2012
Name Prof. Asis Mazumdar
Address SWRE Jadavpur University
Rs. 50/-

A. K. PURKAYASTHA (Stamp Vendor)
Alipore Police Court, Kol - 27

S. C. Mazumder
(Advocate)
Alipore Police Court
Kolkata - 27

16.01.2013

| Name / নাম | Signature / সই |
|---|---|
| KHODA BOKSH | Khoda Boksh |
| HANJALA SK | হানজালা সেখ |
| RAISUDDIN S.K | Raisuddin S.K |
| HABIBULLA Sk | Habibulla Sk |
| AJAHAR UDDIN SK | Ajaharuddin Sk |
| ~~HANJALA SK~~ JENARUL | Jenarul Badsha |
| HANIP Sk | হানিফ সেখ |
| HABIBULLA Sk (BORO) | Habibulla Sk |
| BUJUL RAHAMAN | বুজুল রহমান |
| ARSHED ALI | Arsed Ali |
| MOSTAKIM Sk | Mostakim Sk |
| HENA BIBI | Hena bibi |
| ISMAIL Sk | ইসমাইল সেখ |
| JOJJAMMEL Sk | তোজ্জাম্মেল সেখ |
| REKHA BIBI | রেখা বিবি |
| RUPALI MOLLICK | Rupali Mallik |
| PROVATI MOLLICK | প্রভাতী মল্লিক |
| ITI SARKAR | ইতি সরকার |
| ASMA KHATUN | Asma khatun |
| BEAUTY SARKAR | বিউটি সরকার |
| SADEKA BIBI | সাদেকা বিবি |
| NAJERA BIBI | নাজেরা বিবি |
| SERIFA BIBI | সেরিফা বিবি |
| SAFATULLA Sk | Safatulla Sk |
| MOJAMMEL HAQUE | মোজাম্মেল হক |
| ITI SARKAR | Iti Sarkar |
| LABINA BIBI | Labina Bibi |
| FORMAN ALI | ফরমান আলী সেখ |

*Figure 124 Agreement between ECO-India Partners and Water Committee*

## J. POND SELECTION DATA

*Table 30 Water quality assessment of available ponds*

| Ponds. no. | Paramter | | Salinity | Cond. | D O | DO % Sat. | Temp. | pH | Turbidity | TDS | BOD 3D 27ºC | COD | Alkalinity (as $CaCO_3$) | Ammoniac (N) | Nitrate ($NO_3$) | Tot. Col. | Feac.Col. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | unit | | % | µs/cm | mg/l | | C° | - | NTU | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | MPN/100 ml | MPN/100 ml |
| 1 | upapradhan first suggestion | 01.11.2012 | | | | | | 7,32 | 28 | 316 | 28 | 51 | 225 | 2,4 | <0.2 | | |
| | | 23.11.2012 | 0,2 | 449 | 0,22 | 2,6 | 24 | 6,75 | | 241 | | | | | | | |
| 2 | Adbul Hak suggestion pond a | 01.11.2012 | | | | | | | 16 | 140 | 11 | 27 | | 0,81 | 0,4 | | |
| 3 | Bhagirathi river | 01.11.2012 | | | | | | | 96 | 138 | <1.00 | 5,7 | | 0,09 | 0,8 | | |
| | | 23.11.2012 | 0,1 | 233 | 7,74 | 86,9 | 26,6 | 7,24 | | 124 | | | | | | | |
| 4 | Adbul Hak suggestion pond b | 01.11.2012 | | | | | | | 148 | 182 | 10 | 26 | | 1,93 | 0,6 | | |
| 5 | Adbul Hak suggestion pond c | 01.11.2012 | | | | | | | 19 | 290 | 24 | 45 | | 1,6 | <0.20 | | |
| 6 | Behind Primary school | 01.11.2012 | | | | | | | 43 | 238 | 8 | 19 | | 0,93 | 2,1 | | |
| 7 | Masjid Pond | 01.11.2012 | | | | | 27,4 | 7,94 | 66 | 350 | 12 | 27 | 260 | 0,42 | 1,4 | | |
| | | 23.11.2012 | 0,1 | 251 | 8,27 | 106 | | 7,51 | 65 | 134 | 4 | 12 | 108,6 | 0,16 | 0,77 | 11 | 4 |
| | | 10.12.2012 | | | | | | | 49 | | 8 | 22 | 124,2 | 1,45 | 0,09 | 170 | 79 |
| 8 | Next to Masjid Pond | 01.11.2012 | | | | | | | 21 | 178 | 10 | 25 | | 0,21 | 1,4 | | |
| **9** | **Final project pond** | **01.11.2012** | | | | | | | **7,2** | **564** | **15** | **33** | | **0,02** | **5,5** | | |
| | | **23.11.2012** | **0,3** | **537** | **5,07** | **62,9** | **26** | | **43** | **293** | **7,9** | **26** | **244,4** | **0,11** | **2,42** | **11** | **4** |
| 10 | Khirki | 23.11.2012 | 0,3 | 525 | 5,11 | 62,1 | 25 | | 13 | 283 | 5,1 | 15 | 246,4 | 0,14 | 0,78 | 33 | 8 |
| | | 08.12.2012 | 0,3 | 540 | 4,66 | 51,8 | 20,3 | 8,02 | 12 | 291 | 6,9 | 23 | 275,5 | 0,89 | 0,16 | 130 | 33 |
| 11 | behind Uttam Sarcar house | 23.11.2012 | 0,2 | 341 | 3,18 | 36,9 | 22,4 | | 3 | 183 | 4,8 | 16 | 151,3 | 0,2 | 0,47 | 540 | 220 |
| 12 | B.H. back side (Murjina Bibi) | 23.11.2012 | 0,1 | 241 | 3,35 | 40,8 | 25 | 6,71 | | 129 | | | | | | | |
| | | 08.12.2012 | 0,1 | 265 | 6,41 | 71,3 | 19,6 | 8,4 | 117 | 141 | 7,5 | 30 | 139,7 | 0,77 | 0,08 | 160 | 220 |
| 13 | B.H. front side | 23.11.2012 | 0,2 | 412 | 6,38 | 80 | 25,1 | 7,2 | 16 | 221 | 5,2 | 17 | 168,8 | 0,13 | 0,63 | 170 | 49 |
| | | 08.12.2012 | 0,2 | 418 | 4,54 | 51,9 | 20,9 | 8,2 | | 224 | | | | | | | |
| 14 | small pond 2 next to masjid pond | 23.11.2012 | 0,1 | 239 | 0,4 | 4,8 | 23,6 | 6,74 | 56 | 128 | 9,3 | 27 | 108,6 | 0,26 | 0,46 | 540 | 7 |
| 15 | small pond next to open lawn | 08.12.2012 | 0,5 | 842 | 3,77 | 42 | 19,9 | 8,5 | 27 | 458 | 22 | 85 | 388 | 4,19 | 0,2 | 920 | 280 |
| 16 | big pond next to village center | 08.12.2012 | 0,2 | 449 | 14,67 | 160 | 19,4 | 8,45 | 68 | 242 | 16 | 62 | 155,2 | 4,25 | 0,27 | 540 | 130 |

| | |
|---|---|
| | highly problematic value regarding standards |
| | problematic value regarding standards |
| | elevated value in regards to standards |

*Table 31 Pond selection parameter evaluation*

| Pond s. no. | Current surface water quality lab / field | Water quality by usage | Water quantity | Suitability of quality of activity in catchment | Availability of adjacent land for treatment units (individual community) | Monetary implication for usage of pond | Road access | Investment from JU required | **Overall score** | **Ranking** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| 1 | 12.9 | 4 | 44 | 4 | 1 | 2 | 10 | 1 | **67.9** | **9** |
| 2 | 7.5 | 4 | 52 | 3 | 1 | 4 | 10 | 1 | **71.5** | |
| 3 | 8.3 | 6 | 4 | 6 | 5 | 2 | 1 | 1 | **31.3** | **0** |
| 4 | 15.8 | 4 | 24 | 5 | 5 | 10 | 10 | 1 | **63.8** | **7** |
| 5 | 21.7 | 4 | 32 | 2 | 1 | 14 | 10 | 1 | **74.7** | |
| 6 | 9.2 | 2 | 8 | 5 | 5 | 12 | 1 | 5 | **47.2** | **2** |
| 7 | 6.8 | 2 | 12 | 4 | 5 | 18 | 1 | 1 | **47.8** | **3** |
| 8 | 7.5 | 4 | 56 | 4 | 5 | 6 | 10 | 1 | **82.5** | |
| 9 | 7.9 | 4 | 16 | 6 | 1 | 8 | 1 | 3 | **46.9** | **1** |
| 10 | 2.6 | 4 | 4 | 5 | 5 | 16 | 10 | 5 | **51.6** | **4** |
| 11 | 4.3 | 6 | 64 | 4 | 1 | 2 | 10 | 1 | **81.3** | |
| 12 | 4.8 | 2 | 40 | 1 | 1 | 8 | 10 | 1 | **56.8** | **5** |
| 13 | 0.5 | 4 | 60 | 1 | 1 | 2 | 10 | 1 | **68.5** | **10** |
| 14 | 11.3 | 4 | 48 | 1 | 1 | 6 | 1 | 1 | **71.3** | |
| 15 | 16.0 | 6 | 28 | 2 | 1 | 10 | 1 | 1 | **65.0** | **8** |
| 16 | 16.1 | 2 | 20 | 2 | 1 | 8 | 10 | 1 | **60.1** | **6** |

## K. DESIGN DRAWINGS

### SILT TRAP

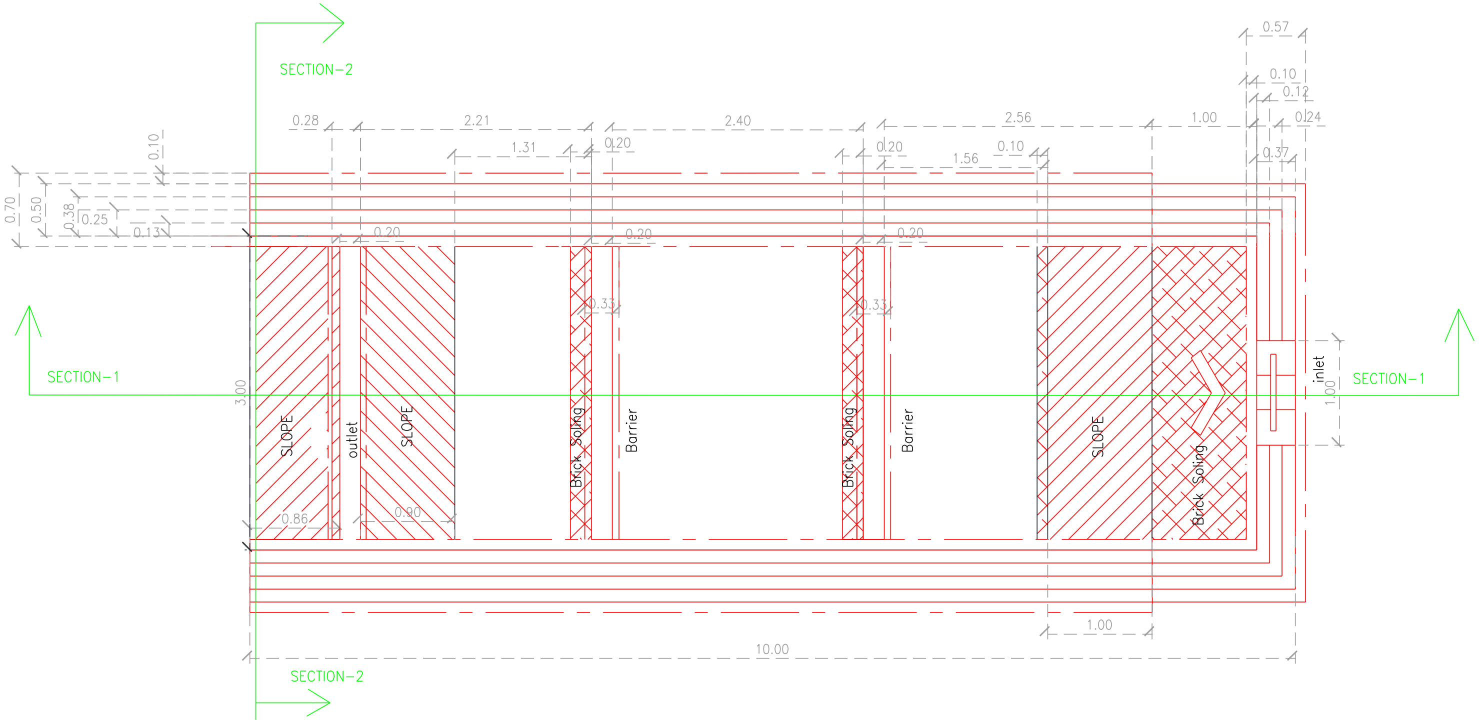



FIG 1- PLAN OF SILT TRAP

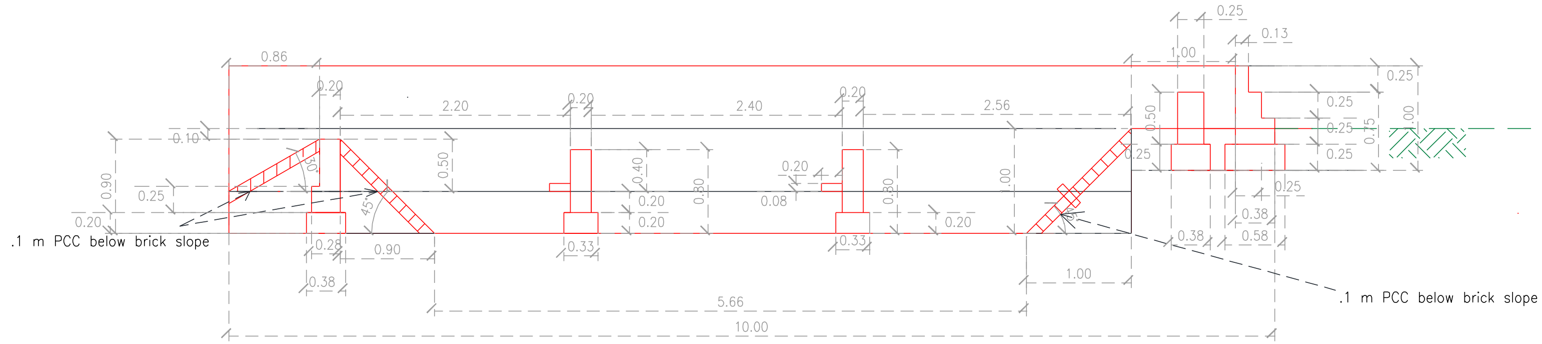



FIG 2- SECTION 1 OF SILT TRAP

*Figure 125 Top and side view of silt trap*

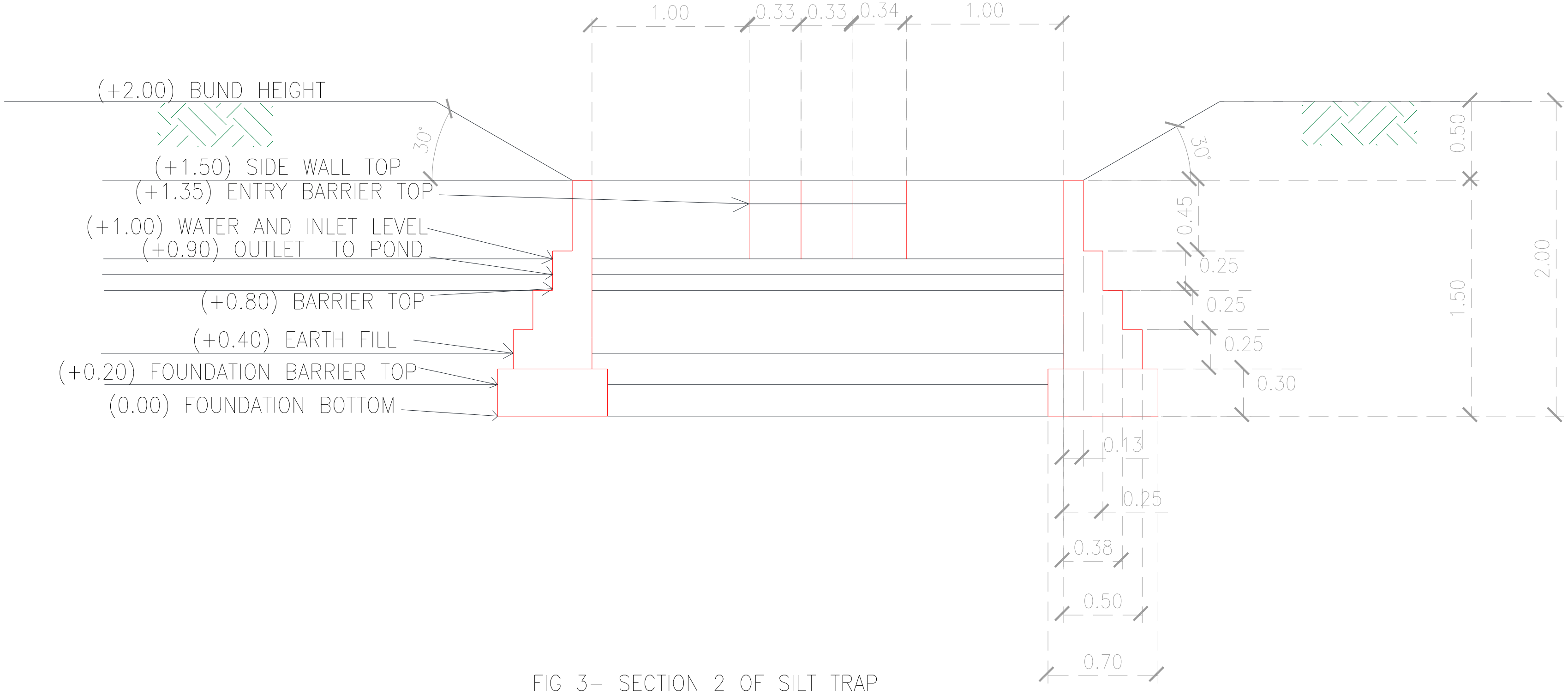
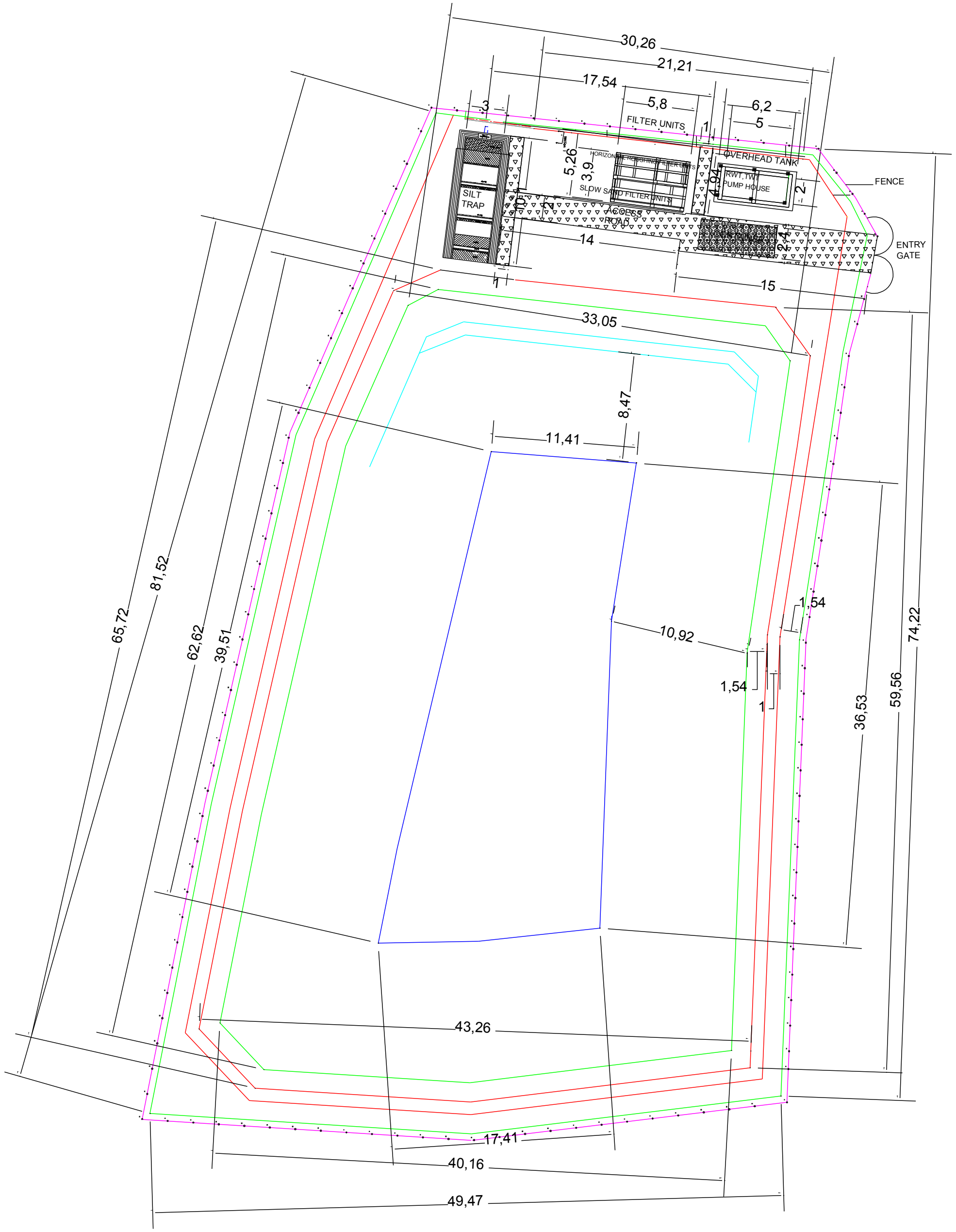



FIG 3– SECTION 2 OF SILT TRAP

*Figure 126 side view from entrance of silt trap*



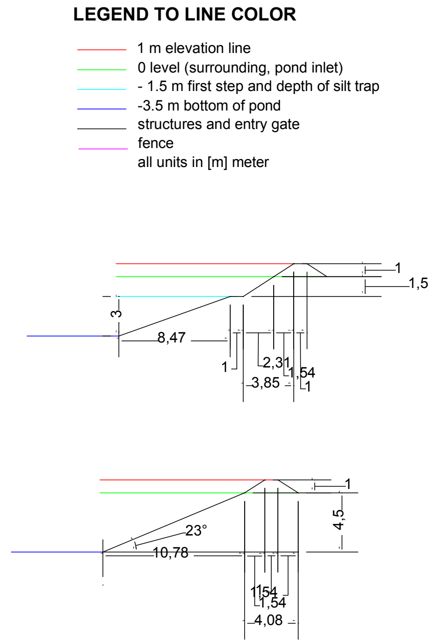




*Figure 127 Dimensions and excavation depth of the pond*

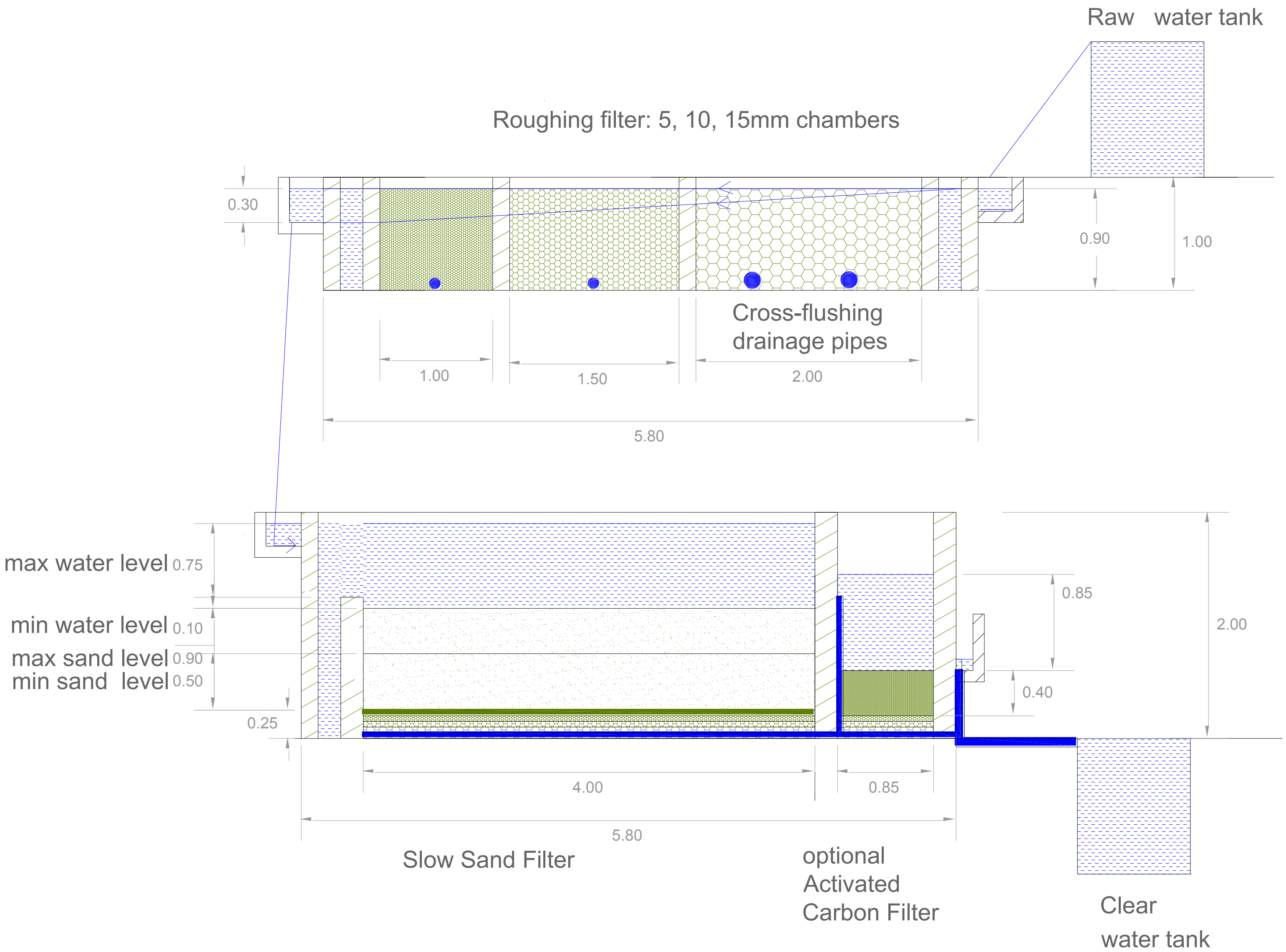



*Figure 128 Filter media and general process flow of filtration system*

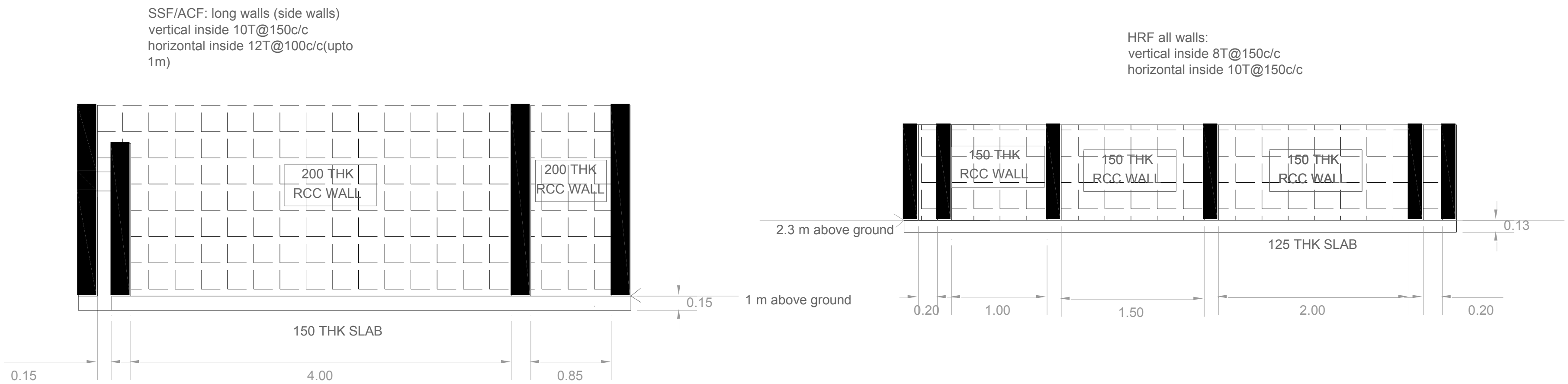



*Figure 129 Sidewall of the filter chambers*

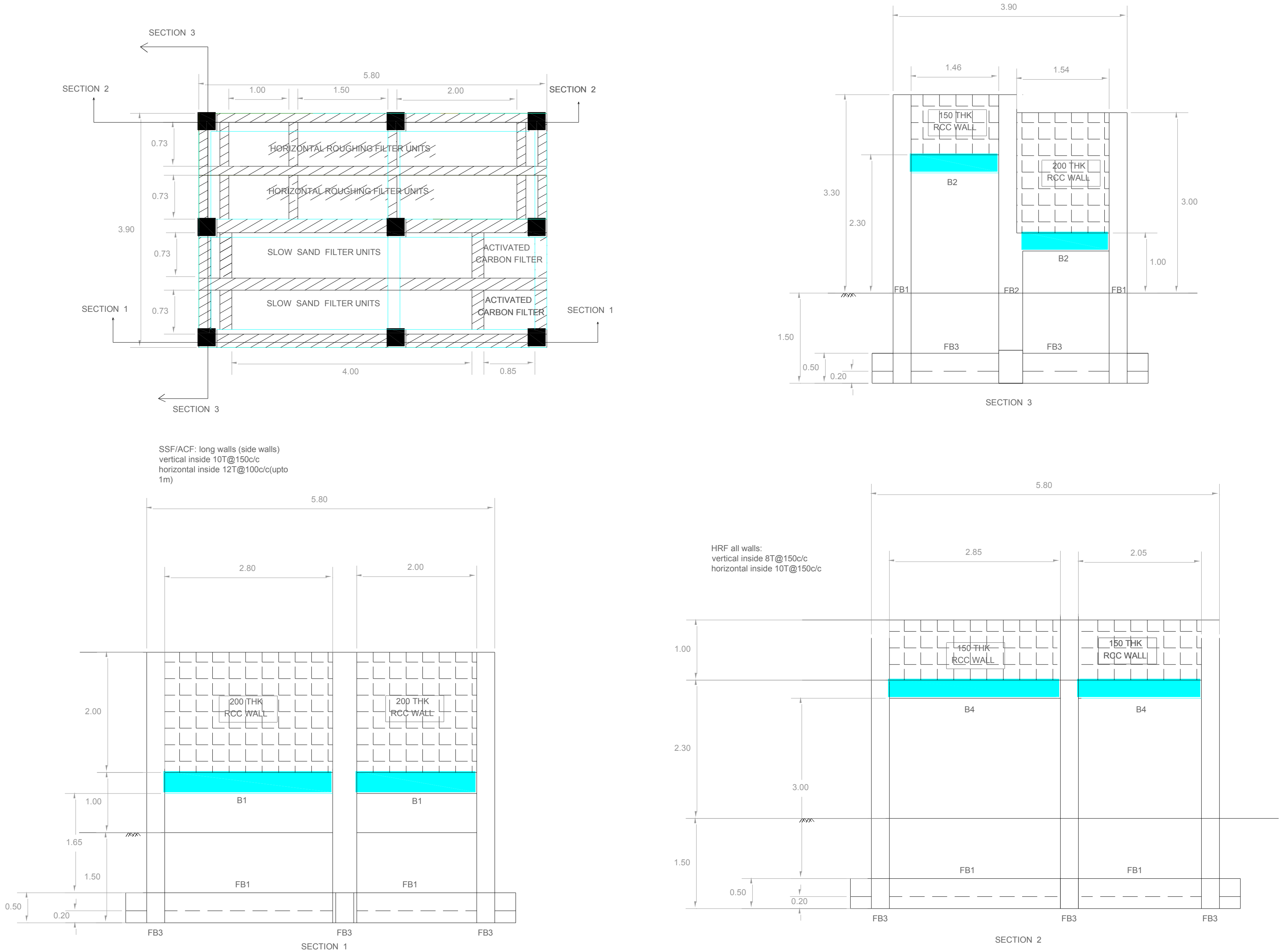
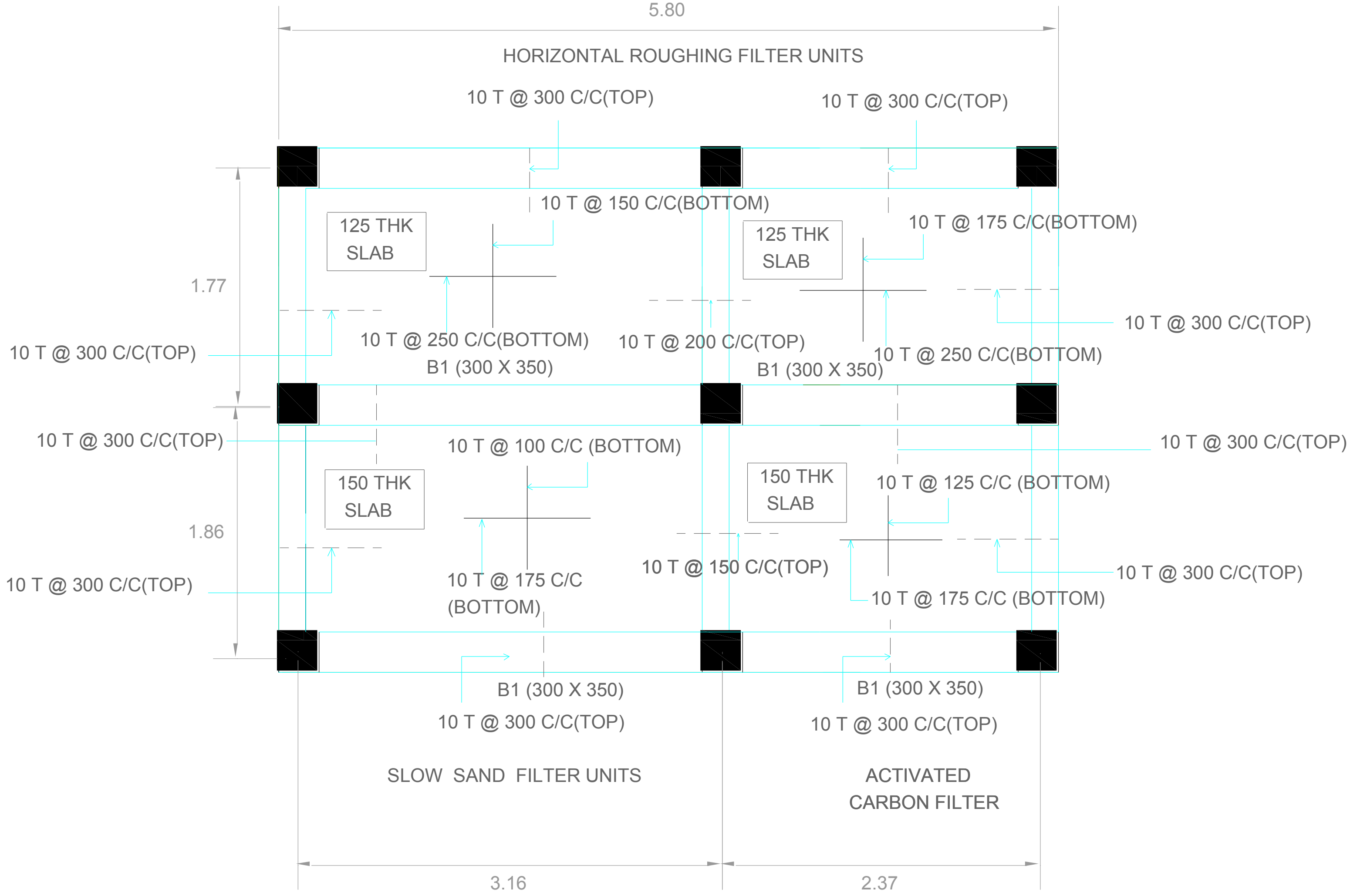



*Figure 130 Location of beams*




ADDITION TO THE REINFORCEMENTS SHOWN EXTRA 2 NOS OF 12 TOR BAR TO BE PROVIDED AT THE BOTTOM OF RCC WALLS CONSTRUCTED FROM SLAB

*Figure 131 Details of the slab at the bottom of the filter units*

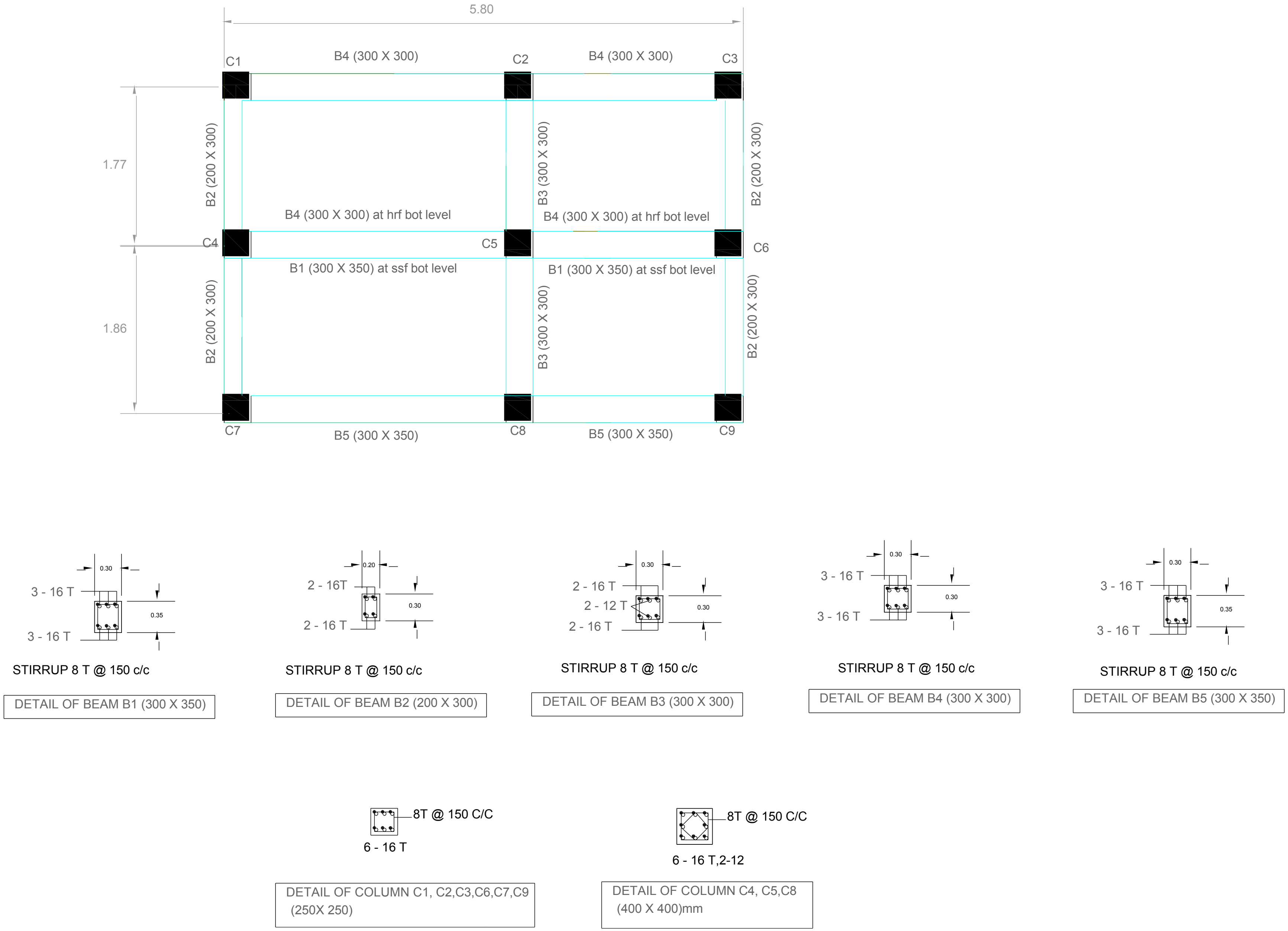



*Figure 132 Stirrup details of the beams and columns*

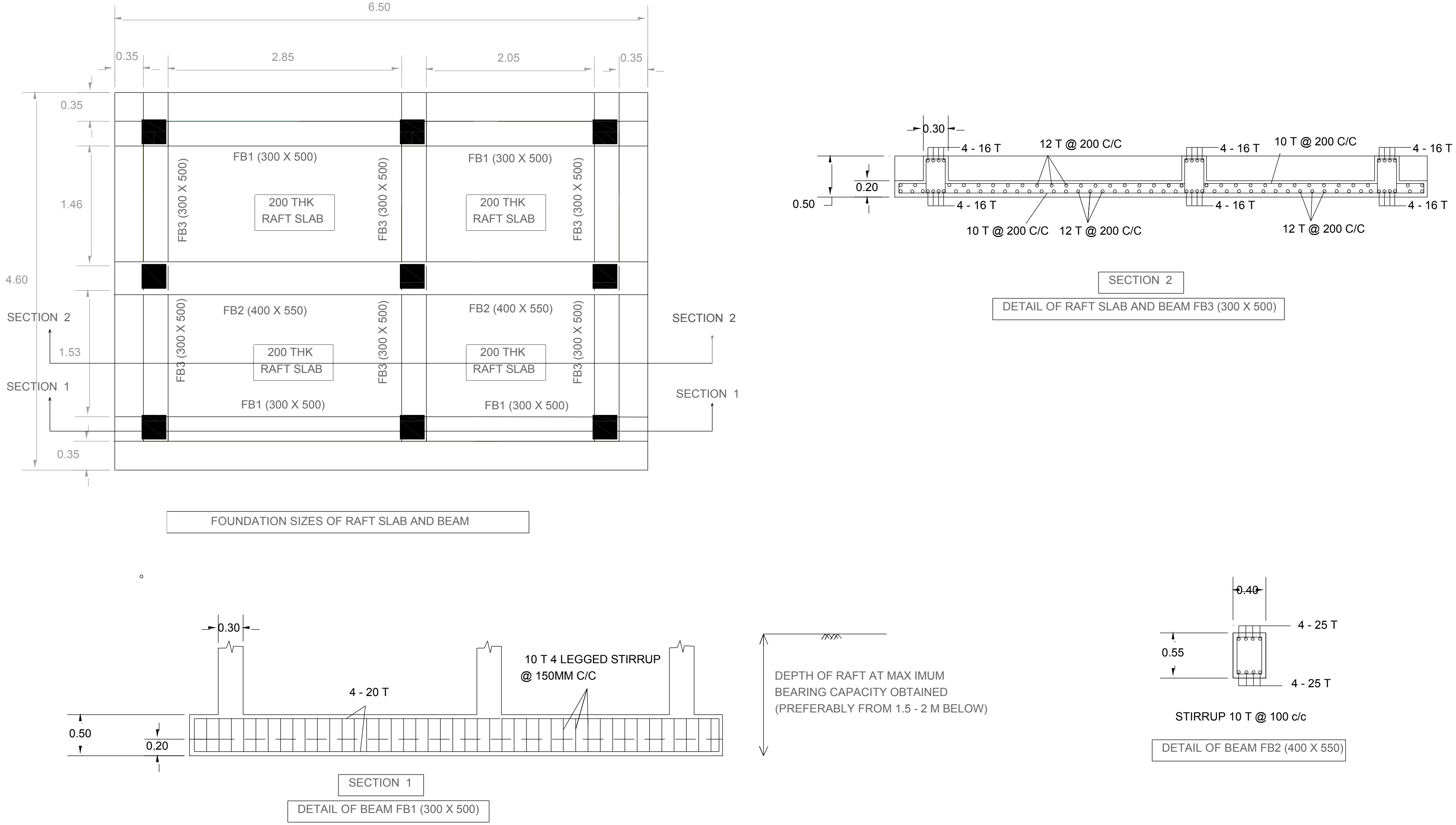



*Figure 133 Details of the foundation*

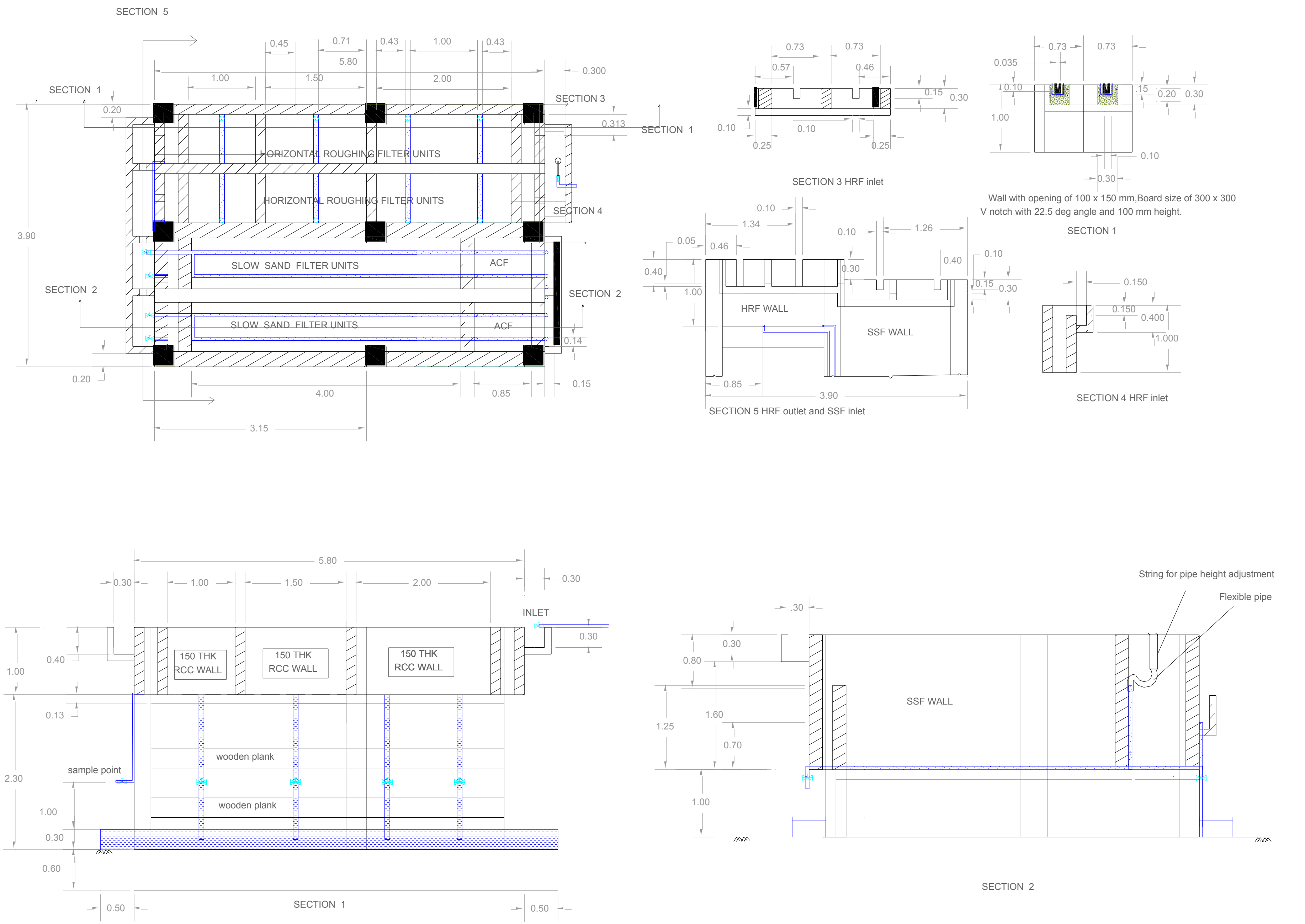
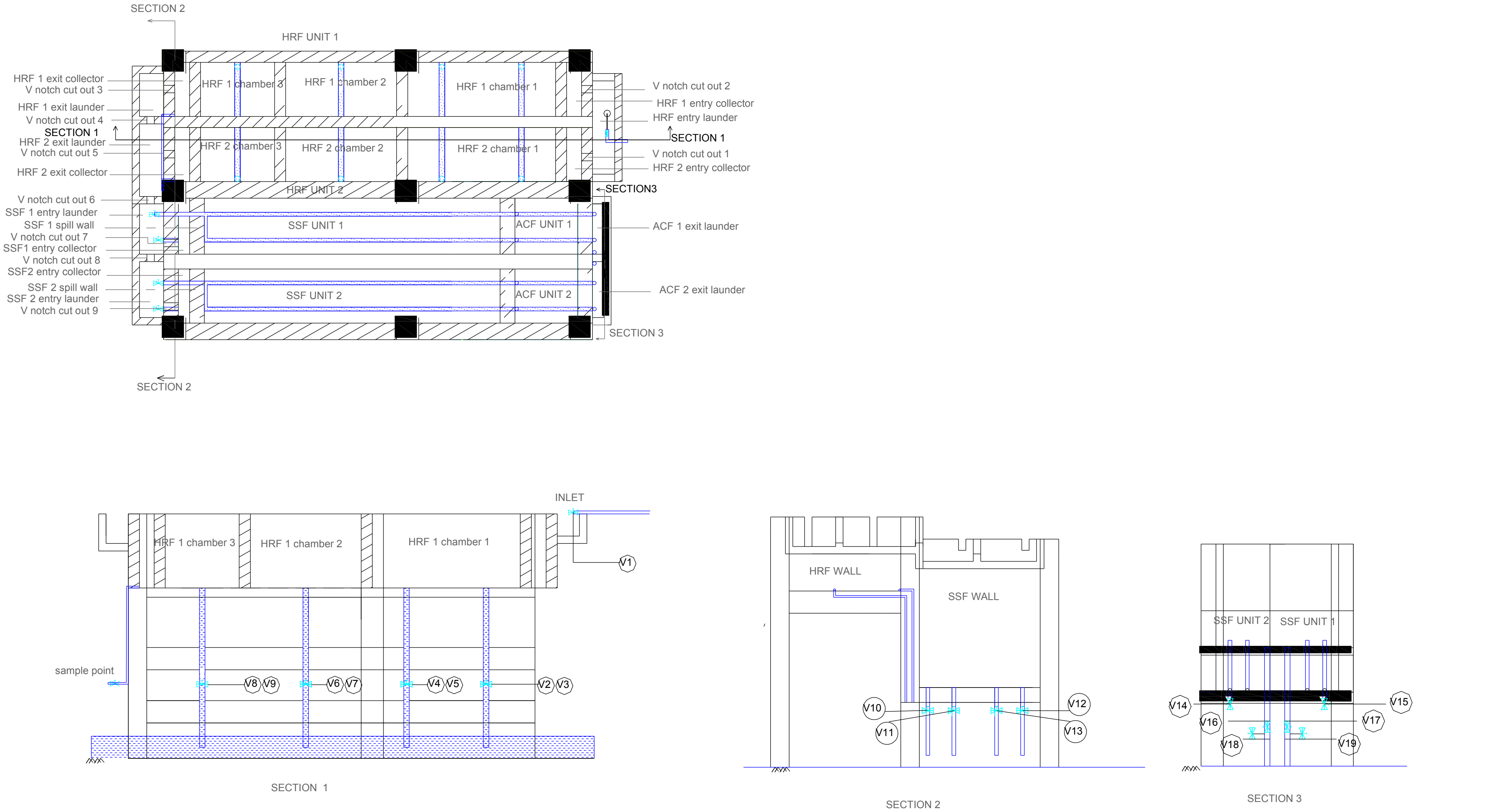



*Figure 134 pipes, drains, and launder details*




V1 HRF INLET VALVE TO CONTROL FILTRATION RATE

V2 V3

V4 V5 HRF 1 AND HRF 2 CHAMBER 1 BACKWASH VALVE RESPECTIVELY

V6 V7 HRF 1 AND HRF 2 CHAMBER 2 BACKWASH VALVE RESPECTIVELY

V8 V9 HRF 1 AND HRF 2 CHAMBER 3 BACKWASH VALVE RESPECTIVELY

V10 SSF 1 EMPTYING VALVE TO EMPTY OUT WATER FROM SSF 1

V11 SSF1 SPILL CHAMBER VALVE

V12 SSF 2 EMPTYING VALVE TO EMPTY OUT WATER FROM SSF 2

V13 SSF2 SPILL CHAMBER VALVE

V14 V15 ACF 2 AND ACF 1 EMPTYING OUT VALVE TO EMPTY ACF CHAMBERS

V16 V17 ACF 2 AND ACF 1 CLEAR WATER VALVE TO ENTER OR EXIT THE CWT

V18 V19 ACF 2 AND ACF 1 DRAIN OUT VALVE FROM EXIT LAUNDER

***Figure 135 Numbering of all valves***

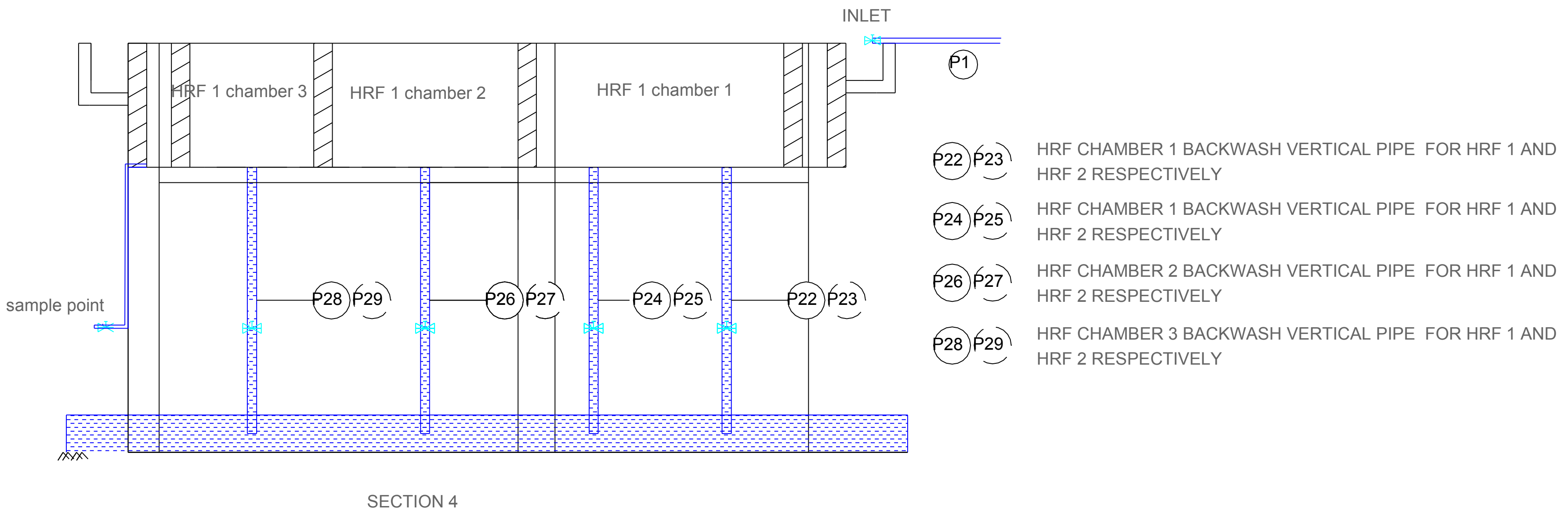



*Figure 136 Number of pipes 1/3*

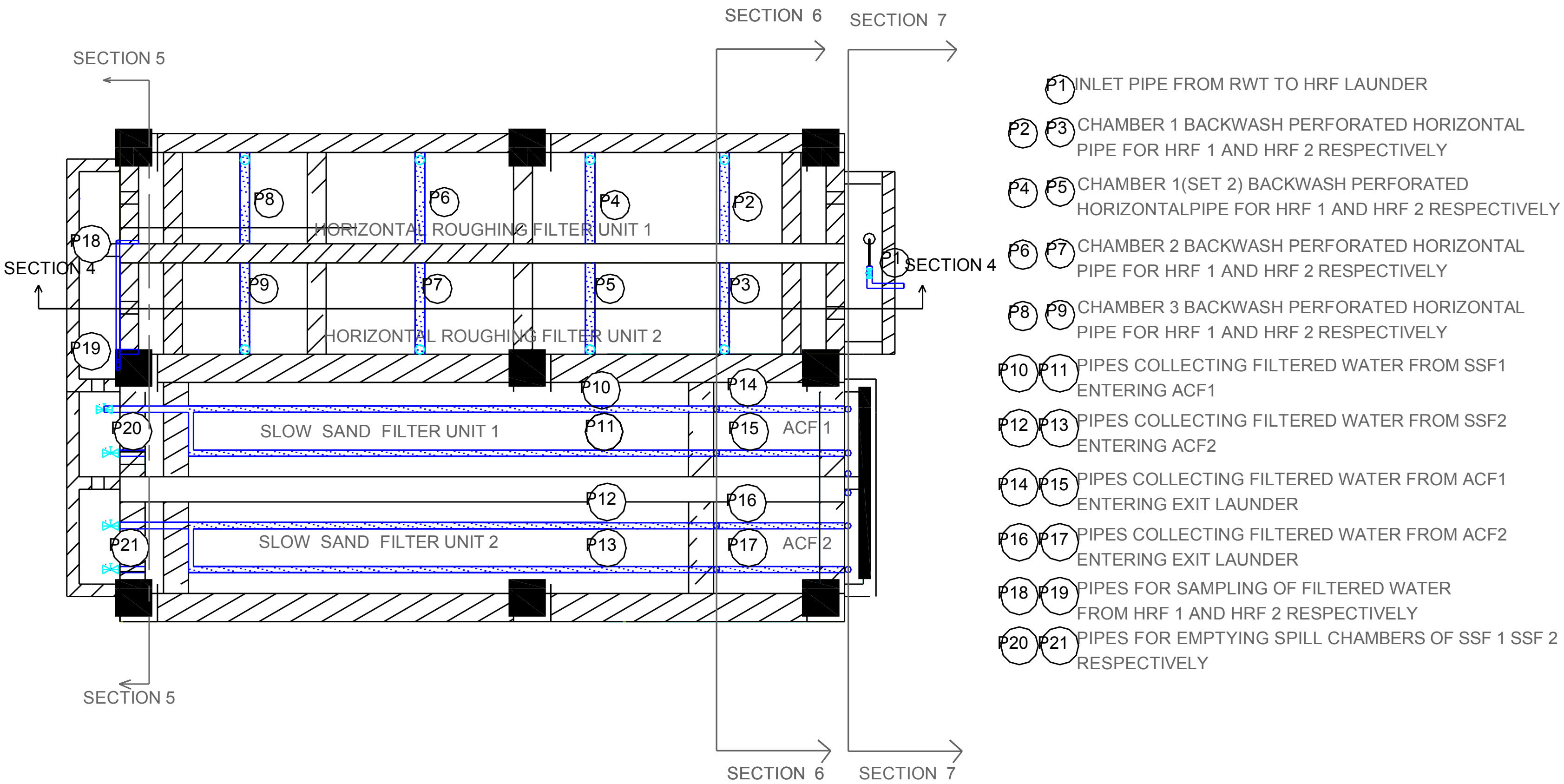
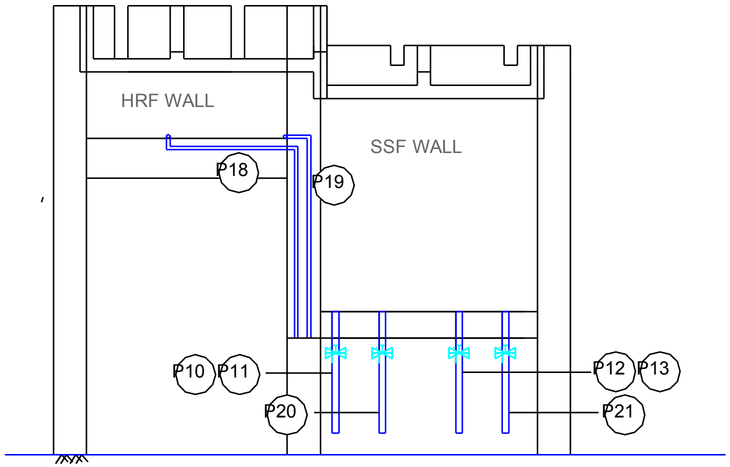
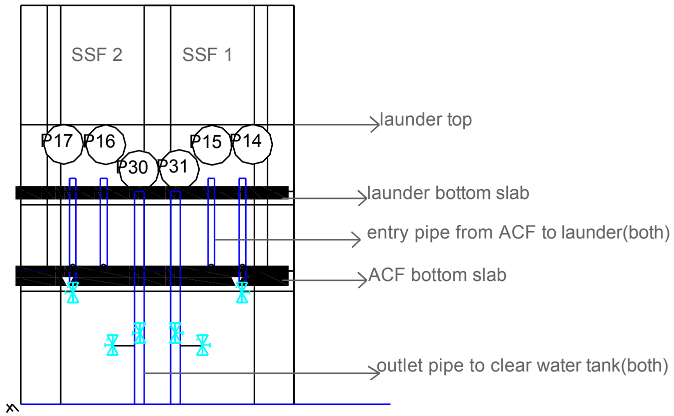


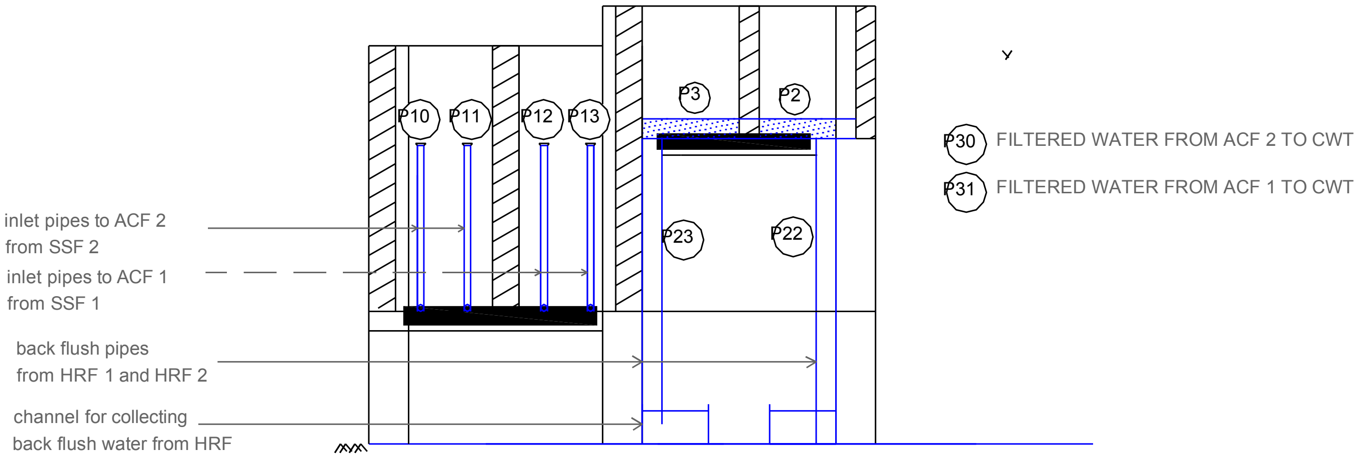

*Figure 137 Number of pipes 2/3*




SECTION 5




SECTION 7




SECTION 6

*Figure 138 Number of pipes 3/3*

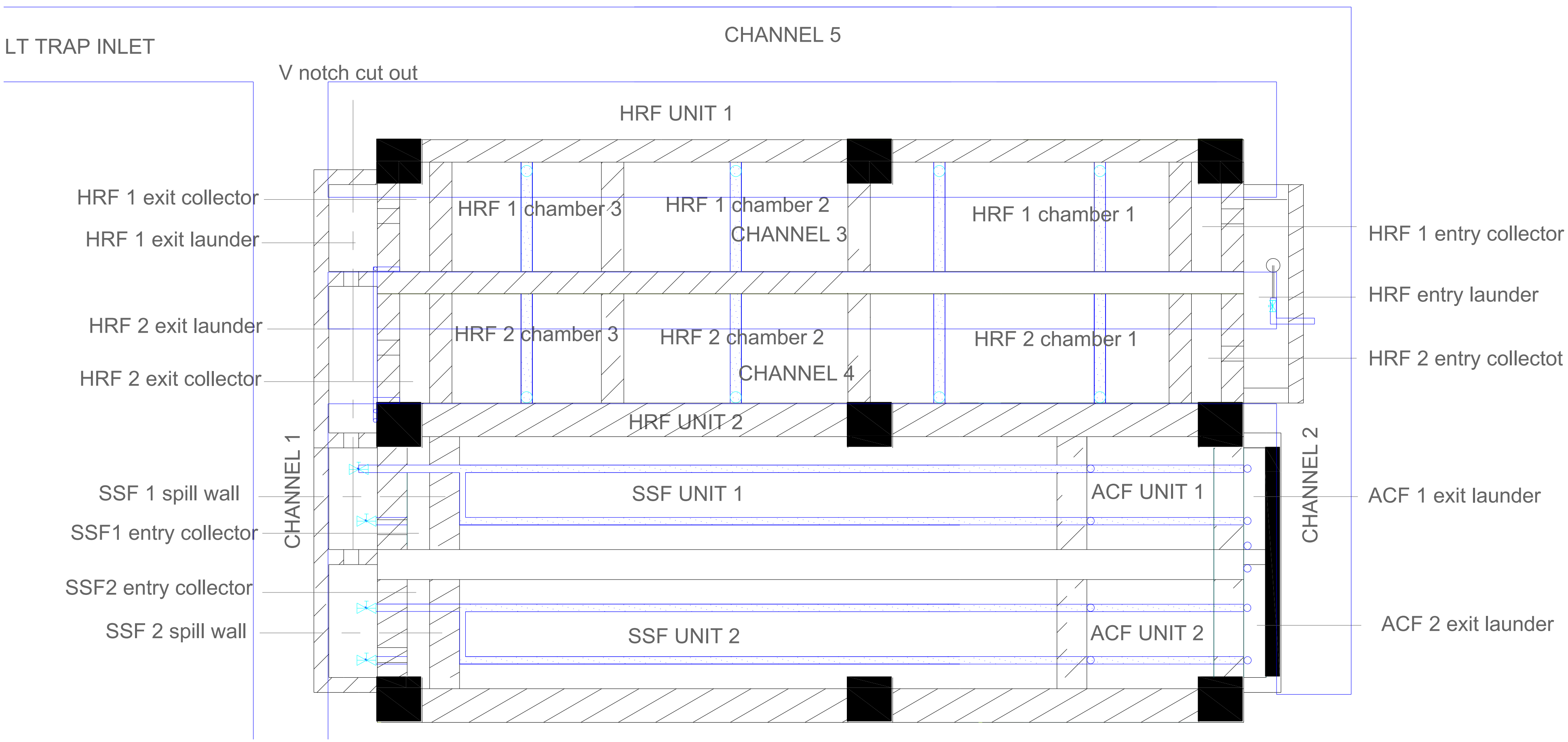



*Figure 139 Naming and numbering of chambers and channels*

steel structure over the whole top of the filter starting with 1m height on the south side and havig an angle of 23° towards the back side thus with 3.9m length the back side would have an elevation of 2.65m and we have a total structure area for the solar cells of 4.27x5.8m. We could thus keep around 25m² of solar cells which would be could be sufficient for our project (considering 100W per m² and our necessity of 2400Wp)

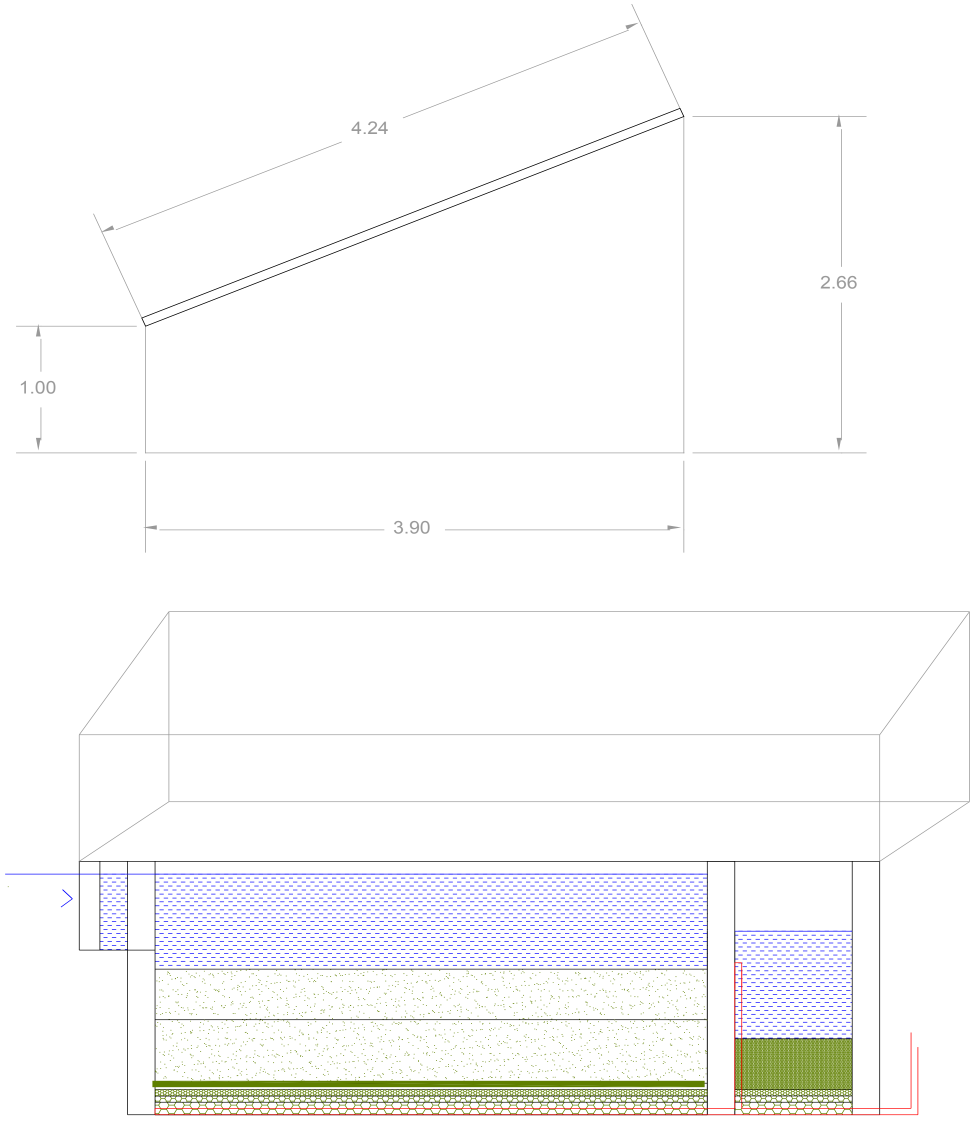



*Figure 140 Sketch with dimensions of the solar PV structure*

## FILTER MATERIAL

*Table 32 Measurement of the porosity of the HRF filter media*

| Material | Size | Volume of fluid [L] | Bulk volume of material [L] | Porosity(in %) |
|---|---|---|---|---|
| | | | | |
| Stone chips | 15-20 mm | 2 | 5 | 40.00 |
| Stone chips | 10-15 mm | 2.2 | 5 | 44.00 |
| Stone chips | 5-10 mm | 2.4 | 5 | 48.00 |
| | | | | |
| Gravel | 15-20 mm | 1.7 | 5 | 34.00 |
| Gravel | 10-15 mm | 1.8 | 5 | 36.00 |
| Gravel | 5-10 mm | 2 | 5 | 40.00 |

*Table 33 Results of sieve ananlysis of the SSF sand*

| | ssf1 | ssf2 |
|---|---|---|
| d60 [mm] | 0.52 | 0.55 |
| d10 [mm] | 0.21 | 0.205 |
| U coeff. | 2.48 | 2.68 |

## REEDBEDFILTER

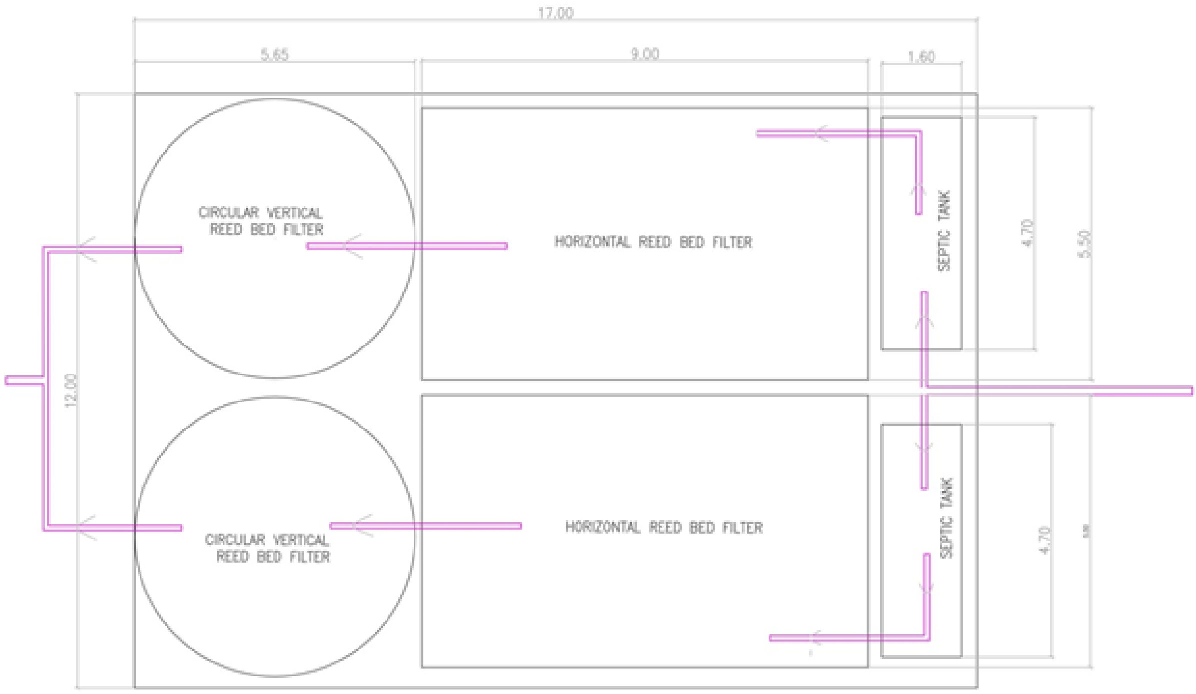



*Figure 141 Top view of components of the reedbedfilter designed for 100 people*

## L. POND VOLUME CALCULATIONS

*Table 34 Pond volume and amount of excavation with deepening of the pond*

| depth | length 1 | length 2 | width 1 | width 2 | area | volume | remarks |
|---|---|---|---|---|---|---|---|
| **initial situation** | | | | | | | |
| 0 | 50 | 61 | 27 | 47 | 2053,50 | | |
| | | | | | | | |
| 1 | 48 | 59 | 25 | 45 | 1872,50 | 1940,38 | |
| | | | | | | | |
| 3,5 | 36,55 | 39,51 | 11,37 | 17,37 | 546,49 | 3653,11 | |
| Total | | | | | | 5593,48 | total initial volume |
| | | | | | | | |
| **after excavation and elevation of bunds** | | | | | | | |
| | | | | | | | |
| 0 | 52 | 63 | 28 | 47 | 2156,25 | | |
| | | | | | | | |
| 1,5 | 49 | 60 | 25 | 44 | 1880,25 | 2975,63 | |
| | | | | | | | |
| 4,3 | 36,55 | 39,51 | 11,37 | 17,37 | 546,49 | 4500,60 | |
| Total | | | | | | 7476,22 | new volume |
| | | | | | | | |
| **total excavation** | | | | | | **1882,74** | difference |

*Table 35 Calculation of catchment inflow and pond storage with 5 year average precipitation and 20KLD*

as per 5 year average | pond area 2156 | catchment area 25000,00 | demand 20 | k 0,34

| Months | prep. (mm) | Evapo (mm) | infiltr (1mm/day) | net storage from prep. Over pond (cu.m) | Demand (average 20cu.m/day) | Runoff received after losses (mm) | Flood water contribution from (cu.m) (20,000m² catchment) | Storage Change | storage w/o GW (max. size 7476 m³) | GW infiltration | Final Storage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 2 | 62 | 31 | -196,196 | 620 | 0 | 0 | -816,196 | 4328,24 | 0 | 4328,24 |
| Feb | 13 | 84 | 28 | -213,444 | 560 | 0 | 0 | -773,444 | 3554,79 | 0 | 3554,79 |
| Mar | 21 | 155 | 31 | -355,74 | 620 | 0 | 0 | -975,74 | 2579,05 | 210,474 | 2789,53 |
| Apr | 33 | 210 | 30 | -446,292 | 600 | 0 | 0 | -1046,292 | 1743,23 | 628,383 | 2371,62 |
| May | 104 | 217 | 31 | -310,464 | 620 | 0 | 0 | -930,464 | 1441,15 | 779,4235 | 2220,58 |
| Jun | 287 | 180 | 30 | 166,012 | 600 | 166,012 | 1411,102 | 977,114 | 3197,69 | 0 | 3197,69 |
| Jul | 278 | 155 | 31 | 198,352 | 620 | 198,352 | 1685,992 | 1264,344 | 4462,03 | 0 | 4462,03 |
| Aug | 281 | 124 | 31 | 271,656 | 620 | 271,656 | 2309,076 | 1960,732 | 6422,77 | 0 | 6422,77 |
| Sep | 284 | 90 | 30 | 353,584 | 600 | 353,584 | 3005,464 | 2759,048 | 7476,00 | 0 | 7476,00 |
| Oct | 95 | 93 | 31 | -62,524 | 620 | 0 | 0 | -682,524 | 6793,48 | 0 | 6793,48 |
| Nov | 1 | 90 | 30 | -256,564 | 600 | 0 | 0 | -856,564 | 5936,91 | 0 | 5936,91 |
| Dec | 13 | 62 | 31 | -172,48 | 620 | 0 | 0 | -792,48 | 5144,43 | 0 | 5144,43 |
| Total | 1412 | 1522 | 365 | -1024,1 | 7300 | 989,604 | 8411,634 | 87,534 | | | |

*Table 36Calculation of catchment inflow and pond storage with actual precipitation and 20KLD*

| if used 2015/16 | | | pond area | 2156 | catchment area | 25000,00 | demand | 20 | k | | 0,34 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | prep. (mm) | Evapo (mm) | infiltr (1mm/day) | net storage from prep. Over pond (cu.m) | Demand (average 20cu.m/day) | Runoff received after losses (mm) | Flood water contribution from (cu.m) (20,000m² catchment) | Storage Change | storage w/o GW (max. size 7476 m³) | GW infiltration | Calculated Final Storage | |
| Jan | 1 | 62 | 31 | -198,352 | 620 | 0 | 0 | -818,352 | 4134,20 | 0 | 4134,20 | |
| Feb | 104 | 84 | 28 | -17,248 | 560 | 0 | 0 | -577,248 | 3556,95 | 0 | 3556,95 | |
| Mar | 146 | 155 | 31 | -86,24 | 620 | 0 | 0 | -706,24 | 2850,71 | 74,646 | 2925,35 | |
| Apr | 0 | 210 | 30 | -517,44 | 600 | 0 | 0 | -1117,44 | 1807,91 | 596,043 | 2403,96 | |
| May | 33 | 217 | 31 | -463,54 | 620 | 0 | 0 | -1083,54 | 1320,42 | 839,7915 | 2160,21 | |
| Jun | 224 | 180 | 30 | 30,184 | 600 | 30,184 | 256,564 | -313,252 | 1846,96 | 576,52175 | 2423,48 | |
| Jul | 1033 | 155 | 31 | 1826,132 | 620 | 1826,132 | 15522,122 | 16728,254 | 7476 | 0 | 7476,00 | |
| Aug | 228 | 124 | 31 | 157,388 | 620 | 157,388 | 1337,798 | 875,186 | 7476 | 0 | 7476,00 | |
| Sep | 189 | 90 | 30 | 148,764 | 600 | 148,764 | 1264,494 | 813,258 | 7476 | 0 | 7476,00 | |
| Oct | 15 | 93 | 31 | -235,004 | 620 | 0 | 0 | -855,004 | 6621,00 | 0 | 6621,00 | |
| Nov | 0 | 90 | 30 | -258,72 | 600 | 0 | 0 | -858,72 | 5762,28 | 0 | 5762,28 | |
| Dec | 5 | 62 | 31 | -189,728 | 620 | 0 | 0 | -809,728 | 4952,55 | 0 | 4952,55 | |
| Total | 1978 | 1522 | 365 | 196,196 | 7300 | 2162,468 | 18380,978 | 11277,174 | | | | |

*Table 37 Calculation of catchment inflow and pond storage with actual precipitation in 2015/16 and actual water usage of approx. 4KLD*

| real 2015/16 | | | pond area | 2156 | catchment area | 25000,00 | demand | 4 | k | 0,34 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Months | prep. (mm) | Evapo (mm) | infiltr (1mm/day) | net storage from prep. Over pond (cu.m) | Demand (average 20cu.m/day) | Runoff received after losses (mm) | Flood water contribution from (cu.m) (20,000m² catchment) | Storage Change | storage w/o GW (max. size 7476 m³) | GW infiltration | Calculated Final Storage |
| Jan | 1 | 62 | 31 | -198,352 | 124 | 0 | 0 | -322,352 | 6102,20 | 0 | 6102,20 |
| Feb | 104 | 84 | 28 | -17,248 | 224 | 0 | 0 | -241,248 | 5860,95 | 0 | 5860,95 |
| Mar | 146 | 155 | 31 | -86,24 | 248 | 0 | 0 | -334,24 | 5526,71 | 0 | 5526,71 |
| Apr | 0 | 210 | 30 | -517,44 | 240 | 0 | 0 | -757,44 | 4769,27 | 0 | 4769,27 |
| May | 33 | 217 | 31 | -463,54 | 124 | 0 | 0 | -587,54 | 4181,73 | 0 | 4181,73 |
| Jun | 224 | 180 | 30 | 30,184 | 120 | 30,184 | 256,564 | 166,748 | 4348,48 | 0 | 4348,48 |
| Jul | 1033 | 155 | 31 | 1826,132 | 124 | 1826,132 | 15522,122 | 17224,254 | 7476 | 0 | 7476,00 |
| Aug | 228 | 124 | 31 | 157,388 | 124 | 157,388 | 1337,798 | 1371,186 | 7476 | 0 | 7476,00 |
| Sep | 189 | 90 | 30 | 148,764 | 120 | 148,764 | 1264,494 | 1293,258 | 7476 | 0 | 7476,00 |
| Oct | 15 | 93 | 31 | -235,004 | 124 | 0 | 0 | -359,004 | 7117,00 | 0 | 7117,00 |
| Nov | 0 | 90 | 30 | -258,72 | 120 | 0 | 0 | -378,72 | 6738,28 | 0 | 6738,28 |
| Dec | 5 | 62 | 31 | -189,728 | 124 | 0 | 0 | -313,728 | 6424,55 | 0 | 6424,55 |
| Total | 1978 | 1522 | 365 | 196,196 | 1816 | 2162,468 | 18380,978 | 16761,174 | | | |

*Table 38 Calculation of catchment inflow and pond storage with actual precipitation in 2015/16 and 28KLD*

If strong use 2015/16 pond area 2156 catchment area 25000,00 demand 28 k 0,34

| Months | prep. (mm) | Evapo (mm) | infiltr (1mm/day) | net storage from prep. Over pond (cu.m) | Demand (average 20cu.m/day) | Runoff received after losses (mm) | Flood water contribution from (cu.m) (20,000m² catchment) | Storage Change | storage w/o GW (max. size 7476 m³) | GW infiltration | Calculated Final Storage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | 62 | 31 | -198,352 | 868 | 0 | 0 | -1066,352 | 3150,20 | 0 | 3150,20 |
| Feb | 104 | 84 | 28 | -17,248 | 784 | 0 | 0 | -801,248 | 2348,95 | 325,526 | 2674,47 |
| Mar | 146 | 155 | 31 | -86,24 | 868 | 0 | 0 | -954,24 | 1720,23 | 639,883 | 2360,12 |
| Apr | 0 | 210 | 30 | -517,44 | 840 | 0 | 0 | -1357,44 | 1002,68 | 998,6615 | 2001,34 |
| May | 33 | 217 | 31 | -463,54 | 868 | 0 | 0 | -1331,54 | 669,80 | 1165,10075 | 1834,90 |
| Jun | 224 | 180 | 30 | 30,184 | 840 | 30,184 | 256,564 | -553,252 | 1281,65 | 859,176375 | 2140,82 |
| Jul | 1033 | 155 | 31 | 1826,132 | 868 | 1826,132 | 15522,122 | 16480,254 | 7476 | 0 | 7476,00 |
| Aug | 228 | 124 | 31 | 157,388 | 868 | 157,388 | 1337,798 | 627,186 | 7476 | 0 | 7476,00 |
| Sep | 189 | 90 | 30 | 148,764 | 840 | 148,764 | 1264,494 | 573,258 | 7476 | 0 | 7476,00 |
| Oct | 15 | 93 | 31 | -235,004 | 868 | 0 | 0 | -1103,004 | 6373,00 | 0 | 6373,00 |
| Nov | 0 | 90 | 30 | -258,72 | 840 | 0 | 0 | -1098,72 | 5274,28 | 0 | 5274,28 |
| Dec | 5 | 62 | 31 | -189,728 | 868 | 0 | 0 | -1057,728 | 4216,55 | 0 | 4216,55 |
| Total | 1978 | 1522 | 365 | 196,196 | 10220 | 2162,468 | 18380,978 | 8357,174 | | | |

## M. REGULAR CHECKLIST FOR TREATMENT PROCESS MONITORING

*Table 39 Checklist for daily performance monitoring of the entire treatment process used by the water committee*

| REGULAR CHECKLIST TREATMENT PROCESS | | | | | | |
|---|---|---|---|---|---|---|
| **INSIDE PUMPHOUSE** | | | | | | |
| **Parameter** | **IS** | **CHANGE / REMEDY** | **REMARKS** | **unit** | **criteria for ok** | **remarks** |
| **Date** | | | | **DD/MM/YYYY** | | |
| **time of assessment** | | | | **HH/MM [24h format]** | | |
| **Name of Assesssor** | | | | | | |
| **offline monitoring of instrument check list** | | | | | | |
| all pumps are working ok | | | | [yes(√)/no(X)] | both tanks have at least 50% water | |
| grid power | | | | [yes(√)/no(X)] | on | meter has display, LED blinking (slowly) |
| Cumulative Active Energy | | | | [kWh] | | meter display: 5. kWh |
| Instant phase active power | | | | [kW] | | meter display: 13. PH: .. |
| solar inverter | | | | [yes(√)/no(X)] | on | |
| solar inverter has grid power | | | | [yes(√)/no(X)] | yes | inverter plug light, if off and grid on then check solar MCB |
| computer | | | | [on/off] | on | |
| internet on | | | | [on/off] | on | |
| online monitoring | | | | [on/off] | on | |
| turbiditymeter | | | | [on/off] | on | |
| flowmeter | | | | [on/off] | on | |
| pump controller | | | | [on/off] | on | |
| **turbidity sensor measuring unit** | | | | | | |
| Turbidity Sensor 1 is measuring: | | | | [SSF1/SSF2/OHT] | any | change after taking reading |
| WQ Turbidity | | | | [FNU] | | |
| Turbidity Sensor2 is measuring: | | | | [RWT/HRF1/HRF2] | any | change after taking reading |
| WQ Turbidity | | | | [FNU] | | |
| **tank status** | | | | | | |
| water level of RWT | | | | [0,25,50,75,100%] | at least 50% | possibly turn pump controller off to save current |
| water level of CWT | | | | [sump light on/off] | on | |
| water level of OHT | | | | [0,25,50,75,100%] | at least 25% | possibly turn pump controller off to save current |
| **treatment process observations** | | | | | | |
| Indicator RAW WQ in normal range | | | | [FNU] | RWT < 60NTU | if above 50, reduce to low flow rate |
| Indicator HRF WQ in normal range | | | | [FNU] | HRF < 20NTU | if above 18, reduce to low flow rate |
| Indicator SSF WQ in normal range | | | | [FNU] | HRF < 5NTU | if above 3, reduce to low flowrate |
| all flowrates are in CORRECT! range | | | | [yes/no] | as per below values | compare Turbidity values with flow rate (normal, low, max) |
| Flow time SSF 1 | | | | sec | normal: 12sec/L (5LPM, | normal 5lpm(12s), low 2lpm(30s), max up to 10lpm(6s), |
| Flow time SSF 2 | | | | sec | normal: 12sec/L (5LPM, | normal 5lpm(12s), low 2lpm(30s), max up to 10lpm(6s), |
| flow rate of ssf 1 IN CWT | | | | l/hr | | |
| flowrate of ssf 2 in CWT | | | | l/hr | | |
| total flow rate from ssf in cwt | | | | l/hr | | |
| time since last dosing | | | | hr | | |
| total flow of treated water since last dosing | | | | l | | |
| amount to be dosed per litre | | | | ml | | |
| type and amount of chlorine to be dosed | | | | ml | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **OUTSIDE PUMPHOUSE** | | | | | | |
| **Parameter** | | | | **unit** | **criteria for ok** | **remarks** |
| **Date** | | | | **DD/MM/YYYY** | | |
| **time of assessment** | | | | **HH/MM [24h format]** | | |
| **filter unit observations** | | | | | | |
| | | | | | | |
| water level HRF 1 input | | | | [cm] | less than 90cm | |
| water level HRF 2 input | | | | [cm] | less than 90cm | |
| water level HRF 1 output | | | | [cm] | more than 70 cm | |
| water level HRF 2 output | | | | [cm] | more than 70 cm | |
| headloss HRF 1(S) | | | | [cm] | | |
| headloss HRF 2(G) | | | | [cm] | | |
| water level SSF 1 | | | | [cm] | less than 170cm | |
| water level SSF 2 | | | | [cm] | less than 170cm | |
| water level ACF 1 | | | | [cm] | less than 120 cm | |
| water level ACF 2 | | | | [cm] | less than 120 cm | |
| SSF1 headloss | | | | | less than 40 | |
| SSF2headloss | | | | | less than 40 | |
| v notch level of SSF 1 input | | | | [cm] | | |
| v notch level of SSF 2 input | | | | [cm] | | |
| v notch level of HRF 1 output | | | | [cm] | | |
| v notch level of HRF 2 output | | | | [cm] | | |
| v notch level of HRF 1 input | | | | [cm] | | |
| v notch level of HRF 2 input | | | | [cm] | | |
| Flowrate RWT - HRF 1+2 | | | | sec /1L /LPM/LPH | CWT-HRF ~6sec/1L (600LPH, 10LPM) | normal 10lpm(6s), low 4lpm(15s), max up to 20lpm(3s), |
| HRF Input launder has algea | | | | [yes/no] | no | if yes, remove algea |
| HRF Output launder has algea | | | | [yes/no] | no | if yes, remove algea |
| SSF Input launder has algea | | | | [yes/no] | no | if yes, remove algea |
| SSF units have swimming algea | | | | [yes/no] | no | if yes, remove algea |
| **container Observation** | | | | | | |
| container has power | | | | | | |
| Ecasol power green | | | | [yes/no] | yes | if red(error) restart |
| Ecasol tank level | | | | **low/mid/hig** | mid | if lower restart system |
| AFM powered and UPS light on | | | | | | |
| **maintanace checklist** | | | | | | |
| last date of backwash HRF 1 | | | | DD/MM/YYYY | | |
| last date of backwash HRF 2 | | | | DD/MM/YYYY | | |
| | | | | | | |
| level of Sand SSF 1 | | | | [cm] | | |
| last date of scrapping of SSF 1 | | | | DD/MM/YYYY | | |
| | | | | | | |
| level of Sand SSF 2 | | | | [cm] | | |
| last date of scrapping of SSF 2 | | | | DD/MM/YYYY | | |

## N. OFFLINE WATER QUALITY ASSESSMENT FORM

*Table 40 Assessment form for documenting offline water quality monitoring results from field test kit measurements*

| Offline WQ Assessment Form | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **unit** | | **Environment** | | | | **general remarks** | | | | | | | | |
| **Date** | **DD/MM/YYYY** | | | | | | only yellow fields are to be filled during a field testing day, the white | | | | | | | | |
| **time of sampling** | **HH/MM** | | | | | | fields are not important. This page is only for printig purpose, | | | | | | | | |
| **Monitoring by:** | [Name] | | | | | | the values will finally be inserted into the file: | | | | | | | | |
| **climate data** | | | | | | | filter assessment on water quality | | | | | | | | |
| air temp | [C] | | | | | | in the individual tabs for each parameter | | | | | | | | |
| last date of rain | [yes/no] | | | | | | | | | | | | | | |
| rain since last visit | [mm] | [little, lot?] | | | | | | | | | | | | | |
| cummulated precipitation | [mm] | | | | | | | | | | | | | | |
| pond water level | [cm] | | | | | | | | | | | | | | |
| Tubewell water depth | [m] | | | | | | | | | | | | | | |
| **monitored parameters:** | | | **Distilled** | **Pond** | **RWT** | **HRF1** | **HRF2** | **SSF1** | **SSF2** | **AFM** | **OHT** | **GW RW** | **GW CW** | **GW FW** | **remarks** |
| **Sample ID** | | | | | | | | | | | | | | | |
| pH value | [pH] | | | | | | | | | | | | | | |
| Turbidity | [NTU] | | | | | | | | | | | | | | |
| TDS | [mg/l] | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| ammonia | [mg/l] | | | | | | | | | | | | | | |
| chloride | [mg/l] | | | | | | | | | | | | | | |
| fluoride | [mg/l] | | | | | | | | | | | | | | |
| free residual chlorine | [mg/l] | | | | | | | | | | | | | | |
| iron | [mg/l] | | | | | | | | | | | | | | |
| nitrate | [mg/l] | | | | | | | | | | | | | | |
| total alkalinity | [mg/l] | | | | | | | | | | | | | | |
| total hardness | [mg/l] | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| Total arsenic | [mg/l] | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| E.Coli | [cells per 100ml]/[p/a] | | | | | | | | | | | | | | |
| TC | [cells per 100ml]/[p/a] | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| DO | [mg/l] | | | | | | | | | | | | | | |
| DO saturation | [%] | | | | | | | | | | | | | | |
| nitrite | [mg/l] | | | | | | | | | | | | | | |
| phosphate | [mg/l] | | | | | | | | | | | | | | |
| water temp | [C] | | | | | | | | | | | | | | |
| ORP | mV | | | | | | | | | | | | | | |
| conductivity | µS/cm | | | | | | | | | | | | | | |

## O. OFFLINE WATER QUALITY MONITORING RESULTS

Manual assessment of turbidity prior to online monitoring period shows average pond turbidity between 30 and 50 NTU between 2012 and 2015 which indicates that the beginning period of the SSF system had extraordinary high turbidity values during May to July 2015 which are not generally expected. The assessment also shows strong daily fluctuations during the daily assessment period mid-June to mid July 2015.

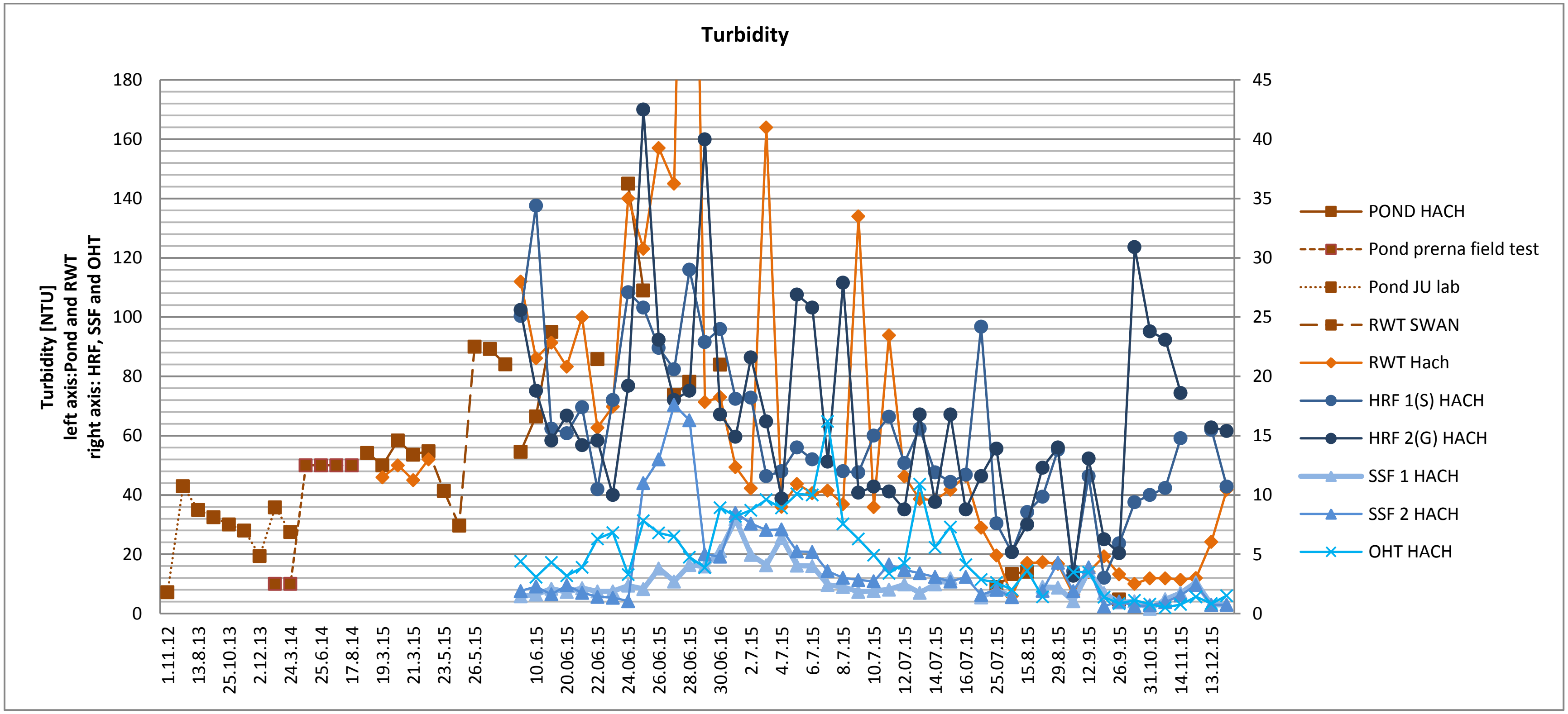



*Figure 142: Turbidity at various points of the treatment process (source: offline monitoring)*

Constantly highest oxygen levels fluctuating between 4 and 8 mg/l are found in the OHT samples. Only pond samples taken from the surface of the pond during daytime show higher values reaching up to 9 mg/l but also have lower values down to 2 mg/l. RWT samples tend to stay around 4 mg/l with fluctuations between 3 and 6 mg/l. Both HRF have quite similar values mostly between 2.5 to 4.5 with slightly higher values June month and lower values during July and August. Slow Sand Filter oxygen values fluctuate quite strongly between 2.5 to 7 mg/l with most values between 4.5 to 6 mg/l.

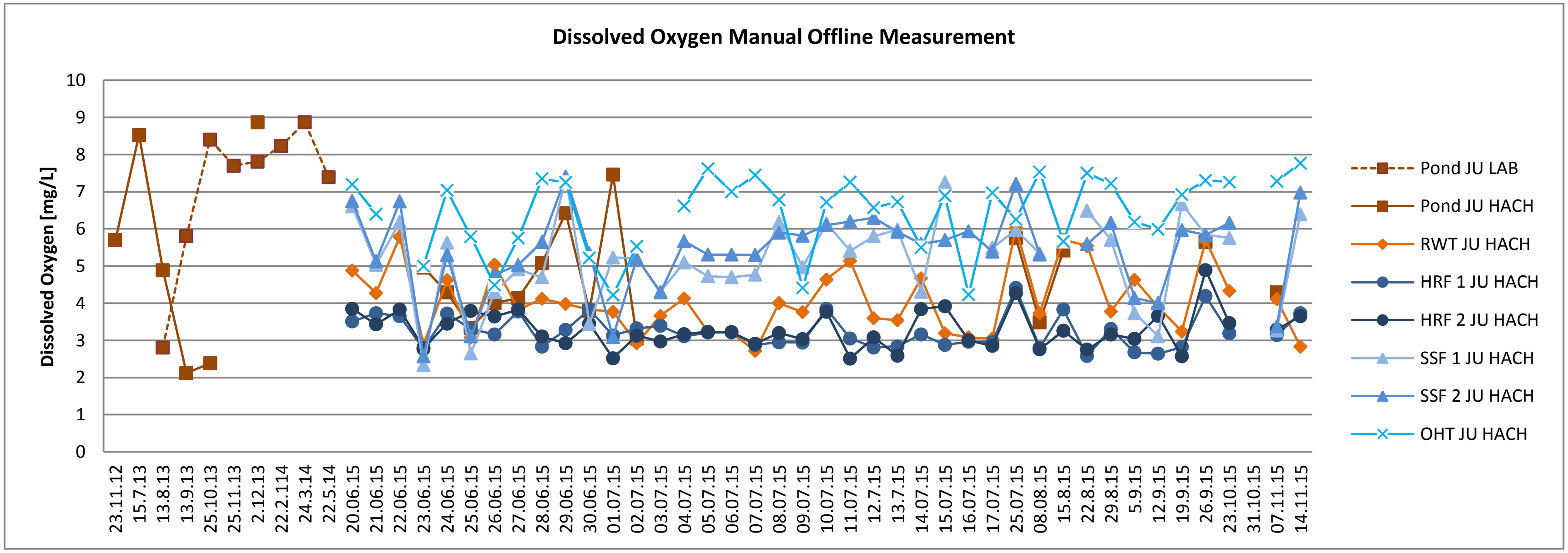



*Figure 143 offline dissolved oxygen measurements for entire project period*

Offline pH measurements show fluctuations of pH levels between 6.5 and 8.7 with a general tendency of increasing pH along the treatment process, with lowest values in the RWT and highest values in the OHT. High pH values in the OHT can be explained with the staying time of the water in concrete structures of the tanks in which the pH level might increase through the leeching of lime.

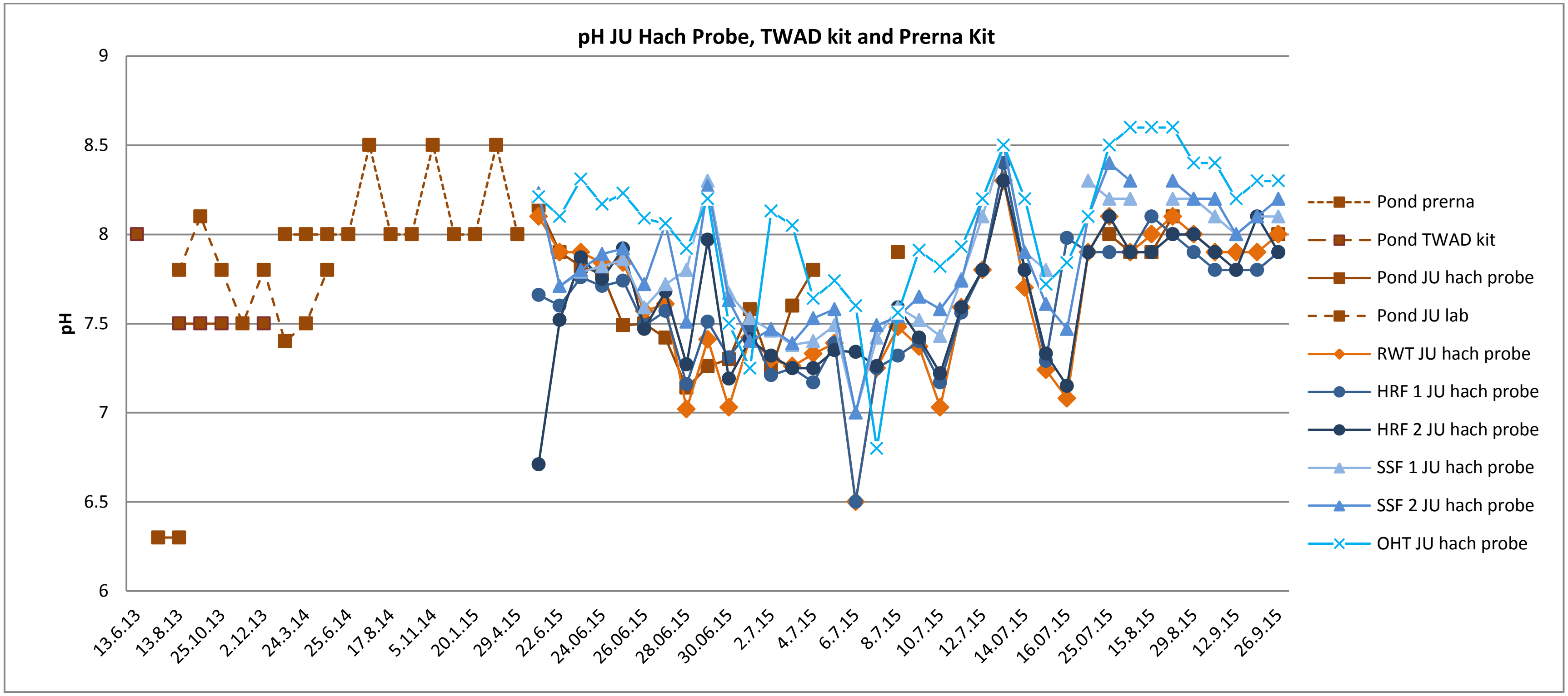



*Figure 144: offline pH measurement during the entire project period with Hach Probe*

The offline FAC measurements could not confirm the partly high online measurements. The initial dosing with the generated mixed oxidants did not lead to sufficient residual chlorine of 0.2mg/l which could be reflected by the missing reliable reduction of bacteria in the OHT water until beginning of November 2015. The usage of liquid chlorine as a disinfectant replacing the mixed oxidants and the bleaching powder shows high achievable FAC levels from beginning of November onwards which could finally lead to reliable reduction of bacteria.

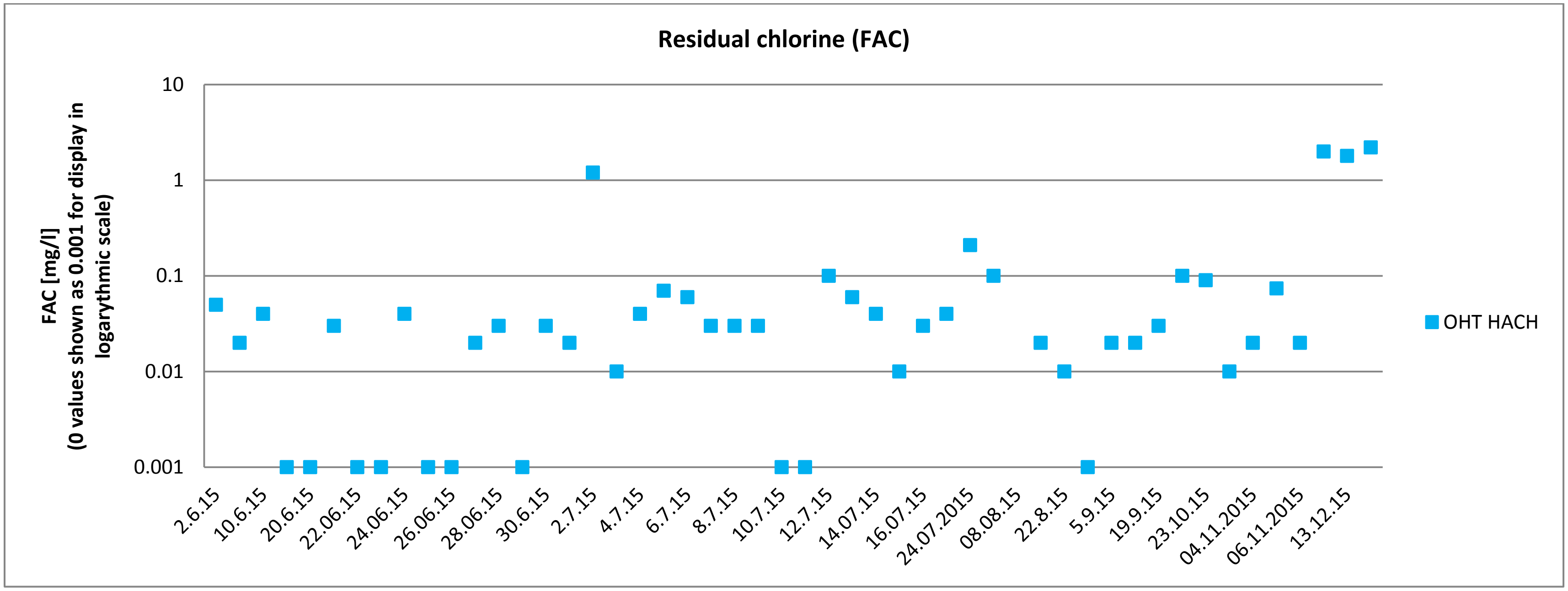



*Figure 145: Free available chlorine measurements in the OHT water (source: offline assessment)*

Ammonia levels measured with the simple TWAD field test kit indicate elevated levels especially of the raw water exceeding the acceptable and permissible limit of 0.5 mg/l. The measurements with the Hach Photometer though show lower levels of the OHT water within the standard around 0.1 mg/l. Still Raw Water and also SSF water levels partly exceed the standard and make this parameter a potential risk which should further be monitored.

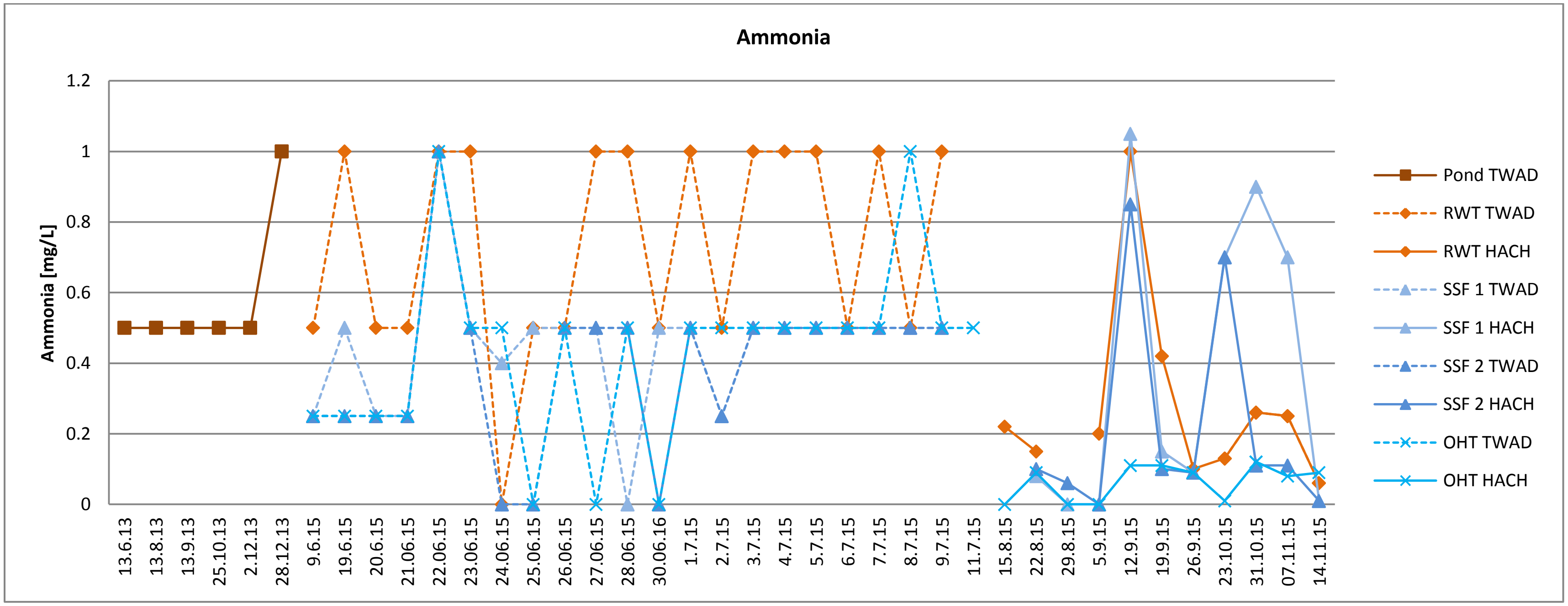



*Figure 146: Ammonia concentration at various treatment steps (source: offline monitoring)*

The high iron concentrations in the raw water partly reach 1.2 to 1.6 mg/l and can be removed down to 0.2 mg/l in general, with a few exception having slightly elevated levels exceeding the acceptable and permissible standards of 0.3mg/l.

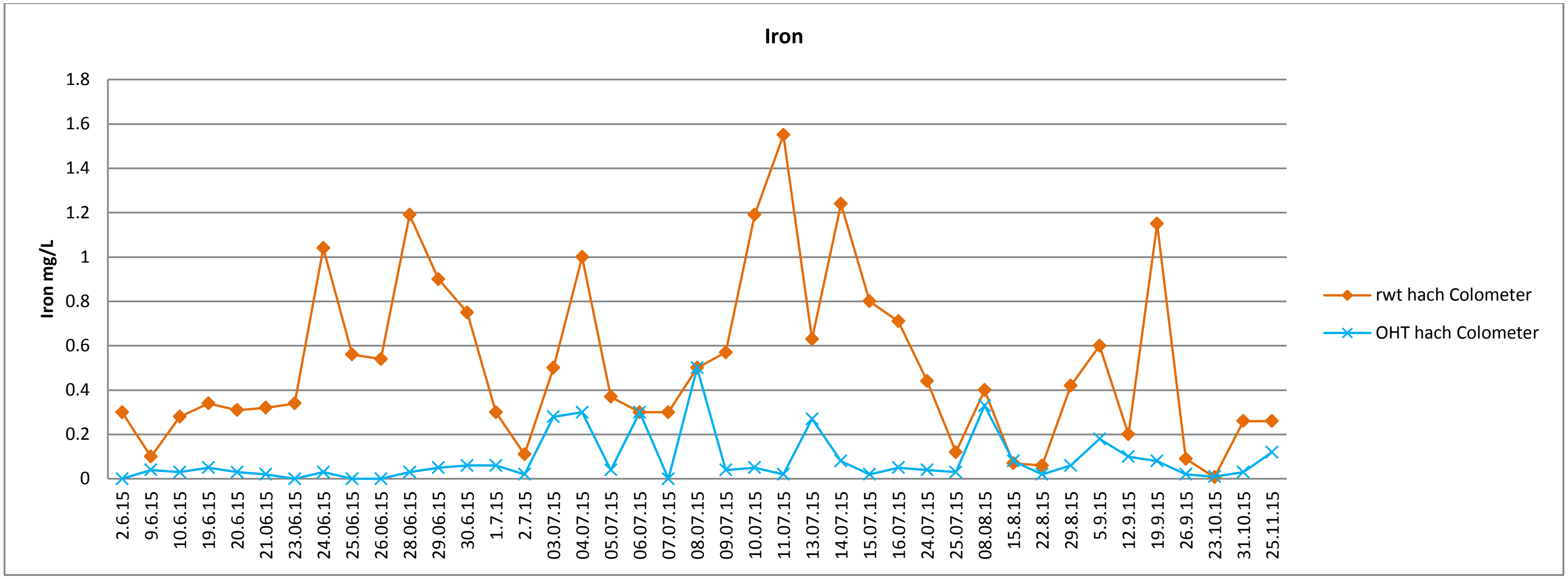



*Figure 147: Iron concentration in raw water and overhead tank (source: offline monitoring)*

The acceptable and permissible limit of nitrate was never exceeded in any of the treatment steps as per the Hach photometer readings. Only one measurement with the TWAD kit of the pond on June 13th 2013 showed an elevated level reaching the standard.

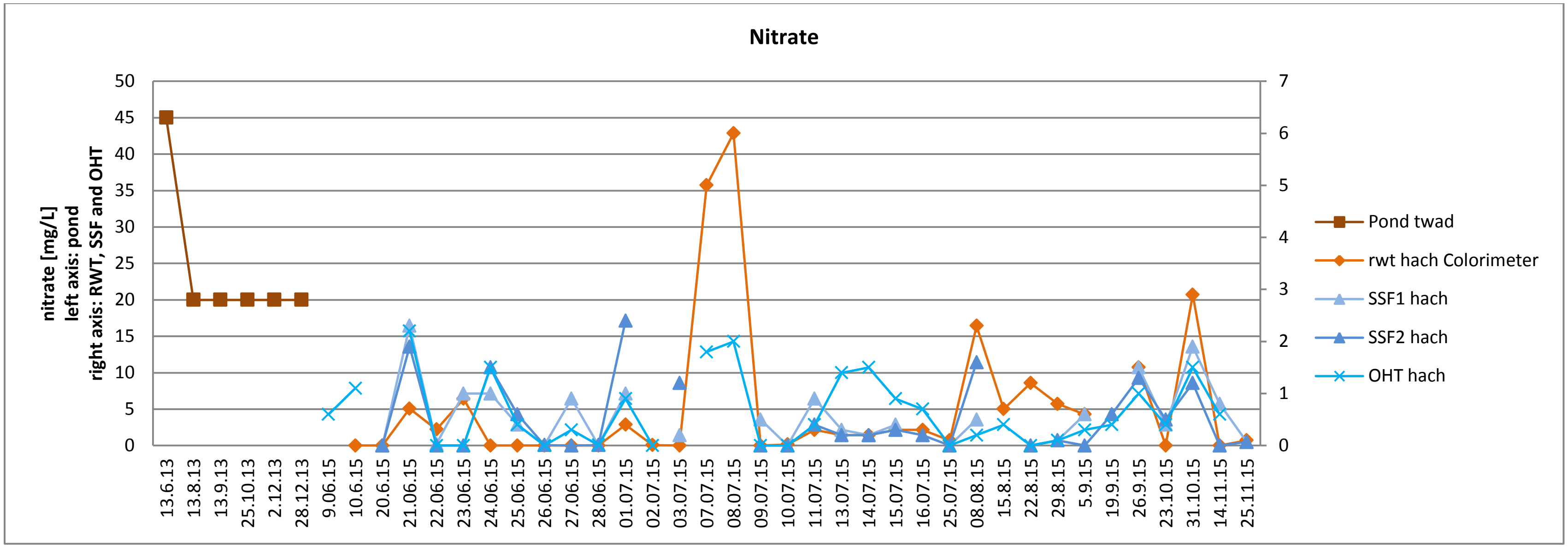



*Figure 148: Nitrate concentration at various treatment steps (source: offline monitoring)*

Acceptable limit of 200mg/l total alkalinity is almost constantly being exceeded with average values around 220 mg/l and even higher values in June 2015 of 270 mg/l. These though stay in the range of the permissible limit which is 600 mg/l.

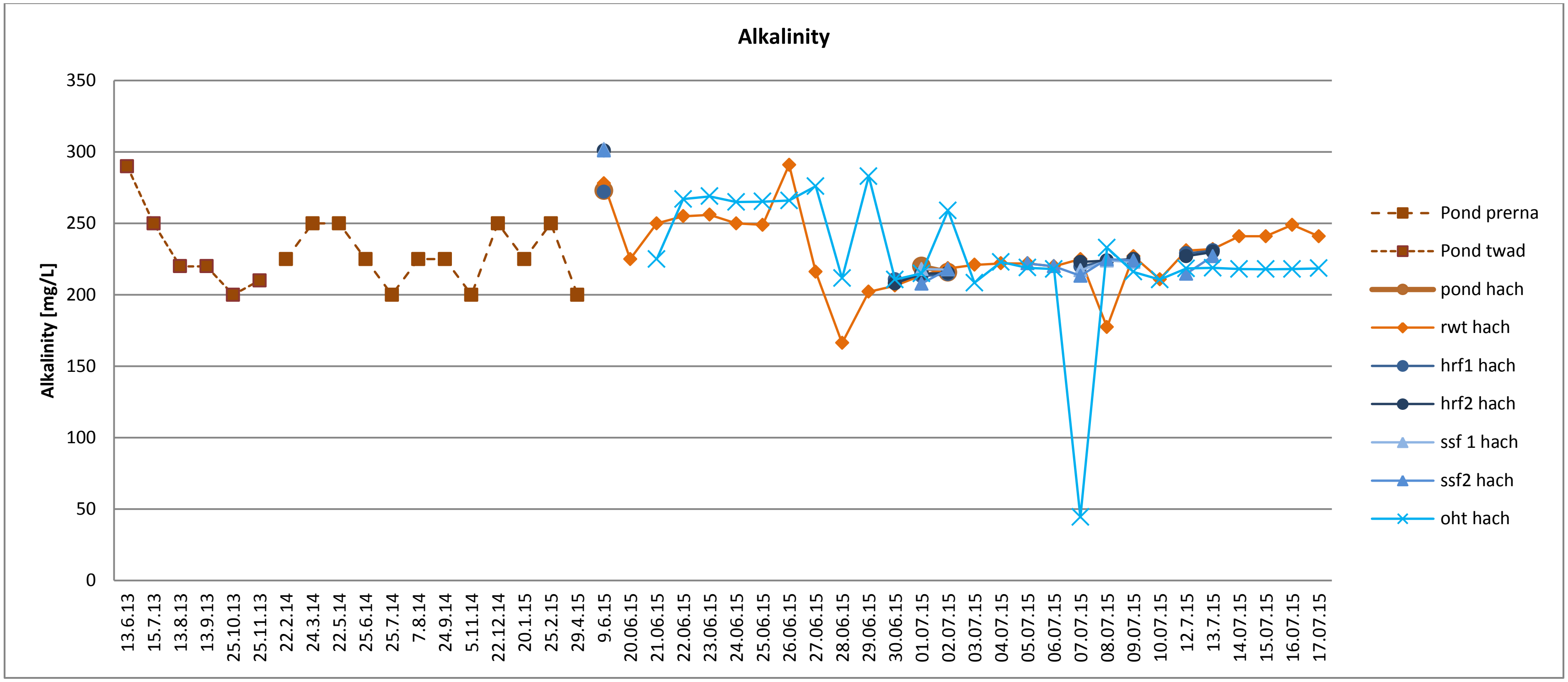



*Figure 149: Alkalinity concentrations at various points of the treatment process (source: offline monitoring)*

Permissible limit of 600mg/l hardness is never exceeded, tough the acceptable limit of 200 mg/l is reached twice and exceeded once (220 mg/l) by the OHT water.

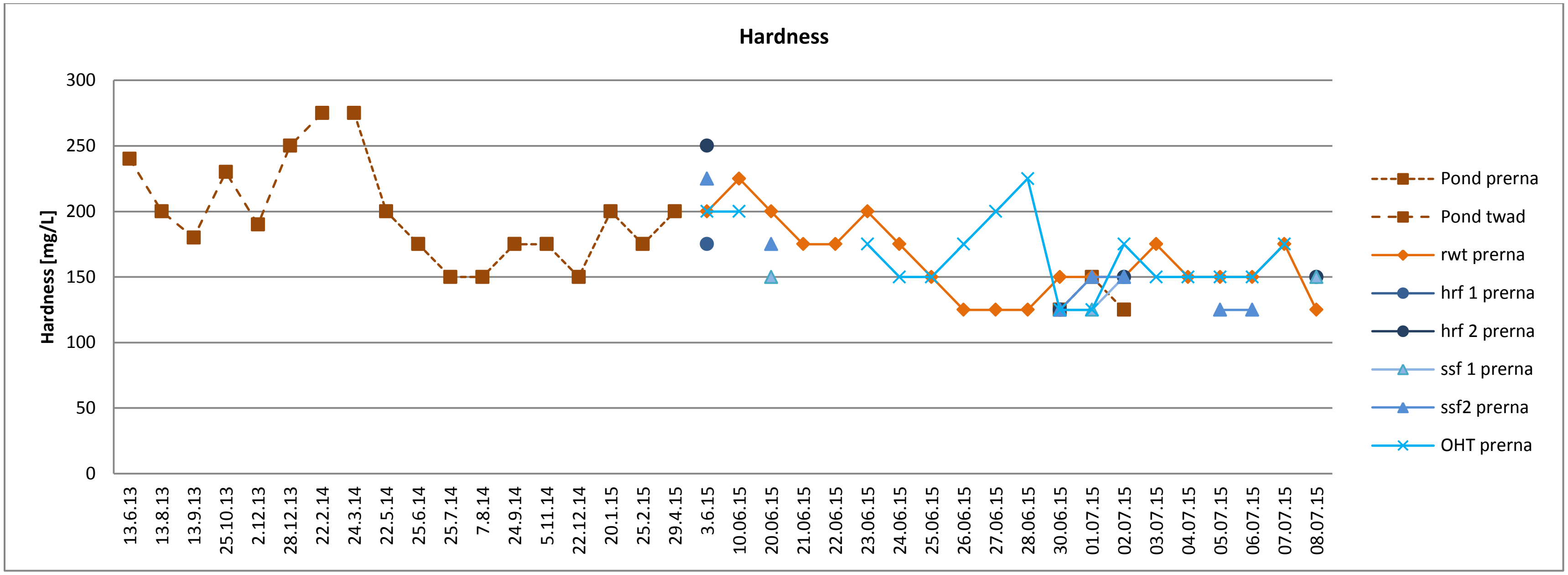



*Figure 150: Hardness at various points of the treatment process (source: offline monitoring)*

Unexpected high concentrations of arsenic could be measured in the process water, especially during end of July to October levels partly exceeded the acceptable limit of 0.01 mg/l and even reached the permissible limit of 0.05mg/l. Elevated levels during dry periods could be explained with the groundwater infiltrating into the pond, but it is surprising that elevated levels can again be observed in the monsoon and post monsoon period. Remobilisation of arsenic from the sludge is little probable due to constant aerobic conditions in the pond. Further comparably high levels of iron in the raw water could allow for co-precipitation of arsenic with oxidized iron.

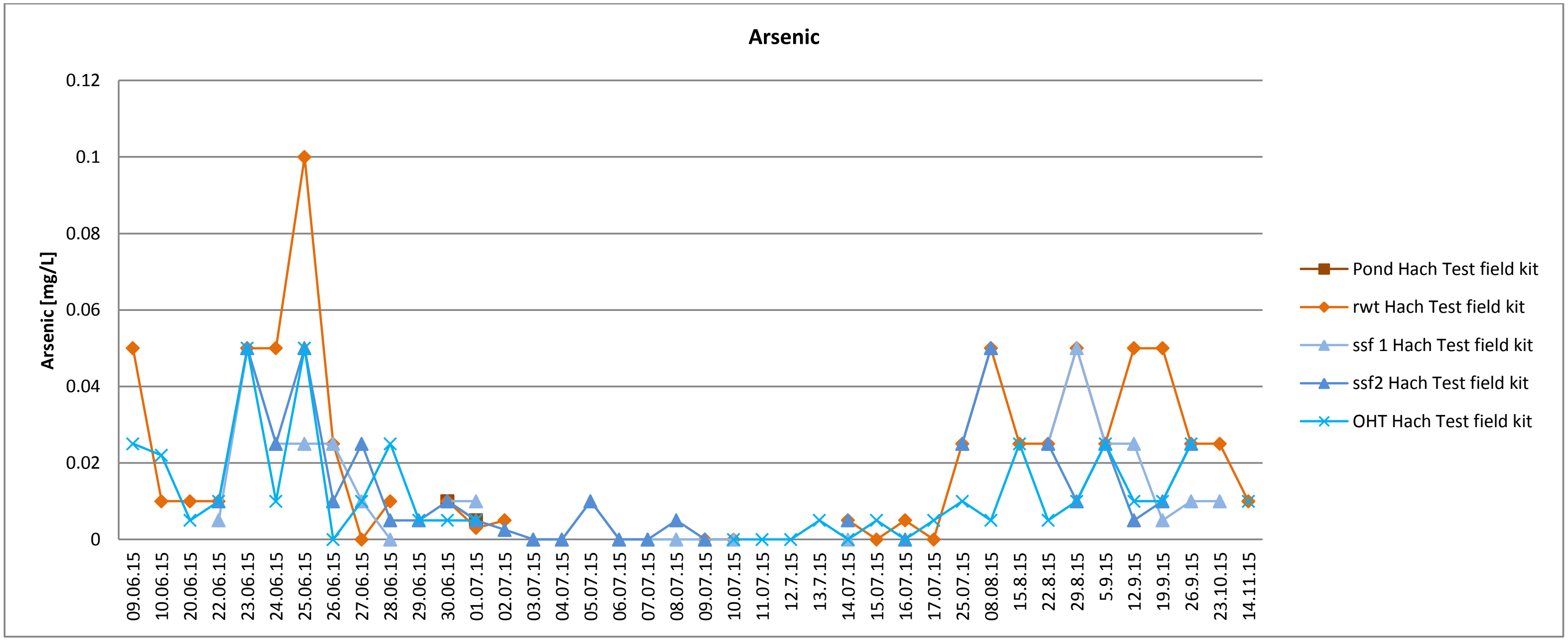


*Figure 151: Arsenic concentrations at various points of the treatment process (source: offline monitoring)*

Nitrite is not mentioned in IS10500, the WHO standard[176] is 3mg/l which is not exceeded in any of the samples. The very low values of max 0.15 in the raw water and max. 0.01 in the OHT water show that this parameter is not critical and does not need to be further monitored.

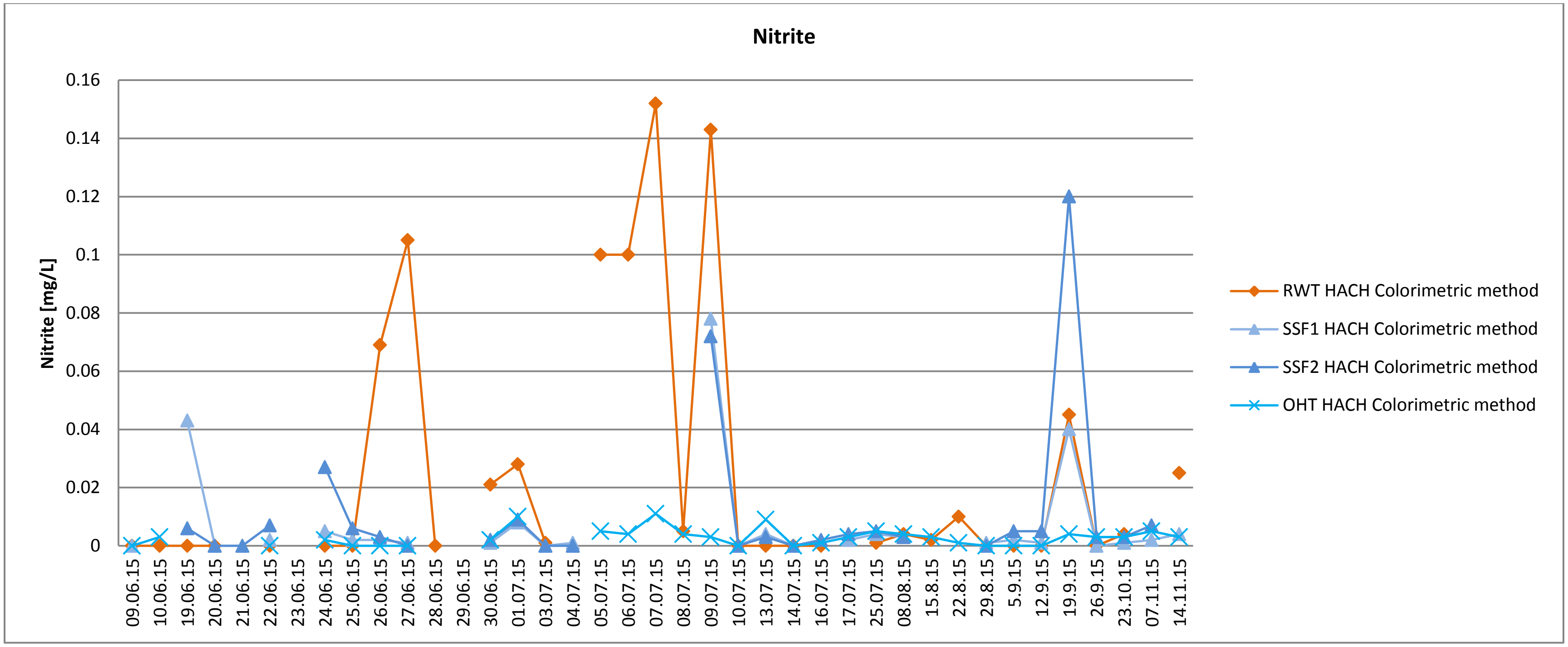



*Figure 152: Nitrite concentrations at various points of the treatment process (source: offline monitoring)*

Similar to nitrite, phosphate is not mentioned in IS10500 and also not in the WHO WQ guidelines. It is monitored as an indicator for nutrient inflow into the pond from the agricultural areas in the catchment. Phosphate is further the limiting nutrient for the growth of algae which lead to faster clogging of the SSF and thus shorter scraping intervals.

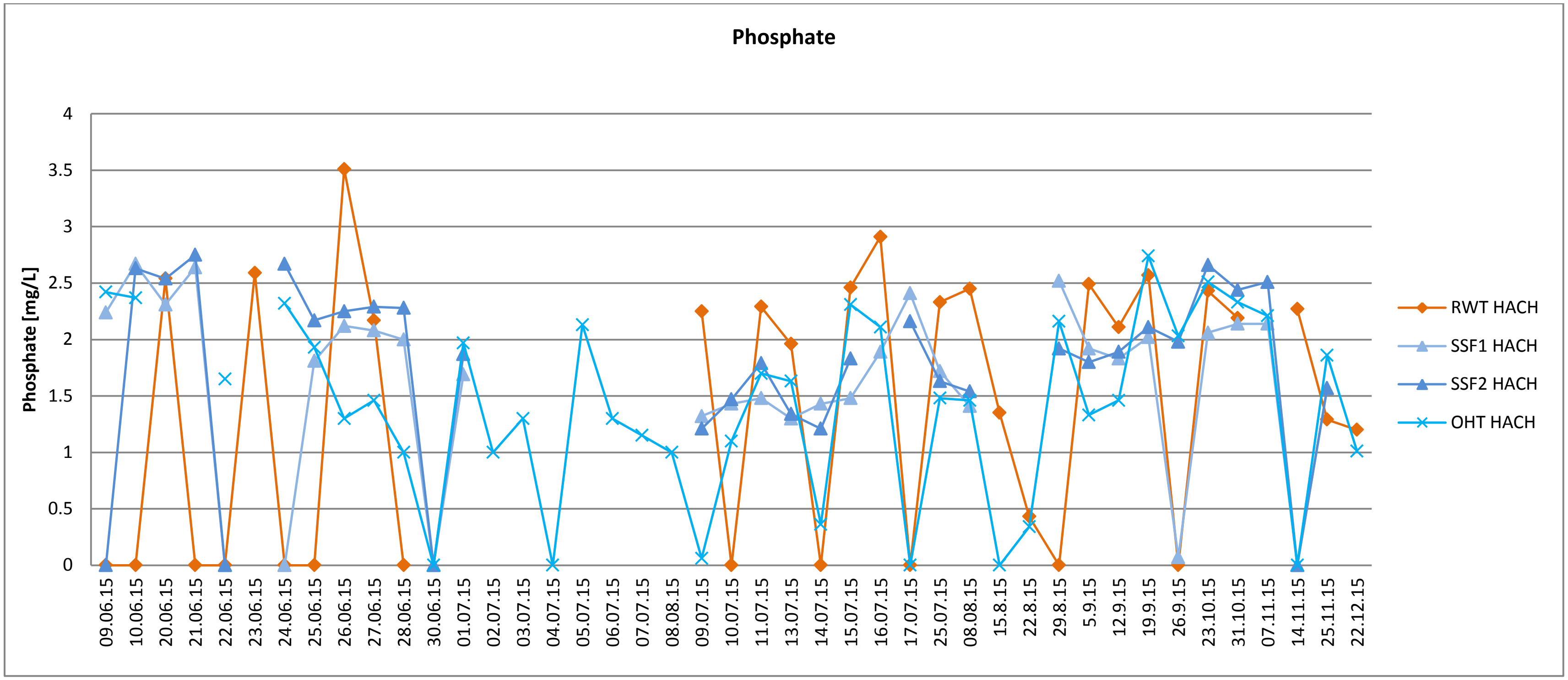



*Figure 153: Phosphate concentrations at various points of the treatment process (source: offline monitoring)*

The temperature in the system stays quite constant during the treatment process, while pond temperature is even slightly higher than the temperature in the tanks and the filters (Figure 154). Following the ambient seasonal temperature it fluctuates between up to 33°C in the summer and 21°C in the winter.

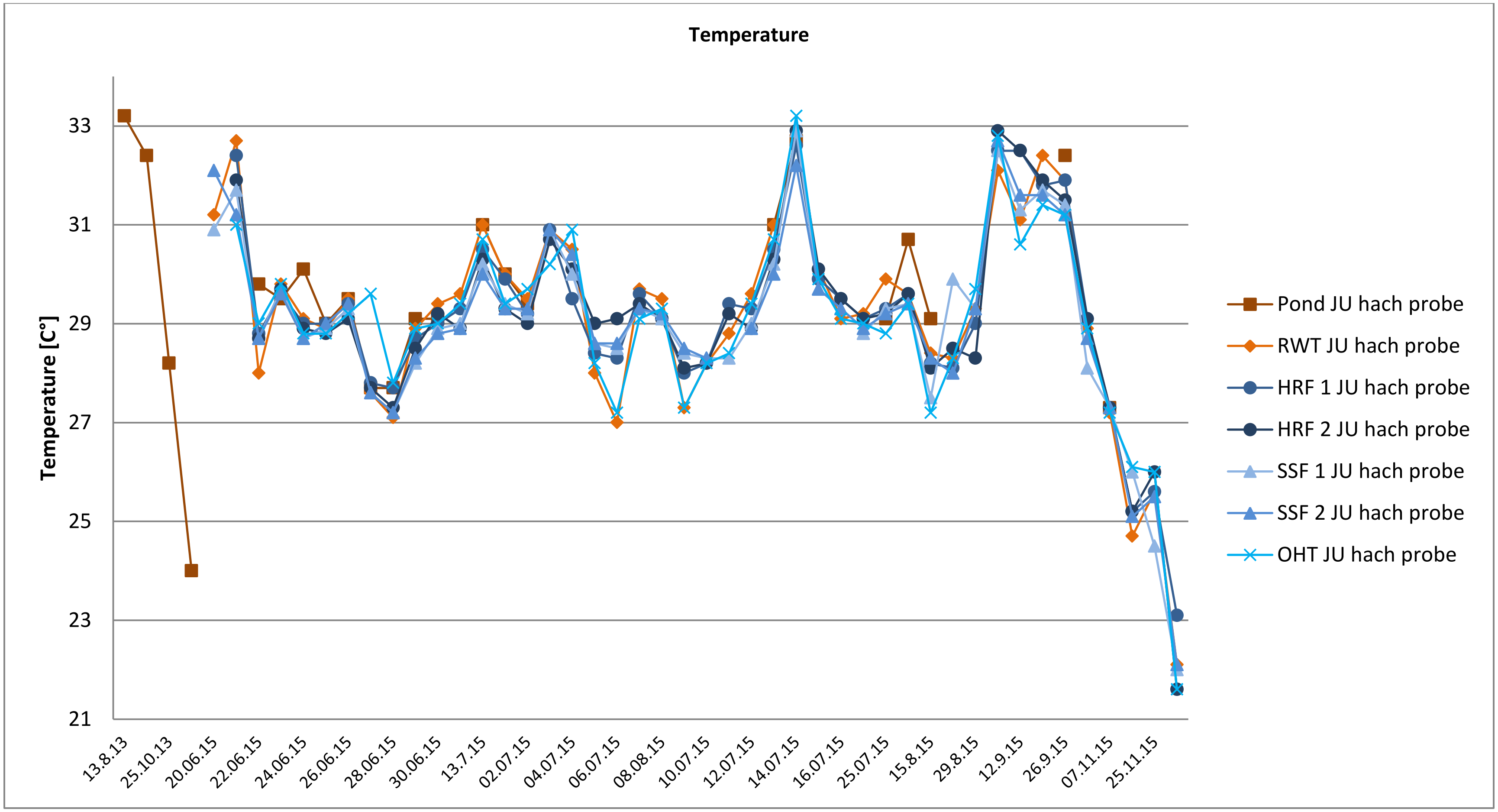



*Figure 154: temperature at various points of the treatment process (source: offline monitoring)*

ORP measurements show fluctuations between 100 and 300 mV with some exceptions of higher values up to 500mV. Levels higher than 485mV have been observed to decrease survival rates of bacteria (Suslow, 2004). This value is not reached (except for one value on 15.07.2015).

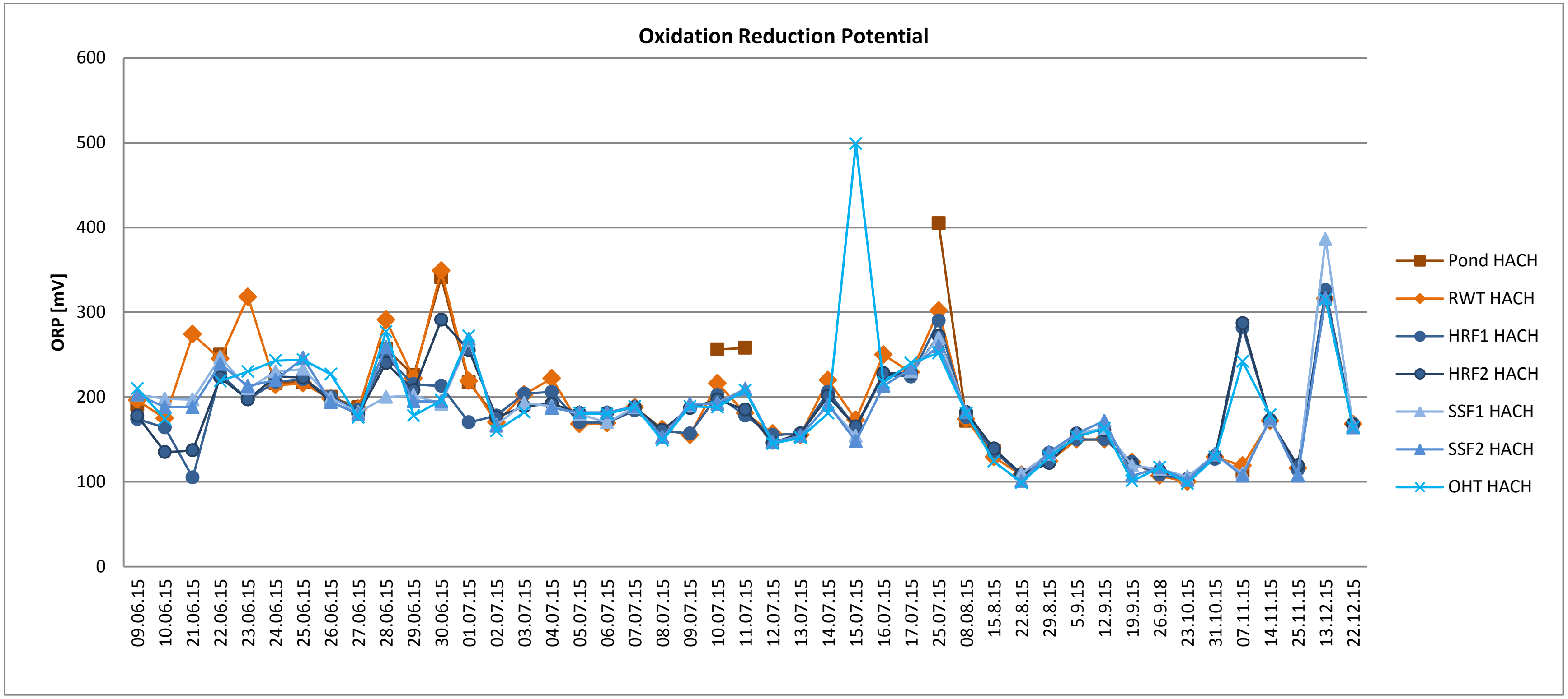



*Figure 155: Oxidation Reduction Potential at various points of the treatment process (source: offline monitoring)*

Table 41 Laboratory results of toxics and pesticides not mentioned in IS10500

| Other toxics and pesticides | unit | Raw Water |
|---|---|---|
| **Bentazon** | ng/L | 0.8 |
| **Caffein** | ng/L | 11.5 |
| **Carbofuran-** | ng/L | 3.8 |
| **Chlorfenvinphos** | ng/L | 0.25 |
| **Clofibric Acid** | ng/L | 152.65 |
| **DEET** | ng/L | 10.6 |
| **Gemfibrozil** | ng/L | 0.7 |
| **Metazachlor** | ng/L | 0.3 |
| **Metalaxyl** | ng/L | 2.1 |
| **S-Metolachlor** | ng/L | 1.05 |
| **Terbutylazine** | ng/L | 0.8 |

*Table 42 Comparison of all IS10500 relevant WQ parameters of alternative and advanced system*

| Parameters (Unit) | Treatment Stage | Measurements results during 10.06.2015 - 9.02.2016 | Average Values | B.I.S. 10500 Acc./perm. |
|---|---|---|---|---|
| **Turbidity** | | | | 1 / 5 |
| (NTU) | RWT | 11.6 - 100 | 20 | |
| | SSF1 | 0.67 - 2.14 | 0.8 | |
| | SSF2 | 0.53 - 2.28 | 0.7 | |
| | AFM | 0.18 - 2.46 | 0.6 | |
| **TDS** | | | | 500 / 2000 |
| (mg/l) | RWT | 283 - 942 | 293 | |
| | SSF1 | 280 - 285 | 283 | |
| | SSF2 | 371 -377 | 374 | |
| | AFM | 289 - 421 | 388 | |
| **Nitrate** | | | | 45 / 45 |
| (mg/l) | RWT | 0.31 | 0.31 | |
| | SSF1 | 0.03-0.4 | 0.2 | |
| | SSF2 | 0.0-0.6 | 0.4 | |
| | AFM | 0.03 -0.5 | 0.2 | |
| **Ammonia** | | | | 0.5 /0.5 |
| | RWT | 0.2 | 0.2 | |
| (mg/l) | SSF | 0.07 | 0.07 | |
| | AFM | 0.06* | 0.06 | |
| **Arsenic** | | | | 0.01 / 0.05 |
| (mg/l) | RWT | 0 - 0.005 | 0.005 | |
| | SSF1 | 0 | 0 | |
| | SSF2 | 0 | 0 | |
| | AFM | 0.005 | 0.005 | |
| **Total hardness** | | | | 200 / 600 |
| (mg/l) | RWT | 225 | 225 | |
| | *SSF1* | *200* | *200* | |
| | *SSF2* | *175* | *175* | |
| | AFM | 150* | 150 | |
| **Alkalinty** | | | | 200 / 600 |
| (mg/l) | RWT | 325 | 325 | |
| | SSF1 | 272 | 272 | |
| | SSF2 | 280 | 280 | |
| | AFM | 225* | 225 | |
| **Iron** | | | | 0.3 /0.3 |
| (mg/l) | *RWT* | *0.15- 0.28* | *0.26* | |
| | *SSF1* | *0 – 0.03* | *0.01* | |
| | *SSF2* | *0.03 – 0.07* | *0.05* | |
| | *AFM* | *0.02 - 0.15* | *0.085* | |
| **Bacteria** | | | | 0/0 |
| **Total Coliform** | *RWT* | *1200* | *1200* | |
| (CFU/100ml) | *SSF1* | *45* | *45* | |
| | *SSF2* | *40* | *40* | |
| | *AFM* | *120** | *120* | |
| **Bacteria** | | | | 0/0 |
| **E.coli** | *RWT* | *450* | *450* | |
| (CFU/100ml) | *SSF1* | *2* | *2* | |
| | *SSF2* | *9* | *9* | |
| | *AFM* | *60** | *60* | |

* Only one value available
° Mean value
BIS: Bureau of Indian Standard

| | |
|---|---|
| (green) | best performance |
| (yellow) | exceeding desirable limit |
| (orange) | exceeding permissible limit |

## P. ONLINE MEASUREMENTS RESULTS

### ONLINE FLOWRATE MEASUREMENT

Repeated calibration attempts as well as complaints and following visits of the magnetic flowmeter distributer were not able to calibrate installed magnetic flowmeters as readings “drifted” in a couple of days. An exceptional constant reading period though indicated strong fluctuations in the inflow of the raw water to the HRF filters as well as the outflow from the SSFs as shown in Figure 156. This is additional information which was not previously noticed from the offline assessment.

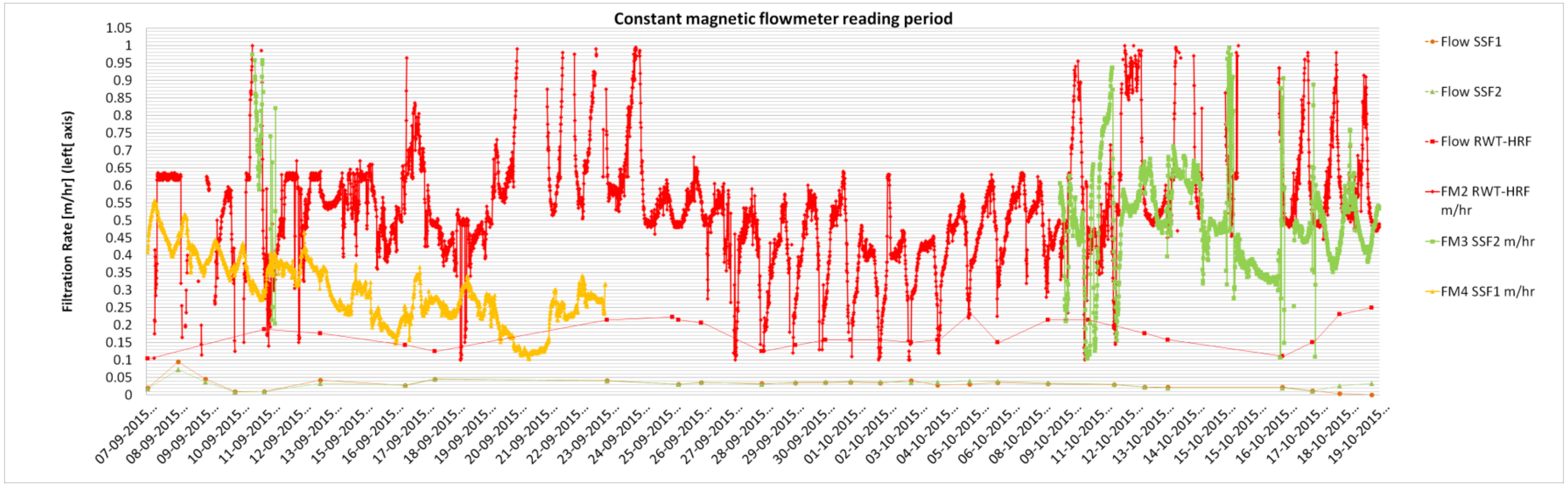



*Figure 156: Period of constant readings from magnetic flowmeters which were used for deriving calibration factors*

Approximate correction factors were derived from the comparison of online and offline data and applied to the online readings as per Table 43. According to the corrected values fluctuations of the inflowing raw water were between 0.0375 and 0.225 m/hr, the outflow of the SSFs were ranging between 0.016 to 0.088 (SSF1) and 0.007 to 0.063 (SSF1) as can be observed from Figure 157. This indicates flowrate variation of factors between 5.5 and 9 despite the inlet valve having the same opening.

*Table 43 Approximation for correction factors after numerous attempts for calibration for the magnetic flow meters on the basis of manual offline assessments*

| Approximation of correction factors in m/hr filtration speed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | reading | manual | correction factor | upper online | lower online | upper corr | lower corr. | fluctuation | fluctuation factor |
| FM2 (RWT-HRF) | 0.4 | 0.15 | 0.375 | 0.6 | 0.1 | 0.225 | 0.0375 | 0.1875 | 6 |
| FM3 (SSF2) | 0.45 | 0.03 | 0.067 | 0.950 | 0.100 | 0.063 | 0.007 | 0.057 | 9.5 |
| FM4 (SSF1) | 0.25 | 0.04 | 0.16 | 0.55 | 0.1 | 0.088 | 0.016 | 0.072 | 5.5 |

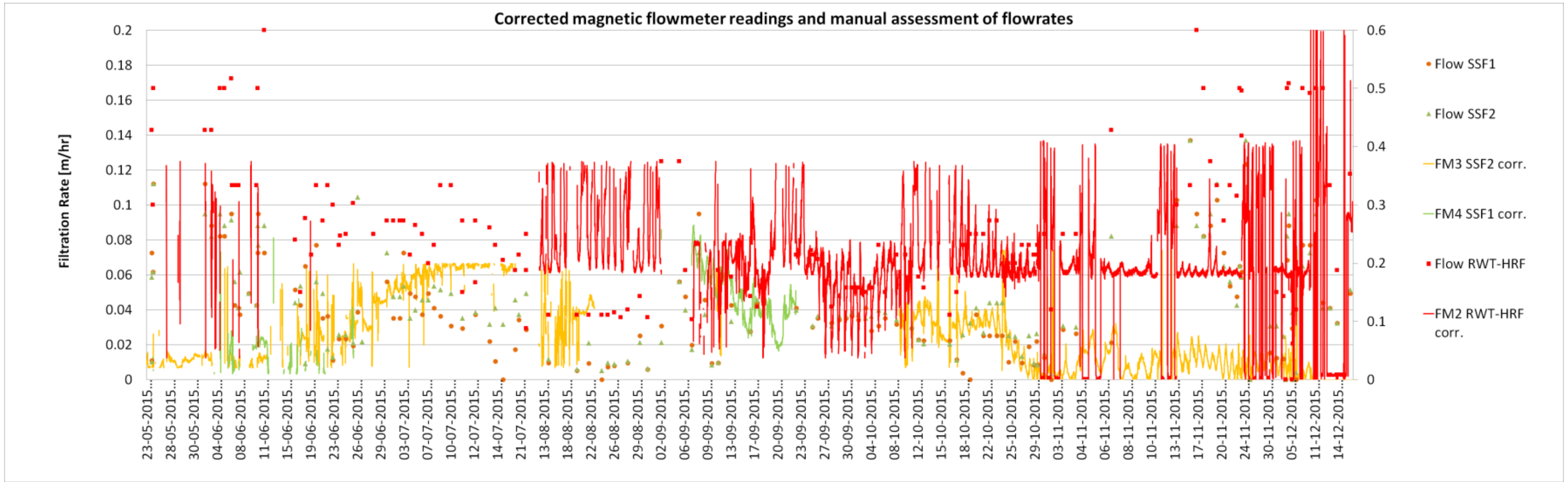



*Figure 157: Magnetic flowmeter readings corrected and compared with offline assessment values (source online monitoring and offline assessment)*

Initial conclusions assuming the flow to correlate with the water level in the raw water tank could be refuted by observing the raw water pump activity. The raw water pump is connected to a pump controller always filling the tank when it is half empty and stopping when it is full. Higher pump activity did not lead to higher flowrates or vice versa as can be observed in Figure 158. Thus the fluctuation of flowrates remains unexplained. Manual hourly measurements were conducted to verify the findings and also showed similar fluctuations.

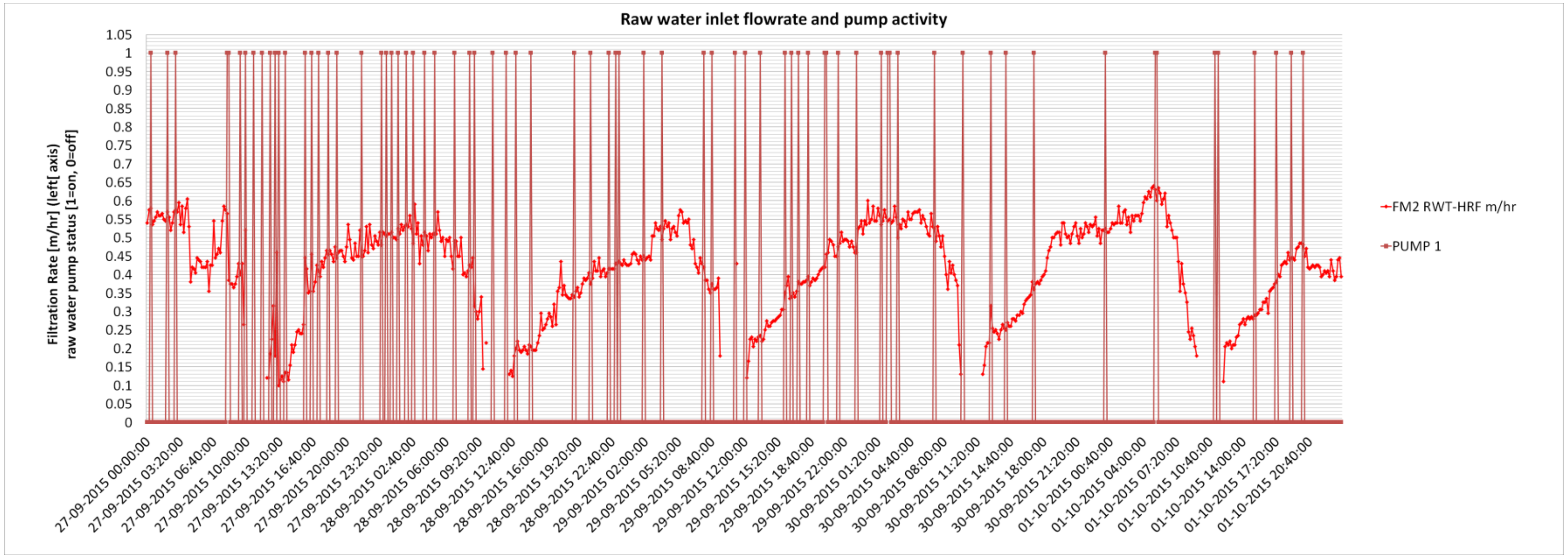



*Figure 158: observing raw water pump activity filling the raw water tank and raw water inlet flowrate into the HRFs*

## DISSOLVED OXYGEN

Online oxygen sensors indicate rather constant oxygen levels around 4 to 5 mg/l in the pond with a slight increase from mid-October to beginning of December as shown in Figure 159. Oxygen level in the raw water tank is considerably lower with levels around 2 to 3 mg/l. HRF exit (SSF surface) values are again higher with strong diurnal fluctuation between 2 and 5 mg/l. SSF exit (ACF surface) concentrations are lowest with diurnal fluctuations between 1 and 2 mg/l, possibly indicating that the SSF bed does not go anoxic. The very high oxygen readings between November 10$^{th}$ to 13$^{th}$ for HRF and SSF are due to the scraping and cross-flushing for which the sensors were removed and kept out of the filters for the period of maintenance. The change of flowrate as per offline assessment indicates that DO levels in HRF and SSF tend to fluctuate less during higher flowrates, e.g. period November 14$^{th}$ to November 20$^{th}$ than in periods of lower flowrates, e.g. October 19$^{th}$ to 24$^{th}$ or November 28$^{th}$ to December 2$^{nd}$ (Figure 159)

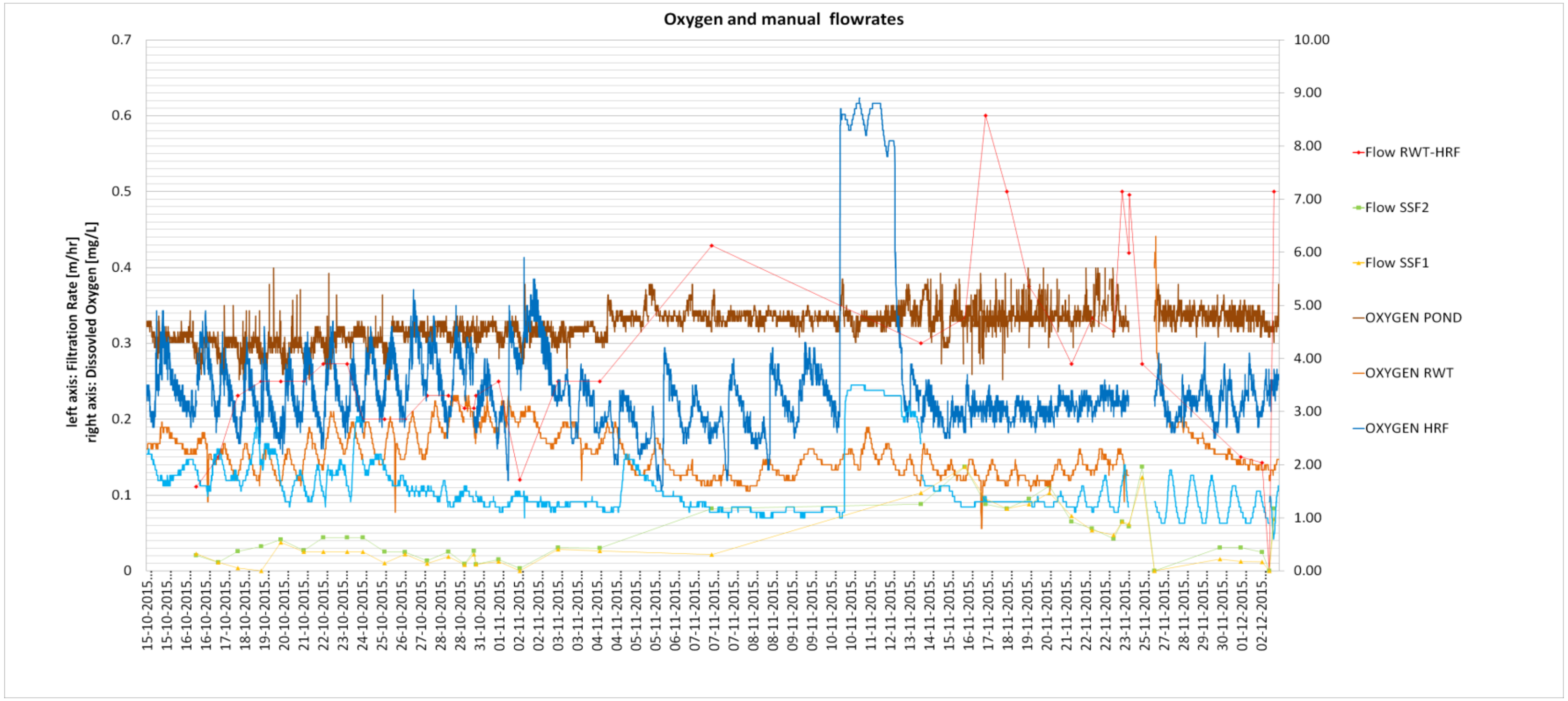



*Figure 159: online oxygen monitoring and against manual flowrate measurements (source: online monitoring and offline assessment, consecutive measured points connected by lines for better visibility)*

Online flowmeter readings show fluctuations in similar frequencies as the oxygen probes as can be observed in Figure 160. Flow rates seem to have periods with stronger fluctuations (October 16th to November 2nd) and periods where HRF input flowrate does not seem to fluctuate much (e.g. November 7th to November 10th or November 15th to November 23rd). It can also be noticed that SSF flowrates seem to fluctuate while HRF flowrates seem constant which hints at diurnal variations in filter resistance of the SSF filter bed.

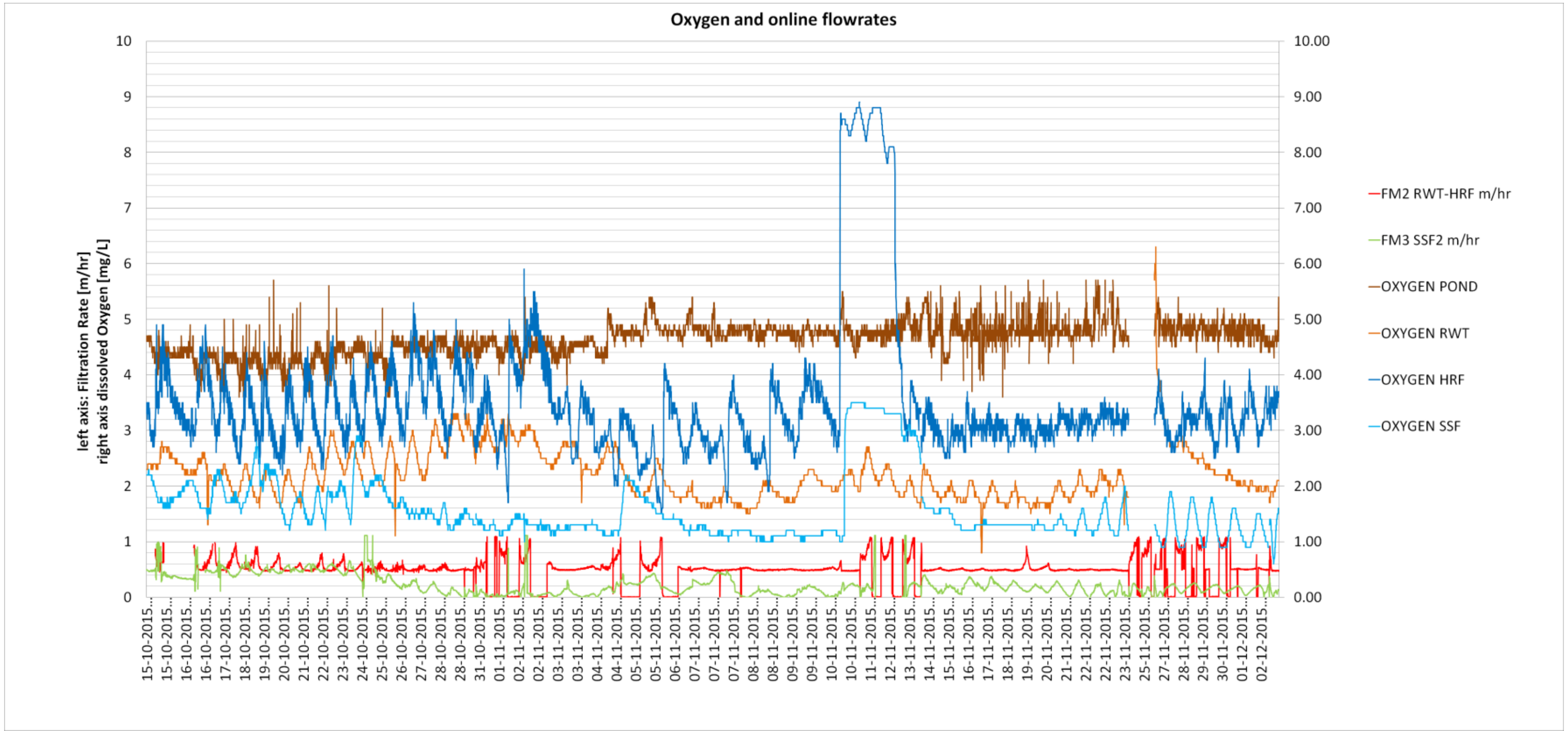



*Figure 160: online oxygen monitoring against uncorrected online flowrate measurements (source: online monitoring, consecutive measured points connected by lines for better visibility)*

When observing the curves for a period of regular fluctuations closer (October 16th to October 23rd as in Figure 161), it can be observed that the pond DO levels have peaks during night from around 20:00 to 5:00 and valleys around daytime from 11:00 to 17:00. This is contrary to expectations that oxygen levels in the pond should decrease at night when photosynthesis is not possible and higher during daytime when algae produce oxygen. A possible explanation could be the height of the oxygen sensor, which is half a meter above the pond ground and in October around 2 to 3 meters below water level. Possibly photosynthesis of algae does not have any influence here, as light does not reach this depth due to turbid waters.

Higher inflows of raw water into the HRF tend to peak in the morning hours between 5:00 to 6:00 with steep declines till 8:00, the timing coincides with the valley of DO in the RWT which correlates in its fluctuations with the DO level at the HRF exit (SSF surface). Thus high flowrates into the HRF are followed by

high DO concentrations at the HRF exit after 9 to 12 hours. This could be explained by the travel time of around 9 hours (4.5m filter length with 0.5m/h filtration speed)
SSF flowrates peaks have half a frequency shift to the HRF flowrate at around 17:00 thus peak of HRF inflow and valley of SSF outflow often meet. This delay could also be explained by the travel time of the water to the SSF causing a higher level of the supernatant. This could possibly explain the partly surprising offline flowrate measurements in the morning hours around 9:00 which at times show that only half of the water being fed into the system is coming out of the system (SSF valley, HRF peak) or afternoon assessment when more water is coming out than is going in (Peak SSF, Valley HRF). SSF exit water DO levels do not show a very regular peak in this period, though rather tending to peak around 5:00 to 8:00 and thus having around half a frequency shift to the SSF flowrates.

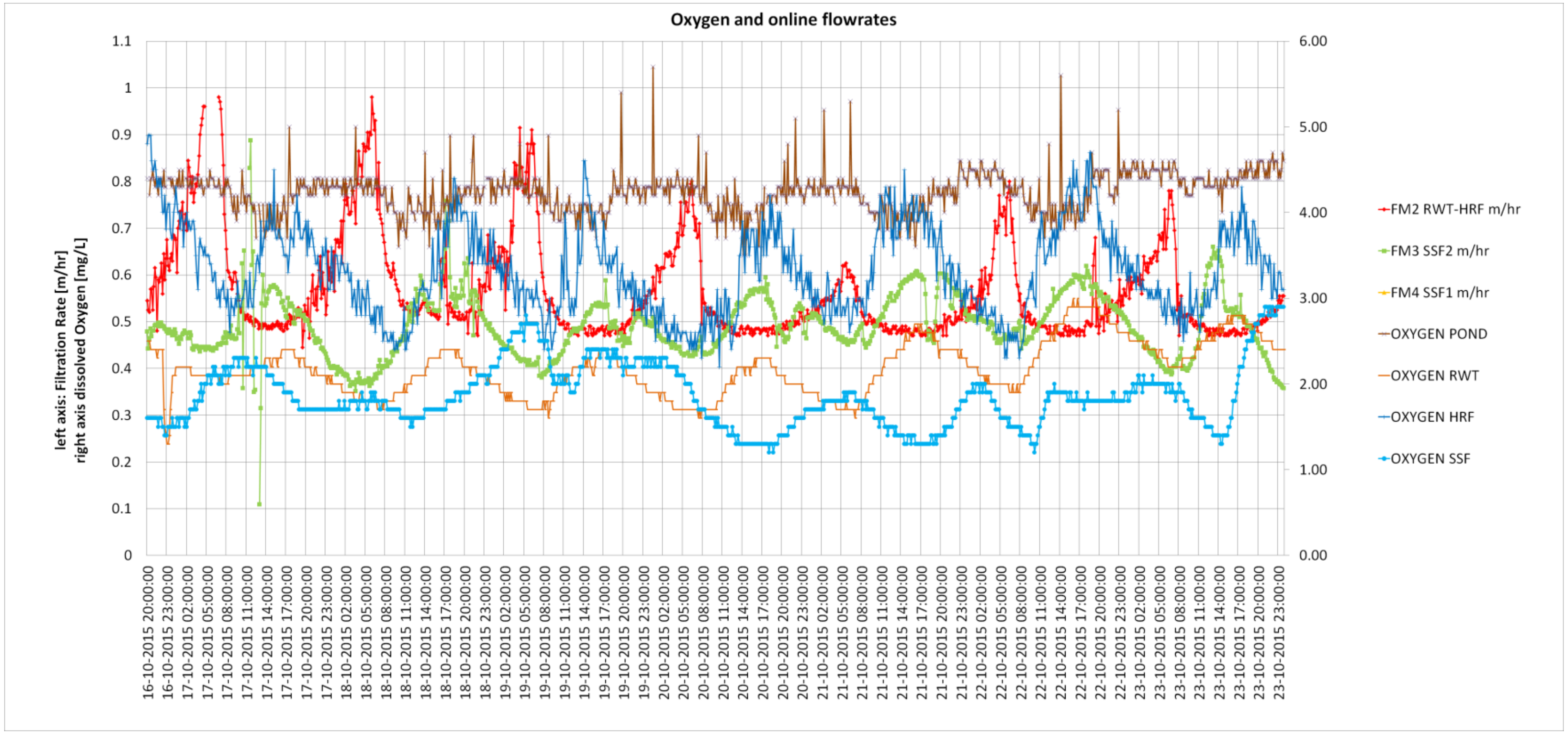



*Figure 161 diurnal changes of online oxygen concentrations against fluctuating flowrates*

Looking at a different period (November 28th to December 2nd) it can be observed from Figure 162 that flowrate peaks, oxygen peaks and turbidity peaks coincide with turbidity frequency lagging a bit behind with around 3 hours.

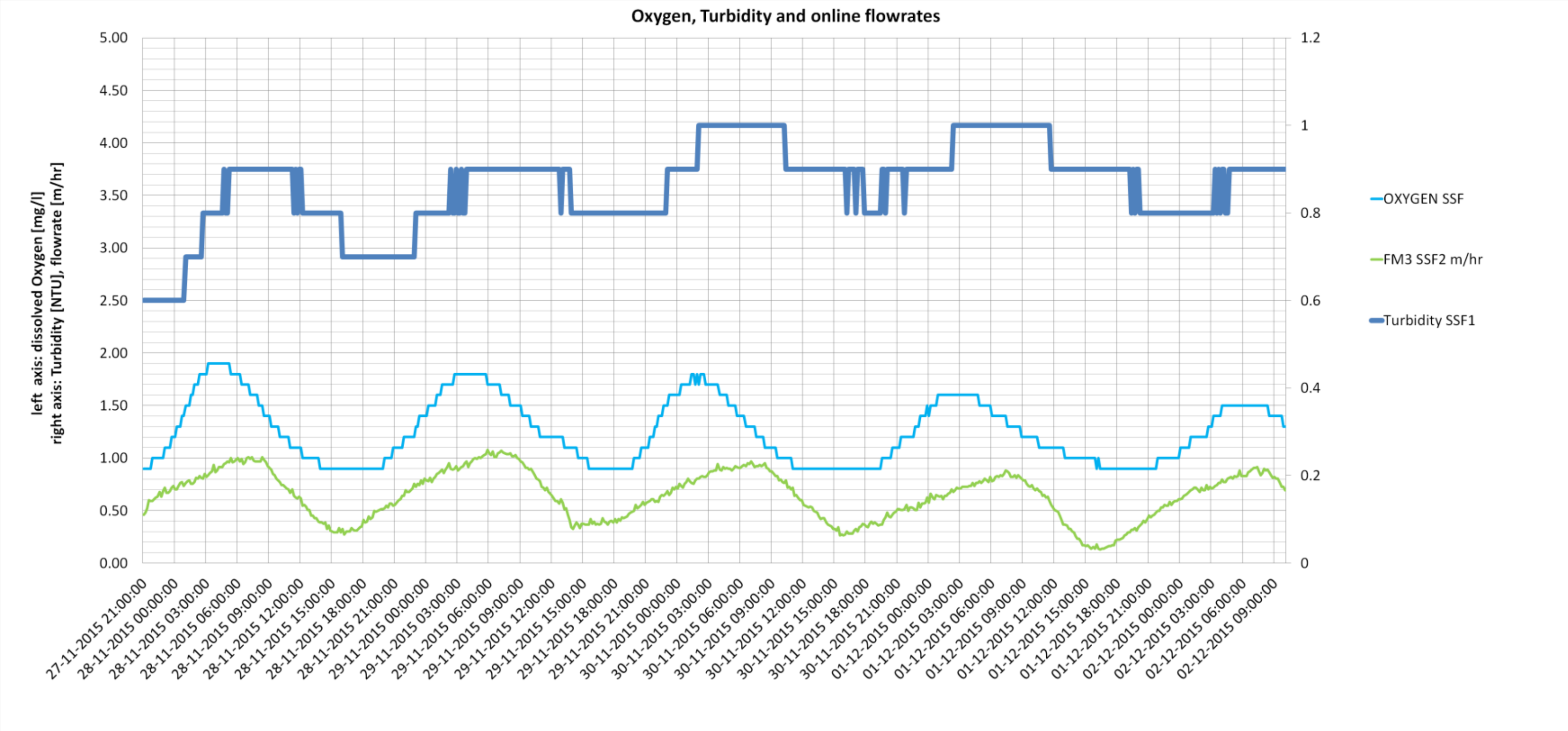



*Figure 162: comparing Oxygen, Turbidity and flowrates of SSF (source: online monitoring)*

## FAC AND PH

Online measurement of pH and FAC is done at the distribution pipe. As the distribution pipeline has not been layed yet flow in the pipeline is very seldom, thus the water stagnates which does not produce reliable information as the sensors are designed for a constant flow passing the probe. A magnetic flowmeter (FM7) connected to the discharge pipeline indicates flow along the sensors (although absolute values are not reliable). Another reliable turbine flowmeter (FM6) indicates the flow induced by the pump from the CWT to the OHT. The dosing pump is triggered by FM6 so that the disinfectant is dosed in proportion to the water inflow of the OHT. Fluctuations in the FAC and pH meters could be observed especially in the period September 24th to October 30th as can be seen in Figure 163. This is also the period when the automatic dosing of the disinfectant was working.

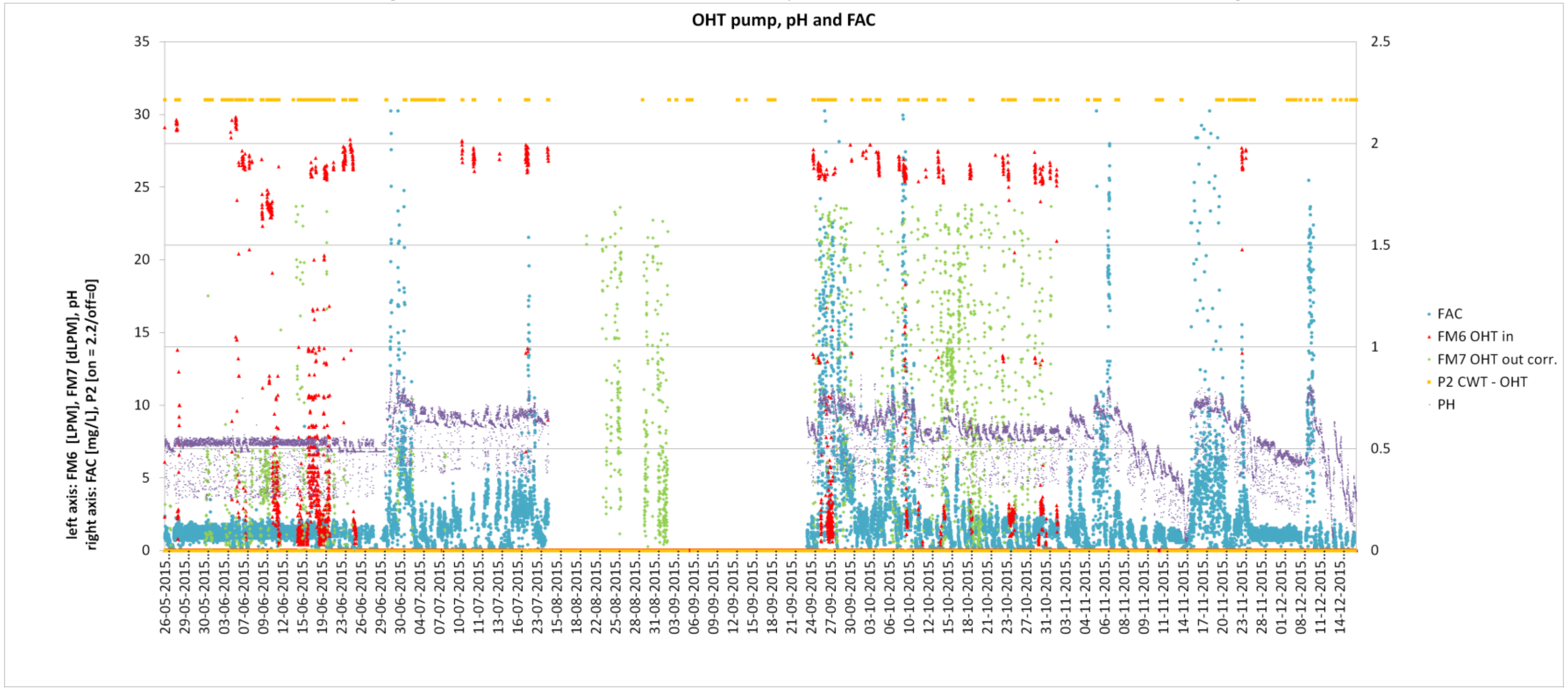



*Figure 163: Free Available Chlorine and pH level of OHT distribution water and CWT to OHT pump activity and flowrate (source: online measurement)*

Closer observation of this period (Figure 164) shows diurnal FAC and pH fluctuations with some peaks coinciding with pump 2 activities and FM 6 readings (flow into the OHT, dosing of disinfectant). Regular FM6 readings especially occur on September 25th and 26th.

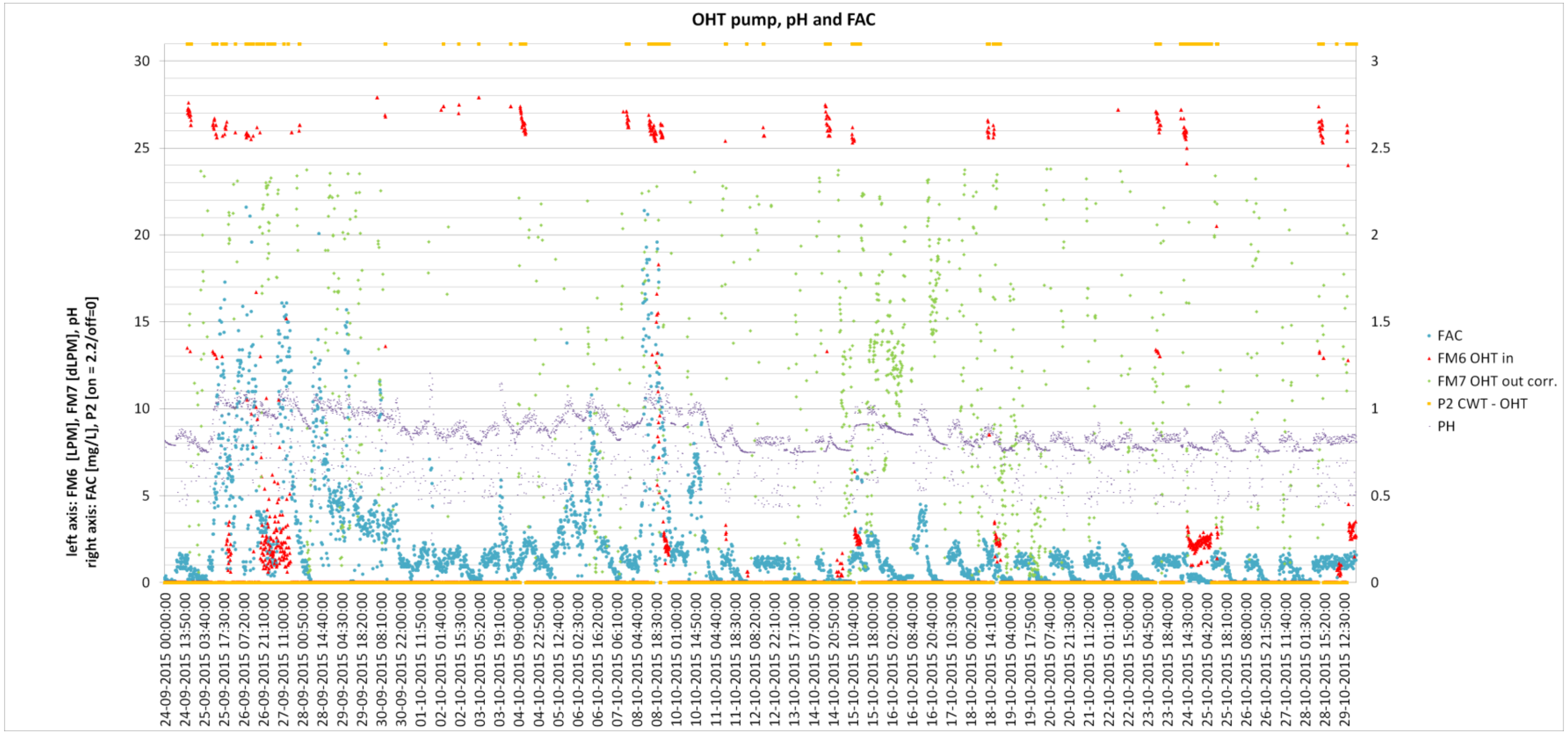



*Figure 164: FAC, pH and pump activity during stable reading period September 24th to October 29th (source: online monitoring)*

An even closer look at the readings especially on September 25th and 26th show that the dosing of disinfectant does lead to higher FAC levels as expected. On the other hand it can also be observed from Figure 165 that a discharge of OHT water measured by FM 7 coincides with a reduction of FAC in the distribution pipe as can be seen at 18:20 on 25th or 18:30 on 26th.

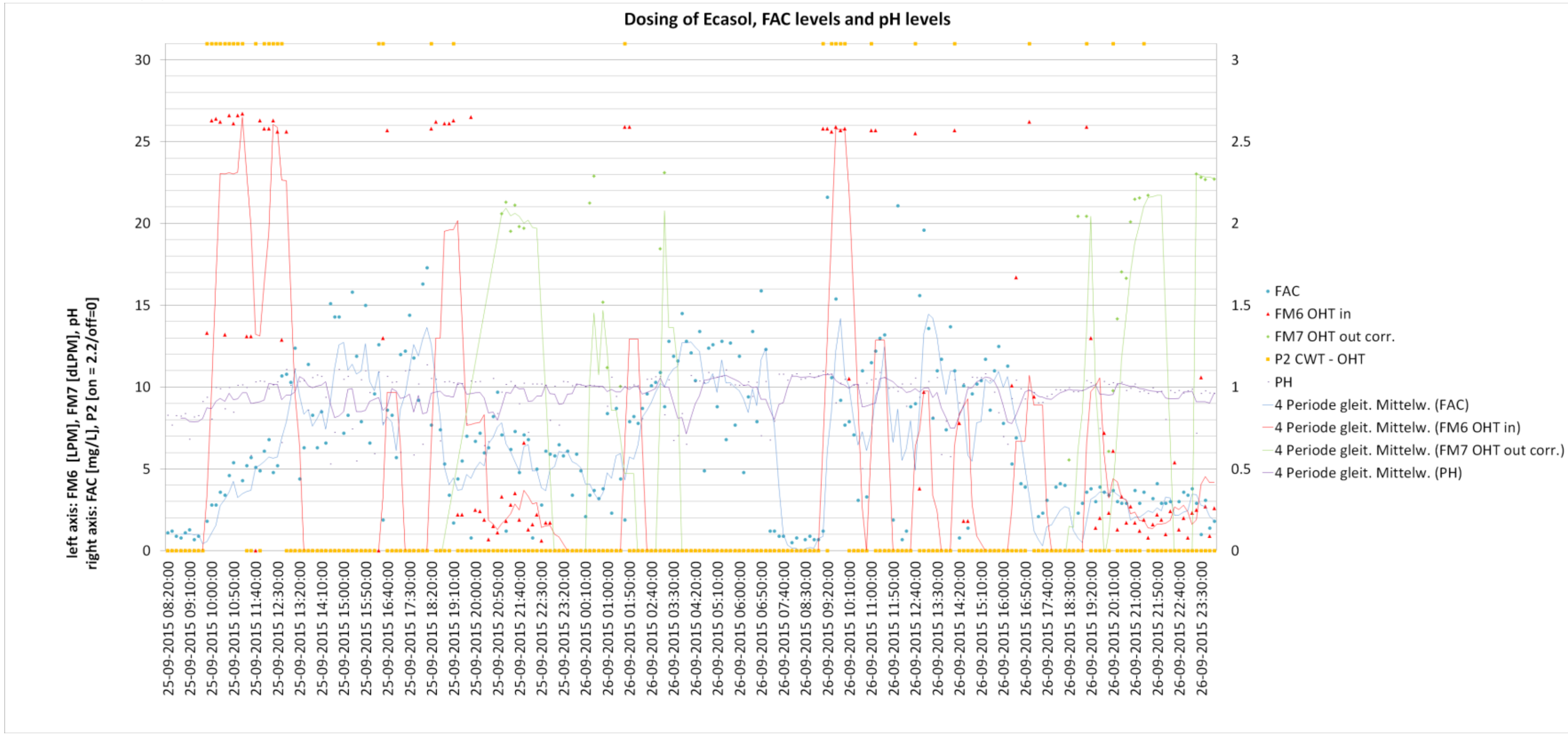



***Figure 165: CWT - OHT flow triggering Chlorine dosing, resulting FAC and pH levels on September 25th and 26th (source: online monitoring, trendlines have been added to improve visibility)***

## Q. LOAD CALCULATION RESULTS

*Table 44 Matlab calculation results of load and total flows of all treatment steps during the scraping intervals*

| Parameter | unit | ssf1 rip | ssf1 per1 | ssf1 per2 | ssf1 per 3 | ssf2 rip | ssf2 per1 | ssf2 per2 |
|---|---|---|---|---|---|---|---|---|
| RW mass | kg | 32.2471 | 12.1459 | 21.2628 | 10.2683 | 28.1181 | 16.0491 | 29.4174 |
| HRF1 mass | kg | 2.894 | 1.898 | 5.4065 | 1.1132 | 2.5087 | 2.2712 | 6.2719 |
| HRF2 mass | kg | 3.0153 | 2.3398 | 5.7567 | 0.9701 | 2.646 | 2.6848 | 6.4784 |
| SSF1 mass | kg | 0.4984 | 0.5582 | 0.4606 | 0.0941 | 0.4715 | 0.6317 | 0.5461 |
| SSF2 mass | kg | 0.7949 | 0.7751 | 0.4513 | 1.40E-01 | 0.6004 | 1.0325 | 0.5747 |
| OHT mass | kg | 1.2446 | 1.2483 | 0.8648 | 0.1799 | 1.1362 | 1.4225 | 1.0056 |
| OHT flow | $m^3$ | 318.933 | 513.9471 | 1.02E+03 | 372.9363 | 297.9936 | 540.4832 | 1.33E+03 |
| HRF1 rem | kg | 13.2295 | 4.175 | 5.2249 | 4.0209 | 11.5504 | 5.7533 | 8.4368 |
| HRF2 rem | kg | 13.1083 | 3.7331 | 4.8747 | 4.164 | 11.413 | 5.3398 | 8.2303 |
| SSF1 rem | kg | 2.4563 | 1.5607 | 5.121 | 0.9476 | 2.1058 | 1.8464 | 5.8291 |
| SSF2 rem | kg | 2.1597 | 1.3438 | 5.1303 | 9.01E-01 | 1.977 | 1.4456 | 5.8004 |
| total rem | kg | 31.0025 | 10.8977 | 20.398 | 10.0884 | 26.9819 | 14.6267 | 28.4118 |
| RW in | kg | 32.2471 | 12.1459 | 21.2628 | 10.2683 | 28.1181 | 16.0491 | 29.4174 |
| REM out | kg | 32.1984 | 12.061 | 21.2157 | 1.02E+01 | 28.1824 | 15.8075 | 29.3022 |
| RW flow | $m^3$ | 372.8573 | 736.3957 | 1.47E+03 | 645.1734 | 338.8366 | 769.9793 | 1.95E+03 |
| HRF1 flow | $m^3$ | 186.4287 | 368.1979 | 734.8806 | 322.5867 | 169.4183 | 384.9897 | 972.9059 |
| HRF2 flow | $m^3$ | 186.4287 | 368.1979 | 734.8806 | 322.5867 | 169.4183 | 384.9897 | 972.9059 |
| SSF1 flow | $m^3$ | 160.209 | 234.5637 | 505.5303 | 163.0475 | 151.9929 | 245.1319 | 645.5723 |
| SSF2 flow | $m^3$ | 158.7241 | 279.3834 | 511.6397 | 209.8888 | 146.0006 | 295.3513 | 685.6719 |
| OHT flow | $m^3$ | 318.933 | 513.9471 | 1.02E+03 | 372.9363 | 297.9936 | 540.4832 | 1.33E+03 |
| mean SSF1 flow | LPM | 3.2708 | 1.2244 | 3.379 | 2.1858 | 3.5402 | 1.2424 | 3.134 |
| mean SSF2 flow | LPM | 3.2404 | 1.4583 | 3.4198 | 2.8138 | 3.4006 | 1.4969 | 3.3287 |
| mean SSF1 rem | kg/d | 0.0722 | 0.0117 | 0.0493 | 0.0183 | 0.0706 | 0.0135 | 0.0407 |
| mean SSF2 rem | kg/d | 0.0635 | 0.0101 | 0.0494 | 1.74E-02 | 0.0663 | 0.0106 | 0.0405 |
| mean SSF mass in | kg/d | 0.0869 | 0.0161 | 0.0537 | 0.0201 | 0.0864 | 0.0181 | 0.0446 |
| mean SSF turb in | NTU | 16.1177 | 5.6154 | 7.5117 | 3.3289 | 15.2699 | 6.0376 | 6.4031 |

*Table 45 Matlab calculations of mass loads during cross-flushing intervals in HRF units*

| From | | 16.9.15 | 9.10.15 | 10.11.15 | 24.11.15 | 4.12.15 | 11.12.15 | 17.2.16 | 17.3.16 | 11.4.16 |
|---|---|---|---|---|---|---|---|---|---|---|
| To | | 9.10.15 | 10.11.15 | 24.11.15 | 4.12.15 | 11.12.15 | 17.12.15 | 17.3.16 | 11.4.16 | 26.4.16 |
| Duration (days) | | 23 | 32 | 14 | 10 | 7 | 6 | 28 | 24 | 15 |
| RW mass in | Kg | 0.85 | 1.77 | 1.78 | 1.59 | 0.82 | 1.14 | 6.04 | 4.78 | 1.74 |
| HRF1 mass rem. | Kg | 0.32 | 0.62 | 0.50 | 0.49 | 0.33 | 0.30 | 2.40 | 1.84 | 0.73 |
| HRF2 mass rem. | Kg | 0.27 | 0.55 | 0.45 | 0.46 | 0.29 | 0.30 | 2.57 | 1.89 | 0.68 |
| HRF1 rem eff. | % | 76.5 | 70.4 | 56.0 | 62.2 | 81.5 | 53.0 | 79.5 | 77.2 | 83.3 |
| HRF2 rem eff. | % | 63.4 | 62.7 | 50.7 | 58.1 | 71.2 | 52.7 | 85.0 | 79.1 | 78.3 |

## R. CODE FOR CALCULATION OF FILTER LOAD

Matlab code of the file HRFSSFanalysis_load.m :

```
%% turbidity masses
% auswertung filterladung

close all;
clear all; clc;
[Time,comment,ecolidistilled,ecoliRWT,ecoliHRF1,ecoliHRF2,ecoliSSF1,ecoliSS
F2,ecoliOHT,totalcoldist,totalcolRWT,totalcolHRF1,totalcolHRF2,totalcolSSF1
,totalcolSSF2,totalcolOHT,FACOHT,pHOHT,ScrapingSSF1,ScrapingSSF2,HeadlossSS
F1,HeadlossSSF2,TURBIDITYMETER1,TurbiditySSF1,TurbiditySSF2,TurbidityOHT,Cr
ossFlushHRF1,CrossFlushHRF2,HeadlossHRF1,HeadlossHRF2,vnotchSSF1in,vnotchSS
F2in,vnotchHRF1out,vnotchHRF2out,vnotchHRF1in,vnotchHRF2in,TURBIDITYMETER2,
TurbidityHRF1,TurbidityHRF2,TurbidityRawWater,SSFHRF,HRFSSF,SSSRWT,RWTSSF,T
URBIDITYMETER3,FLOWMETER1,FLOWMETER2,FM2RWTHRFmhr,FM2RWTHRFcorr,FlowRWTHRFL
PM,FlowRWTHRF,FLOWMETER3,FM3SSF2mhr,FM3SSF2corr,FlowSSF2LPM,FlowSSF2,FLOWME
TER4,FM4SSF1mhr,FM4SSF1corr,FlowSSF1LPM,FlowSSF1,FLOWMETER5,FM6OHTin,FLOWME
TER7,FM7OHToutcorr,PUMP1,PUMP2,P2CWTOHT,PUMP3,PH,FAC,OXYGENPOND,OXYGENCWT,O
XYGENSSF,OXYGENHRF,OXYGENRWT,OXYGENAFMRWT,OXYGENAFMCWT,ECOTRIOSYSTEM] =
xlsimportfunction4('combined_om_20160810_time_unique_2.xlsx','DATA
unique',15319,19533);
Time=Time+693960;

%% RAW WATER
%remove NaN values in raw water
time_rawwater = Time;
time_rawwater(isnan(TurbidityRawWater))=[];
TRW_2 = TurbidityRawWater;
TRW_2(isnan(TurbidityRawWater))=[];

% interpolate raw water values and plot
timeint = min(Time):1/144:max(Time);
figure ('Name','RW Turbidity');
TRWINT = interp1(time_rawwater,TRW_2,timeint,'pchip','extrap');
plot(time_rawwater,TRW_2,'k',timeint,TRWINT,'r:');
datetick('x');

% calculate area under raw water curve
arearw = trapz(timeint,TRWINT)

%CALCULATE RW MASS INTO FILTER

%remove NaN values in FlowRWTHRFLPM
time_rawwatermass = Time;
time_rawwatermass(isnan(FlowRWTHRFLPM))=[];
TRWFL = FlowRWTHRFLPM;
TRWFL(isnan(FlowRWTHRFLPM))=[];

timeint = min(Time):1/144:max(Time);
figure('Name','Flow RWT to HRF [LPM]')
TRWINTFL = interp1(time_rawwatermass,TRWFL,timeint,'pchip','extrap');
plot(timeint,TRWINTFL);
datetick('x');

% value of flow for removal in kg (factor) 1NTU =  1mg/L SS
% LPM to LPD 60*24= 1440
```

```matlab
% mg to kg /1000000 final unit [kg/day]

figure ('Name','raw water turbidtiy mass');
FLKGRWTHRF = TRWINT * 1 * 1440 /1000000;
TRWINTMASS = TRWINTFL .* FLKGRWTHRF;
plot(timeint,TRWINTMASS,'r');
datetick('x');

% calculate area under raw water mass curve
arearwmass = trapz(timeint,TRWINTMASS)

% total loading of filter

%% HRF1

%remove NaN values
time_HRF1 = Time;
time_HRF1(isnan(TurbidityHRF1))=[];
THRF_1 = TurbidityHRF1;
THRF_1(isnan(TurbidityHRF1))=[];

% interpolate HRF1
timeint = min(Time):1/144:max(Time);
figure ('Name','HRF 1 turbidity');
THRF1INT = interp1(time_HRF1,THRF_1,timeint,'pchip','extrap');
plot(time_HRF1,THRF_1,'k',timeint,THRF1INT,'r:');
datetick('x');

% calculate area
areahrf1 = trapz(timeint,THRF1INT)

%CALCULATE HRF1 MASS INTO SSF

 %remove NaN values in FlowRWTHRFLPM
time_HRF1mass = Time;
time_HRF1mass(isnan(FlowRWTHRFLPM))=[];

%simplify flow through each HRF = RWTHRF/2
HRF1FL = FlowRWTHRFLPM / 2;
HRF1FL(isnan(FlowRWTHRFLPM))=[];
timeint = min(Time):1/144:max(Time);
figure ('Name','flowrate HRF1');
HRF1INTFL = interp1(time_HRF1mass,HRF1FL,timeint,'pchip','extrap');
plot(timeint,HRF1INTFL);
datetick('x');

FLKGHRF1 = THRF1INT * 1 * 1440 /1000000;
HRF1INTMASS = HRF1INTFL .* FLKGHRF1;
figure ('Name','HRF1 turbidity mass out');
plot(timeint,HRF1INTMASS,'r');

datetick('x');

% calculate area under HRF1 mass curve
areaHRF1mass = trapz(timeint,HRF1INTMASS)

%% HRF2

%remove NaN values
```

```
time_HRF2 = Time;
time_HRF2(isnan(TurbidityHRF2))=[];
THRF_2 = TurbidityHRF2;
THRF_2(isnan(TurbidityHRF2))=[];

% interpolate HRF2
timeint = min(Time):1/144:max(Time);
figure ('Name','HRF2 turbidity');
THRF2INT = interp1(time_HRF2,THRF_2,timeint,'pchip','extrap');
plot(time_HRF2,THRF_2,'k',timeint,THRF2INT,'r:');
datetick('x');
title('pchip interpolated HRF 2 turbidity [NTU]');

% calculate area
areahrf2 = trapz(timeint,THRF2INT)

%CALCULATE HRF2 MASS INTO SSF

%remove NaN values in FlowRWTHRFLPM
time_HRF2mass = Time;
time_HRF2mass(isnan(FlowRWTHRFLPM))=[];
%simplify flow through each HRF = RWTHRF/2
HRF2FL = FlowRWTHRFLPM / 2;
HRF2FL(isnan(FlowRWTHRFLPM))=[];

timeint = min(Time):1/144:max(Time);
figure ('Name','flowrate HRF2');
HRF2INTFL = interp1(time_HRF2mass,HRF2FL,timeint,'pchip','extrap');

plot(timeint,HRF2INTFL);
datetick('x');
%title('pchip interpolated flowrate HRF2 [LPM]');

% value of flow for removal in kg (factor) 1NTU =  1mg/L SS
% LPM to LPD 60*24= 1440
% mg to kg /1000000 final unit [kg/day]

 figure ('Name','HRF2 turbidity mass out');
FLKGHRF2 = THRF2INT * 1 * 1440 /1000000;
HRF2INTMASS = HRF2INTFL .* FLKGHRF2;

plot(timeint,HRF2INTMASS,'r');
datetick('x');
title('pchip interpolated HRF2 turbidity mass out [kg/day]');

 % calculate area under HRF1 mass curve
areaHRF2mass = trapz(timeint,HRF2INTMASS)

%% SSF1

%remove NaN values
time_SSF1 = Time;
time_SSF1(isnan(TurbiditySSF1))=[];
TSSF1 = TurbiditySSF1;
TSSF1(isnan(TurbiditySSF1))=[];

% plot pchip interpolated SSF1
timeint = min(Time):1/144:max(Time);
figure ('Name','SSF1 turbidity');
```

```
TSSF1INT = interp1(time_SSF1,TSSF1,timeint,'pchip','extrap');
plot(time_SSF1,TSSF1,'k',timeint,TSSF1INT,'r:');
datetick('x');

% calculate area
areaSSF1 = trapz(timeint,TSSF1INT)

%CALCULATE remaining SSF1 MASS

%remove NaN values in FlowSSF1LPM
time_SSF1mass = Time;
time_SSF1mass(isnan(FlowSSF1LPM))=[];
SSF1FL = FlowSSF1LPM;
SSF1FL(isnan(FlowSSF1LPM))=[];

timeint = min(Time):1/144:max(Time);
figure ('Name','flowrate SSF1');
SSF1INTFL = interp1(time_SSF1mass,SSF1FL,timeint,'pchip','extrap');

plot(timeint,SSF1INTFL);
datetick('x');
title('pchip interpolated flowrate SSF1 [LPM]');

% value of flow for removal in kg (factor) 1NTU =  1mg/L SS
% LPM to LPD 60*24= 1440
% mg to kg /1000000 final unit [kg/day]

figure  ('Name','SSF1 turbidity mass out');
FLKGSSF1 = TSSF1INT * 1 * 1440 /1000000;
SSF1INTMASS = SSF1INTFL .* FLKGSSF1;

plot(timeint,SSF1INTMASS,'r');
datetick('x');
title('pchip interpolated SSF1 turbidity mass out [kg/day]');


% calculate area under SSF1 mass curve
areaSSF1mass = trapz(timeint,SSF1INTMASS)


%remove NaN values headloss loss
time_SSF1HL = Time;
time_SSF1HL(isnan(HeadlossSSF1))=[];
HLSSF1 = HeadlossSSF1;
HLSSF1(isnan(HeadlossSSF1))=[];

%SSF1 interpolated flowrate in m/hr
time_SSF1flmh = Time;
time_SSF1flmh(isnan(FlowSSF1))=[];
SSF1FLmh = FlowSSF1;
SSF1FLmh(isnan(FlowSSF1))=[];

timeint = min(Time):1/144:max(Time);

SSF1INTFLmh = interp1(time_SSF1flmh,SSF1FLmh,timeint,'pchip','extrap');

% interpolate HL SSF1
```

```
timeint = min(Time):1/144:max(Time);
figure('Name','Headloss and flowarte SSF1');
HLSSF1INT = interp1(time_SSF1HL,HLSSF1,timeint,'pcchip','extrap');
plot(Time,HeadlossSSF1,'*','Color',[0.466666666666667 0.674509803921569
0.188235294117647]);
datetick('x');
hold on;
[hAx,hLine1,hLine2] = plotyy(timeint,HLSSF1INT,timeint,SSF1INTFL);

hLine1.LineStyle = '--';
hLine1.Color = [0 0 1];
hLine2.LineStyle = '-';
ylabel (hAx(1),'Headloss [cm]','Color',[0 0 1])
ylabel (hAx(2),'Flowrate [LPM]')
set (hAx(1),'YTick',[0:10:100]);
set (hAx(2),'YTick',[0:1:5]);
xlabel('Scraping intervall');
legend('SSF1','SSF1i','Flowrate');


%% SSF2

%remove NaN values
time_SSF2 = Time;
time_SSF2(isnan(TurbiditySSF2))=[];
TSSF2 = TurbiditySSF2;
TSSF2(isnan(TurbiditySSF2))=[];


% interpolate SSF2
timeint = min(Time):1/144:max(Time);
figure ('Name','Turbidity SSF2');
TSSF2INT = interp1(time_SSF2,TSSF2,timeint,'pchip','extrap');
plot(time_SSF2,TSSF2,'k',timeint,TSSF2INT,'r:');
datetick('x');
title('pchip interpolated SSF2 turbidity [NTU]');

% calculate area
areaSSF2 = trapz(timeint,TSSF2INT)

%CALCULATE remaining SS2 MASS

%remove NaN values in FlowSSF2LPM
time_SSF2mass = Time;
time_SSF2mass(isnan(FlowSSF2LPM))=[];
SSF2FL = FlowSSF2LPM;
SSF2FL(isnan(FlowSSF2LPM))=[];

timeint = min(Time):1/144:max(Time);
figure ('Name','flowrate SSF2');
SSF2INTFL = interp1(time_SSF2mass,SSF2FL,timeint,'pchip','extrap');

plot(timeint,SSF2INTFL);
datetick('x');

figure('Name','turbidity mass out SSF2');
FLKGSSF2 = TSSF2INT * 1 * 1440 /1000000;
SSF2INTMASS = SSF2INTFL .* FLKGSSF2;
```

```
plot(timeint,SSF2INTMASS,'r');
datetick('x');
title('pchip interpolated SSF2 turbidity mass out [kg/day]');


% calculate area under SSF2 mass curve
areaSSF2mass = trapz(timeint,SSF2INTMASS)


%remove NaN values headloss loss
time_SSF2HL = Time;
time_SSF2HL(isnan(HeadlossSSF2))=[];
HLSSF2 = HeadlossSSF2;
HLSSF2(isnan(HeadlossSSF2))=[];



% interpolate HL SSF2
timeint = min(Time):1/144:max(Time);
figure('Name','Headloss SSF2');
HLSSF2INT = interp1(time_SSF2HL,HLSSF2,timeint,'pchip','extrap');
plot(timeint,HLSSF2INT,'g');
datetick('x');
title('pchip interpolated SSF2 HL [cm]');
xlabel('scraping period');
ylabel('Head Loss [cm]');

%% OHT

%remove NaN values
time_OHT = Time;
time_OHT(isnan(TurbidityOHT))=[];
TOHT = TurbidityOHT;
TOHT(isnan(TurbidityOHT))=[];


% interpolate OHT
timeint = min(Time):1/144:max(Time);
figure ('Name','turbidity OHT');
TOHTINT = interp1(time_OHT,TOHT,timeint,'pchip','extrap');
plot(time_OHT,TOHT,'k',timeint,TOHTINT,'r:');
datetick('x');
%title('pchip interpolated OHT turbidity [NTU]');

% calculate area
areaOHT = trapz(timeint,TOHTINT)

%CALCULATE remaining OHT MASS

%remove NaN values in FlowSSF2LPM
figure ('Name','flowrate into OHT');
OHTINTFL = SSF1INTFL + SSF2INTFL;
plot(timeint,OHTINTFL);
datetick('x');
title('pchip interpolated flowrate INTO OHT (CWT)[LPM]');
figure ('Name','tubidity mass into OHT');
FLKGOHT = TOHTINT * 1 * 1440 /1000000;
OHTINTMASS = OHTINTFL .* FLKGOHT;
```

```
plot(timeint,OHTINTMASS,'r');
datetick('x');
title('pchip interpolated remaining OHT mass [kg/day]');


% calculate area under OHT mass curve
areaOHTmass = trapz(timeint,OHTINTMASS)

% total flow LPM to KLD -> *1.44
 totalflowOHT = 1.44 * trapz(timeint,OHTINTFL)

%% Calculation of removal

rem_RW_HRF1 = arearwmass / 2 - areaHRF1mass
rem_RW_HRF2 = arearwmass / 2 - areaHRF2mass
rem_HRF_SSF1 = (areaHRF1mass + areaHRF2mass) / 2 - areaSSF1mass
rem_HRF_SSF2 = (areaHRF1mass + areaHRF2mass) / 2 - areaSSF2mass
rem_RW_OHT = arearwmass - areaOHTmass

check_input = arearwmass
check_removal =
rem_RW_HRF1+rem_RW_HRF2+rem_HRF_SSF1+rem_HRF_SSF2+areaOHTmass


RWINTFL = HRF1INTFL + HRF2INTFL;

totalflowRW = 1.44 * trapz(timeint,RWINTFL)
totalflowHRF1 = 1.44 * trapz(timeint,HRF1INTFL)
totalflowHRF2 = 1.44 * trapz(timeint,HRF2INTFL)
totalflowSSF1 = 1.44 * trapz(timeint,SSF1INTFL)
totalflowSSF2 = 1.44 * trapz(timeint,SSF2INTFL)
totalflowOHT = 1.44 * trapz(timeint,OHTINTFL)
averageflowSSF1 = mean (SSF1INTFL)
averageflowSSF2 = mean (SSF2INTFL)
HRFINTMASS = (HRF1INTMASS + HRF2INTMASS) / 2;
averageremSSF1 = mean (HRFINTMASS - SSF1INTMASS)
averageremSSF2 = mean (HRFINTMASS - SSF2INTMASS)
averageHRFINTMASS = mean (HRFINTMASS)
THRFINT = (THRF1INT+THRF2INT)/2;
averageTHRF = mean (THRFINT)
averageWQSSF1 = mean (TSSF1INT)
averageWQSSF2 = mean (TSSF2INT)

%% Removal and flowrate

% input water quality and removal efficiency

THRFINT = (THRF1INT+THRF2INT)/2;
RESSF1INT = ((THRFINT - TSSF1INT) ./ THRFINT) * 100;
REOSSF1INT = ((TRWINT - TSSF1INT) ./ TRWINT) * 100;

timeint = min(Time):1/144:max(Time);
figure('Name','RE flowrate SSF1');
plot(timeint,RESSF1INT,'g-');
datetick('x');
hold on;
[hAx,hLine1,hLine2] = plotyy(timeint,REOSSF1INT,timeint,SSF1INTFLmh);
```

```
hLine1.LineStyle = '--';
hLine2.LineStyle = '-';
ylabel (hAx(1),'Removal efficiency [%]')
ylabel (hAx(2),'Flowrate [m/hr]')
set (hAx(1),'YTick',[0:10:100]);
%set (hAx(2),'YTick',[0:1:5]);
xlabel('scraping intervall');
legend('RESSF1','ORESSF1','Flowrate');

%% LOAD SSF2

% removal efficiencies

REMEFFHRF1 = ((TRWINTMASS/2 - HRF1INTMASS) ./ (TRWINTMASS/2)) * 100;
REMEFFHRF2 = ((TRWINTMASS/2 - HRF2INTMASS) ./ (TRWINTMASS/2)) * 100;
HRFINTMASS = (HRF1INTMASS + HRF2INTMASS)/2;
REMEFFSSF2 = ((HRFINTMASS - SSF2INTMASS) ./ HRFINTMASS) *100;
OREMEFFSSF2 = ((TRWINTMASS/2 - SSF2INTMASS) ./ (TRWINTMASS/2)) *100;

figure('Name','Removal efficiency HRFs and SSF2');
plot (timeint,REMEFFHRF1,'r',timeint,REMEFFHRF2,'k',timeint,REMEFFSSF2,'g',
timeint,OREMEFFSSF2,'b');
datetick('x');
legend('HRF1','HRF2','SSF2 to HRF','SSF2 to RW','Location','southwest');
title('Removal efficiency HRFs and SSF2');
xlabel('scraping period 1');
ylabel('removal efficiency in [%]');

% removal efficiency in dependence of input water quality

figure('Name','Removal efficiency against input WQ HRF1');
scatter (REMEFFHRF1,TRWINT);
title('Removal efficiency against input WQ HRF1');
xlabel('removal efficiency in [%]');
ylabel('Input Water Quality [NTU]');

figure('Name','Removal efficiency against input WQ HRF2');
scatter (REMEFFHRF2,TRWINT);
title('Removal efficiency against input WQ HRF2');
xlabel('removal efficiency in [%]');
ylabel('Input Water Quality [NTU]');

THRFINT = (THRF1INT + THRF2INT)/2;

figure('Name','Removal efficiency against HRF input WQ SSF2');
scatter (REMEFFSSF2,THRFINT);
title('Removal efficiency against HRF input WQ SSF2');
xlabel('removal efficiency in [%]');
ylabel('Input Water Quality [NTU]');


figure('Name','Overall removal efficiency against RW input WQ SSF2');
scatter (OREMEFFSSF2,TRWINT);
title('Removal efficiency against RW input WQ SSF2');
xlabel('removal efficiency in [%]');
ylabel('Input Water Quality [NTU]');
```

```
figure('Name','Bacteria and Turbidity SSF2');
scatter (TurbiditySSF2,ecoliSSF2);
title('Bacteria WQ SSF2');
xlabel('SSF output WQ [NTU]');
ylabel('E.Coli [CFU/100ml]');

%turb HRF SSF

figure('Name','Turbmass HRF and SSF2');
plot (timeint,HRFINTMASS,'r',timeint,SSF2INTMASS,'g');
datetick('x');
legend('SSF input','SSF output');
title('Tubiditymass in and out of SSF2');
xlabel('scraping period');
ylabel('Turbiditymass [mg/L]');

%% Turbiditymassremoval against Cumulative Flow

remSSF2INTMASS = HRFINTMASS - SSF2INTMASS;

%cumulative flow
% SSF2INTFL is in LPM thus convert *10 /1000 = /100
FLSSF2M3 = cumtrapz (SSF2INTFL/100);
figure('Name','totalflowSSF2');
plot (timeint,FLSSF2M3);
datetick('x');
title('totalflow SSF2');
xlabel('scraping period');
ylabel('Cumulative Flow in [m³]')

%loading
% intmass is in kg/day thus for 10min spans /144
LOADSSF2 = cumtrapz (remSSF2INTMASS/144);
figure('Name','loading of SSF2');
plot (timeint,LOADSSF2);
datetick('x');
title('loading of SSF2');



%turbidity removal against flow
figure('Name','turbidity mass removal against flow SSF2');
plot (FLSSF2M3,LOADSSF2,'g');
title('turbidity mass removal against flow SSF2');
xlabel('Filtered Water in [m³]');
ylabel('Removed Turbidity in [kg]')



%turbidity removal against pressure loss
figure('Name','pressure loss against turbidity mass removal SSF2');
plot (LOADSSF2,HLSSF2INT,'g');
title('Headloss against turbidity mass removal SSF2');
xlabel('Removed Turbidity in [kg]');
ylabel('Headloss in [cm]')

%% Loading

figure('Name','load wq SSF2')
plot (LOADSSF2,TSSF2INT)
```

```
title('Load against WQ SSF2 [NTU]');

figure('Name','turbidityremoval SSF2')
REMSSF2 = (THRF1INT+THRF2INT)/2 - TSSF2INT;
plot (timeint,REMSSF2);
datetick('x');
title ('Turbidity removal of SSF2 [NTU]');

figure('Name','load_turbidityrem SSF2')
plot (LOADSSF2,REMSSF2);
title ('Load against Trubidity removal');
xlabel ('Cumulative Load of SSF2 in [kg]');


%% SSF1 scraping

%turb HRF SSF

HRFINTMASS = (HRF1INTMASS + HRF2INTMASS)/2;

figure('Name','Turbmass HRF and SSF1');
plot (timeint,HRFINTMASS,'r',timeint,SSF1INTMASS,'g');
datetick('x');
legend('SSF input','SSF output');
title('Tubiditymass in and out of SSF1');
xlabel('scraping period');
ylabel('Turbiditymass [mg/L]');

%% Turbiditymassremoval against Cumulative Flow

remSSF1INTMASS = HRFINTMASS - SSF1INTMASS;

%cumulative flow
% SSF1INTFL is in LPM thus convert *10 /1000 = /100
FLSSF1M3 = cumtrapz (SSF1INTFL/100);
figure('Name','totalflowSSF1');
plot (timeint,FLSSF1M3);
datetick('x');
%title('totalflow SSF1');
xlabel('scraping period');
ylabel('Cumulative Flow in [m³]')

%loading
% intmass is in kg/day thus for 10min spans /144
LOADSSF1 = cumtrapz (remSSF1INTMASS/144);
figure('Name','loading of SSF1');
plot (timeint,LOADSSF1);
datetick('x');
xlabel('scraping period');
ylabel('Cumulative load in [kg³]')


%turbidity removal against flow
figure('Name','turbidity mass removal against flow SSF1');
plot (FLSSF1M3,LOADSSF1,'g');
title('turbidity mass removal against flow SSF1');
xlabel('Filtered Water in [m³]');
ylabel('Removed Turbidity in [kg]')
```

```
%% Loading

figure('Name','load wq SSF1')
plot (LOADSSF1,TSSF1INT)
title('Load against WQ SSF1');

figure('Name','turbidityremoval SSF1')
REMSSF1 = (THRF1INT+THRF2INT)/2 - TSSF1INT;
plot (timeint,REMSSF1);
datetick('x');
title ('Turbidity removal of SSF1');

figure('Name','load_turbidityrem SSF1')
plot (LOADSSF1,REMSSF1);
title ('Load against Trubidity removal');
xlabel ('Cumulative Load of SSF1 in [kg]');
```

**Cost-Analysis**

The CBA encompasses a micro-economic analysis considering only internal costs (both for initial investments and O&M) and a macro-economic analysis taking into account a few externalities. Table 46 provides an overview of all the costs included in the CBA with a brief description. The Advanced Setup is itself not independent, but presents another technical option to the water purification part (Life Cycle Stage II). As such, it relies on the infrastructure to collect the rain in the catchment area and to settle it in the pond (Life Cycle Stage I), to distribute it via stand posts and at household level (Life Cycle Stage III ) and to collect and treat the resulting wastewater (Life Cycle Stage IV). The cost-analysis takes this into account by calculating, for both the Alternative and Advanced Setup, the same costs for Life Cycle Stage I, III and IV. The total yearly maintenance costs for the structural installations are considered with 5 % of the overall investment costs. This estimation is based on standard practices by PHED for water supply schemes in West Bengal.

*Table 46 Selection of Cost Items*

| CBA Part | Type of Costs | Direct Costs | Description |
|---|---|---|---|
| **Micro-economic Analysis** | **Investment** (Non-recurring) | Design cost | Architectural and civil engineering tasks (e.g. conceptualization, system dimensioning etc.) (has been neglected here) |
| | | Technology and equipment needs and costs | Pumps, solar panels, pipes |
| | | Material Costs | Among others raw material (e.g. concrete), filter media (sand, etc.), fences |
| | | Shipping costs | Of materials, technology, equipment, import duties (the technology of the Advanced setup comes from Scotland) |
| | | Construction and assembly cost | Machines like diggers, shovels, electricity |
| | | Land acquisition | Costs for leasing the land or the pond |
| | | Construction and assembly | Local labor (alternative setup); external labor (advanced setup) |
| | **Maintenance (**Recurring) | Labor | Operation of equipment |
| | | Electricity | Power for running the pumps, the wastewater treatment plant |
| | | Chemical | Chlorine, Flocculants, Salt, etc.… |
| | | Spare parts and repair | Filter media, worn out parts of machines, etc. (5% of investment costs) |
| **Macro-Economic Analysis** | **Externalities (Community)** | Decline of Income from Aquaculture | Value from loss of produced fish measured by taking annual lease price for pond |
| | | Decline of Bottle-Sales Business | Bottles/price/per day per household (with piped water access) |
| | | Lowered Harvests in Organic Farming | Loss of value from reduced harvests per area compared to conventional agriculture (USD/$m^2$/year) |
| | | Increase of Domestic Water Filter Purchases | Loss of water service fees per each household with filter per year |
| | **Externalities (Society)** | CO2-Emissions | Social costs inflicted per unit of CO2-emissions causes (price/tonne) |

**Calculation of Water Price**

The approach to calculate the water price reflects the total costs to be acquired to make the system break even. In order to be able to draw differentiated inferences about the cost-effectiveness, not only in between the setups but the extend of project interventions included, different scenarios are used for each setup that distinguish in a) their lifetime, b) the infrastructure they include, c) the amount of water which is produced in the number of households they reach, and d) the inclusion of investment in the calculation of the water price.

a) The lifetime is generally assumed to be 30 years for all setups. As several core parts of the advanced setup need to be exchanged after 10 years a scenario with a 10 year lifetime for the advanced setup is also considered as this leads to lower operation and maintenance costs.
b) Three extends of infrastructure included in the investment are considered for each scenario,
    a. Including all infrastructure: catchment area management, water treatment, distribution and waste water treatment.
    b. Including catchment area management and water treatment (without distribution and waste water treatment)
    c. Only the water treatment
c) The systems can be run under different production capacities. Although the sustainable extraction of water from the pond reservoir is calculated to be no more than 20 KLD, scenarios have been calculated for the normal and maximum water production. The alternative system can run on flowrates between 0.1 to 0.2 m/hr SSF filtration speed leading to 14 -28 KLD. The advanced system can treat 2.5 KL per hour thus achieving a maximum production of 60 KLD.
d) As the project had "granted" the setup to the water committee the actual price for water constitutes only of the O&M expenses, thus the water price is also calculated without considering the investment.

**Benefit-Analysis**

*Table 47 Basic values for valuation of benefits*

| Basic Figures | | | |
|---|---|---|---|
| **Parameter** | **Unit** | **Value** | |
| Household size | People/household | 5 | |
| Income per household | INR per year | 18000 - 54000 INR | |
| Additional households gained access to clean water | Number | Alternative | Advanced |
| | | 140-280<br>(14-28 KLD) | 140-600<br>(14 – 60 KLD) |
| Daily income | INR per day | 250,- INR (150 – 350) | |
| Current disease-related sickness | Days/household/per year | 110 (30%) | |
| Averted days of sickness with safe water | Days/household/per year | 73 (20%) | |
| Costs for medicine/hospital visits | INR/per household/per year | 6000,- INR (10 % of average income) | |
| Time surplus from improved water supply | Days / household / year | 30 days | |
| Members employed per household | People/household | 1-2 | |
| Assumed water consumption | Litres/household/day | 100 l (5people x 20L) | |
| Value for bottled water | INR/per 20 litre | 20 INR | |
| Willingness to Pay for Clean Water | Yearly contribution per household | 600,- INR (12months x50 INR) | |

Similar to the costs, the benefits are also calculated for the extend of the infrastructure included, and the number of households that can be reached depending on the amount of treated water. Considering 20L of drinking water demand per person, 140, 280, and 600 households would have an estimated of 14, 28 and 60 KLD per day respectively. Importantly, there are two benefits that can be seen as revenues countable against the investment and O&M costs: The fees to be charged and the support by external donors such as non-profit organization or governmental agencies. The range of benefits accruing to the consumer and the community is much more extensive, yet not all of the benefits are quantifiable and monetizable. Table 473 provides values for basic parameters repeatedly needed for the calculations and
Table 484 exhibits a selection of benefits (and methods to monetize them) addressed in this study.
Each benefit stems from an impact that is, in most cases, calculated on the basis of the relevant Inventory Indicator. For many benefits, the respective Inventory Indicator is the number of households provided with clean drinking water, as can be seen in Table 48.

*Table 48 Benefits and Monetization Methods*

| | Recipient | Benefits (Internal) | Inventory Indicator | Method for Estimation of the Economic Value |
|---|---|---|---|---|
| **Micro-Economic Analysis** | **(Virtual) Project Owner** | Drinking water charge | Clean water delivered to number of households in the village | Willingness to pay for a fixed water fee per year (independent of the volume used), a value that has been attained by a village-wide survey. As a result, each household would spend 600 INR per year (50 INR per month). It is assumed that 210 households would be covered by the Alternative and 370 by the Advanced Setup.<br>(households)*(annual charge) |
| | | Governmental/donor support | Clean water delivered to number of households in the village | As per the GOI norms[40] 50% of O&M can be funded by the central government. |
| | | Loss or profit | | Profit, or amount unmet by the villagers and governmental support, which is required to achieve cost recovery. |
| **Macro-Economic Analysis** | **Consumer** | Time surplus for economic activities | Clean water delivered to number of households in the village | Income gained due to additional working time as of access to clean water at household level per year (considering 8 hours working time and a daily average wage of 250 INR). With an estimated 0,5 hour for each household to acquire water daily, on an annual basis 30 days would be saved. This applies, of course, only to the households with in-house access.<br><br>*(households)*(days)*(daily income) |
| | | Health-related work productivity | Clean water delivered to number of households | Additionally earned income on extra working days per household per |

| | | | | |
|---|---|---|---|---|
| | | | in the village | year as of averted diseases. Currently, it is assumed that a household succumbs to illness 110 days a year, of which 73 days can be averted and additionally be used for working through access to clean water.<br>(households)*(days)*(daily income) |
| | | Reduced costs from purchasing bottled water | Clean water delivered to number of households in the village | Willingness to pay (monthly) (cost of bottled water). Initially each household which will have access to safe water has to spend 600 INR per month for 4LPD safe water bottled.<br>(households)*(daily water consumption)*(cost of a bottle) |
| | | Cost savings from reduced medicine purchases and medicine and hospital visits | Clean water delivered to number of households in the village | Average costs avoided per household per year as of averted diseases. It is assumed that prior to the intervention a household spends 10% (or at least actually needs to spend) of its daily income for medicine and visits to the hospital. It is proposed that, after the intervention only 5% has to be spent thus 5% reduction. Average salary of 60.000 INR per year |
| | **Community** | Employment in the water supply | Workers employed permanently full-time | Income generated for the community due to new (permanent) employment. It is assumed that employment is created in operating the system (with a monthly salary of 5,000 INR). For the treatment plant alternative 1, advanced 0,25 full time job. For the catchment area management 0,25, for waste water treatment plant operation 1 |
| | | Increase in property value | Access to sanitation provided to the number of households/clean water delivered to the number households in the village | Value enhancement of community land through better environmental quality by an estimated rise of 10 % per year (for 1 katha land present price 12000 INR assuming each family has 1 katha). It is assumed that up to 35,000 m2 is affected by the value upgrading. |
| | | Cost savings for leisure activities | Access to sanitation provided to the number of households | Savings on travel costs by avoided trips to surrounding recreational sites per household per year. It is assumed that each household makes 10 trips per year, with an average costs of 60 INR to each of the five household members. (households)*(trips)*(price/travel) |
| | | Improved environmental | Access to sanitation provided to the number | Costs for cleaning up the environment from visible waste, for |

| | | | | |
|---|---|---|---|---|
| | | quality | of households/ Clean water delivered to the number households in the village | example faeces or plastic bottles. It is assumed that 35,000 $m^2$ (maximum organic area) need to be cleaned up, and that 60 $m^2$ can be cleaned up in one hour for an assumed per-hour-wage of 20 INR. $\frac{(Total\ area)}{(Area\ cleaned\ per\ hour)}$*(wage/hour) |
| | | Independent Maintenance | Skill development/capacity training | Decreased maintenance costs: Of the maintenance costs (5 % of overall investment) approximately 30 % are labour costs. Local workers, trained in technical skills through the capacity building workshops, have 5 times lower salaries than personnel by external companies, costs that are saved hence. |
| | | Better Salaries | Better salaries for involved employees in construction of water supply | Increase of salaries: unskilled labours with 200,- INR per month get training and are skilled and receive incomes on 300,- INR for alternative: construction: 20, operation: 4; yearly benefit of (240days * 100INR* 24 people = 576 000 INR) |
| | | Increased organic fish production | Amount of natural and well-tasting fish produced within the community | Reduced costs from purchasing well-tasting fish that is now produced in the local pond. It is assumed that the organic fish needs 6 times as long as the aquaculture fish and is only twice as valuable thus the added value is one third of the pond lease thus 8333,- INR (25000/3) |

**Benefit-Cost Ratio**

The benefit cost ratio is the ratio of the present value of the benefits to the present value of the costs. The benefits and costs are each discounted at the applicable discount rate. The ratio has to be greater than 1 for the option to be acceptable. [177]

$$BCR = \frac{Present\ Value\ of\ Benefits}{Present\ Value\ of\ Cost}$$

## T. COST CALCULATIONS

Costs mentioned in D2.2 are updated in addition varying scales or production quantities are considered.

*Table 49 Cost Current setup with tube wells*

| Current Setup | Years | | | | | |
|---|---|---|---|---|---|---|
| Lifetime | 10 | | | | | |
| Investement: | Unit Price [INR] | No. / Amount | Total Price [INR] | No. / Amount | Total Price [INR] | Remarks |
| Tubewell [piece] | 35,000 ₹ | 140 | **4,900,000 ₹** | **280** | **9,800,000 ₹** | one tubewell for each household |
| Land [m²] (2m² per tubewell) | 47 ₹ | 280 | **13,192 ₹** | **560** | **26,384 ₹** | 2m² per tubewell |
| **Total investemet** | | | **4,913,192 ₹** | | **9,826,384 ₹** | |
| **Operating costs per month:** | | | | | | |
| Fixed operating costs (labour) | 469 ₹ | 140 | **65,625 ₹** | **280** | **131,250 ₹** | time for hand pumping, 30 min per day per household (0,5/8h *250 INR*30 days) |
| Variable operating costs (energy) | 5 ₹ | 0 | **0 ₹** | | **0 ₹** | no electric current |
| Variable operating costs (chemicals) | | 0 | **0 ₹** | | **0 ₹** | no chemicals for treatment or monitoring |
| Variable operating costs (structural and spares) | 146 ₹ | 140 | **20,472 ₹** | **280** | **40,943 ₹** | spare parts: washers, nuts and bolts, strainer cleaning, resinking (5% of investement) |
| Variable operating costs (WQ monitoring) | | 0 | **0 ₹** | | **0 ₹** | monitoring is not done |
| **Total O&M per month** | | | **86,097 ₹** | | **172,193 ₹** | |

*Table 50 Estimated costs of a Conventional setup*

| Conventional Setup | Years |
|---|---|
| Lifetime | 30 |

| Investment: | Unit Price [INR] | No. / Amount | Total Price [INR] | Remarks |
|---|---|---|---|---|
| Screening | 79,860 ₹ | 1 | **79,860 ₹** | |
| Sedimantation tank | 159,720 ₹ | 1 | **159,720 ₹** | |
| Coagulation tank | 79,860 ₹ | 1 | **79,860 ₹** | |
| Rapid Sand Filter | 319,440 ₹ | 1 | **319,440 ₹** | |
| Disinfection chamber /chemical house | 159,720 ₹ | 1 | **159,720 ₹** | |
| Pumps and piping | 159,720 ₹ | 1 | **159,720 ₹** | |
| Electric Installation | 79,860 ₹ | 1 | **79,860 ₹** | |
| Dosing Equipment | 159,720 ₹ | 1 | **159,720 ₹** | |
| OHT and CWT | 958,320 ₹ | 1 | **958,320 ₹** | |
| Land [$m^2$] | 47 ₹ | 20 | **942 ₹** | |
| **Total Investment** | | | **2,157,162 ₹** | |
| **Operating costs per month:** | | | | |
| Fixed operating costs (labour) | 10,000 ₹ | 1 | **10,000 ₹** | one full time skilled operator |
| Variable operating costs (energy) | 5 ₹ | 225 | **1,125 ₹** | 2x750 pumps*5 hours per day |
| Variable operating costs (chemicals) | 34 ₹ | 84 | **2,856 ₹** | coagulant and disinfection per $m^3$ |
| Variable operating costs (structural) | 8,988 ₹ | 1 | **8,988 ₹** | spare parts: pump replacement, structural repairs, |
| Variable operating costs (WQ monitoring) | 2,500 ₹ | 1 | **2,500 ₹** | laboratory measurements |
| pond lease | 2,083 ₹ | 1 | **2,083 ₹** | 25000 per year |
| **Total O&M per month** | | | **27,553 ₹** | |

*Table 51 Investment costs of the Alternative setup*

| Alternative Setup (overall) | Years |
|---|---|
| **Lifetime** | 30 |

| Investment: | Unit Price [INR] | No. / Amount | 14 KLD Total Price [INR] | No. / Amount | 28 KLD Total Price [INR] |
|---|---|---|---|---|---|
| **collection and protection** | | | | | |
| Catchment engineering | 50,000 ₹ | 1 | **50,000 ₹** | **1.5** | **75,000 ₹** |
| Pond renovation | 115,000 ₹ | 1 | **115,000 ₹** | | **115,000 ₹** |
| Silt trap | 150,000 ₹ | 1 | **150,000 ₹** | | **150,000 ₹** |
| Fencing | 200,000 ₹ | 1 | **200,000 ₹** | | **200,000 ₹** |
| **Water treatment** | | | | | |
| HRF/SSF/ACF | 900,000 ₹ | 1 | **900,000 ₹** | | **900,000 ₹** |
| RWT, OHT, CWT and pump house | 900,000 ₹ | 1 | **900,000 ₹** | | **900,000 ₹** |
| Solar System | 380,000 ₹ | 1 | **380,000 ₹** | **1.5** | **570,000 ₹** |
| Pumps and Piping | 100,000 ₹ | 1 | **100,000 ₹** | | **100,000 ₹** |
| **Water Distribution** | | | | | |
| distribution line (pipes) | 1,422,839 ₹ | 1 | **1,422,839 ₹** | **1.5** | **2,134,259 ₹** |
| **Sewerage and Waste Water Treatment** | | | | | |
| sewerage | 2,361,194 ₹ | 1 | **2,361,194 ₹** | **1.5** | **3,541,791 ₹** |
| settling tanks | 359,370 ₹ | 1 | **359,370 ₹** | **1.5** | **539,055 ₹** |
| decentral reedbed filter | 831,875 ₹ | 1 | **831,875 ₹** | **1.5** | **1,247,813 ₹** |
| **Total Investment all incl.** | | | **7,770,278 ₹** | | **10,472,917 ₹** |
| **treatment + catchment** | | | **2,795,000 ₹** | | **3,010,000 ₹** |
| **only water production** | | | **2,280,000 ₹** | | **2,470,000 ₹** |

*Table 52 Bill of Quantities (BOQ) and estimation according to the schedule of rates*[178]

| ESTIMATION OF COST Slow Sand Filter SSF Horizontal Roughing Filter HRF Activated Carbon Filter ACF | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SR | | ITEMS | | LENGTH | WIDTH | HEIGHT | AREA | NUMBER | VOLUME | RATE | TOTAL |
| | | | | (M) | (M) | (M) | SHUTTERI | | (M$^{3)}$ | (INR) | (INR) |
| | | CONCRETE M20 | | | | | | | | | |
| | | | | | | | | | | | |
| 1 | | Long Walls(hrf) | | 5.8 | 0.15 | 1 | 23.8 | 2 | 1.74 | | |
| | | | | | | | | | | | |
| 2 | | Short walls - 1 m height(hrf) | | 0.73 | 0.15 | 1 | 7.04 | 4 | 0.438 | | |
| | | | | | | | | | | | |
| 3 | | Short walls(hrf) | | 0.73 | 0.15 | 1 | 14.08 | 8 | 0.876 | | |
| | | | | | | | | | | | |
| 4 | a | Long Walls(ssf)-upto 1m from base | | 5.8 | 0.2 | 1 | 36 | 3 | 3.48 | | |
| | | | | | | | | | | | |
| | b | Long Walls(ssf)- 1m-2m | | 5.8 | 0.15 | 1 | 35.7 | 3 | 2.61 | | |
| | | | | | | | | | | | |
| 5 | a | Short walls - 1 m height(ssf) | | 0.73 | 0.15 | 1 | 3.52 | 2 | 0.219 | | |
| | | | | | | | | | | | |
| | b | Short walls(ssf)-upto 1m from base | | 0.73 | 0.175 | 1 | 18.1 | 10 | 1.2775 | | |
| | | | | | | | | | | | |
| | c | Short walls(ssf)-1m- 2m | | 0.73 | 0.15 | 1 | 17.6 | 10 | 1.095 | | |
| | | | | | | | | | | | |
| 7 | | Slab | | 5.8 | 1.86 | 0.15 | 2.298 | 1 | 1.6182 | | |
| | | | | | | | 10.79 | | | | |
| | | | | | | | | | | | |
| 7 | | Slab | | 5.8 | 1.77 | 0.125 | 1.8925 | 1 | 1.28325 | | |
| | | | | | | | 10.27 | | | | |
| | | | | | | | | | | | |
| 8 | | Column(ssf) | | 0.3 | 0.3 | 1.65 | 5.94 | 3 | 0.4455 | | |
| | | | | | | | | | | | |
| 9 | | Column(ssf) | | 0.4 | 0.4 | 1.65 | 7.92 | 3 | 0.792 | | |
| | | | | | | | | | | | |
| 10 | | Column(hrf) | | 0.3 | 0.3 | 3 | 10.8 | 3 | 0.81 | | |
| | | | | | | | | | | | |
| 11 | | Beam B1 | | 5.8 | 0.3 | 0.35 | 8.54 | 2 | 1.218 | | |
| | | | | | | | | | | | |
| 12 | | Beam B2 | | 1.86 | 0.2 | 0.3 | 4.944 | 4 | 0.4464 | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | | Beam B3 | | 1.86 | 0.3 | 0.3 | 2.592 | 2 | 0.3348 | | |
| 14 | | Beam B4 | | 5.8 | 0.3 | 0.3 | 7.32 | 2 | 1.044 | | |
| 15 | | Foundation | | 6.5 | 4.6 | 0.2 | 4.44 | 1 | 5.98 | | |
| 16 | | Foundation beam fb2 | | 6.5 | 0.4 | 0.35 | 4.83 | 1 | 0.91 | | |
| | | Foundation beam fb1 | | 6.5 | 0.3 | 0.25 | 6.8 | 2 | 0.98 | | |
| | | Foundation beam fb3 | | 3.6 | 0.3 | 0.25 | 5.85 | 3 | 0.81 | | |
| | | Foundation pcc | | 6.5 | 4.6 | 0.05 | | 1 | 1.50 | | |
| | | SUBTOTAL concrete | | | | | | | 29.90 | 6000 | 179,386 ₹ |
| | | Plastrocate super | | | | | | | | | 3,500 ₹ |
| 17 | | Sand SSF | | 4 | 0.73 | 0.9 | | 2 | 5.256 | 830 | 4,362 ₹ |
| | | Gravel layer SSF | | 4 | 0.73 | 0.25 | | 2 | 1.46 | 1400 | 2,044 ₹ |
| | | Gravel 1 HRF | | 2 | 0.73 | 1 | | 2 | 2.92 | 1400 | 4,088 ₹ |
| | | Gravel 2 HRF | | 1.5 | 0.73 | 1 | | 2 | 2.19 | 1400 | 3,066 ₹ |
| | | Gravel 3 HRF | | 1 | 0.73 | 1 | | 2 | 1.46 | 1400 | 2,044 ₹ |
| | | Activated carbon | | 0.85 | 0.73 | 0.4 | | 2 | 0.4964 | | 18,308 ₹ |
| | | Gravel ACF | | 0.85 | 0.73 | 0.2 | | 2 | 0.2482 | 1400 | 347 ₹ |
| 18 | | Shuttering with 12mm ply | | | | | 251.06 | | | 683 | 171,419 ₹ |
| 19 | | Excavation 5x7x1.5 | | | | | | | 52.5 | 108 | 5,670 ₹ |
| 20 | | Steel | | 1.50% | | | | | 3.32 | 65450 | 217,498 ₹ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | | Pipe | 25 mm dia | 6 | | | | 1 | | 300 | 1,800 ₹ |
| | | Pipe | 40 mm dia | 30 | | | | 1 | | 507 | 15,210 ₹ |
| | | Pipe | 75 mm dia | 22 | | | | 1 | | 829 | 18,238 ₹ |
| 22 | | Tap | 25mm | 1 | | | | 2 | | 600 | 1,200 ₹ |
| | | Valves | 40mm | 1 | | | | 14 | | 2650 | 37,100 ₹ |
| | | Valves | 75mm | 1 | | | | 8 | | 6653 | 53,224 ₹ |
| | | Socket, L, T, union, fittings | | | | | | | | | 4,080 ₹ |
| 23 | | Launder, plastering, pipe fitting | | | | | | | | | 15,000 ₹ |
| 24 | | Drain | brickwork | 36 | 0.75 | 0.075 | | | 2.025 | 5173 | 10,475 ₹ |
| | | Drain | cement sand | | | | | | | | 6,000 ₹ |
| 25 | | Drilling of holes in HRF chambers | | | | | | | | | 3,000 ₹ |
| 26 | | Two coats of non toxic (potable | | | | | | | 48 | 80 | 3,840 ₹ |
| | | Outside one coat of weather proof | | | | | | | 48 | 40 | 1,920 ₹ |
| | | Epoxy lining | | | | | | | | | 30,000 ₹ |
| 27 | | Miscellaneous 5% of total | | | | | | | | | 40,641 ₹ |
| | | **TOTAL** | | | | | | | | | **853,461 ₹** |

*Table 53 Operation costs Alternative setup*

| Operating costs per month: | Unit Price [INR] | No. / Amount | 14 KLD Total Price [INR] | No. / Amount | 28 KLD Total Price [INR] | Remarks |
|---|---|---|---|---|---|---|
| **Fixed Labour costs (Treatment)** | 5,000 ₹ | 0.75 | **3,750 ₹** | 1 | **5,000 ₹** | unskilled operator |
| **Fixed Labour Cost (Catchment Area)** | 5,000 ₹ | 0.25 | **1,250 ₹** | 0.5 | **2,500 ₹** | unskilled operator |
| **Fixed Labour Cost (Distribution and Waste Water)** | 5,000 ₹ | 1 | **5,000 ₹** | 1.5 | **7,500 ₹** | unskilled operator |
| **Variable operating costs (energy)** | 5 ₹ | 0 | **0 ₹** | | **0 ₹** | Solar pumps thus no energy needed |
| **Variable operating costs (chemicals)** | 34 ₹ | 42 | **1,411 ₹** | 84 | **2,822 ₹** | Reduced disinfection due to SSF and ACF |
| **Structural O&M (5 % of Treatment)** | 9,500 ₹ | 1 | **9,500 ₹** | 1.08 | **10,292 ₹** | factors according to investment rattio |
| **Structural O&M (5% of Catchment)** | 2,146 ₹ | 1 | **2,146 ₹** | 1.05 | **2,250 ₹** | factors according to investment rattio |
| **Structural O&M (5% of Distribution and Waste Water)** | 20,730 ₹ | 1 | **20,730 ₹** | 1.50 | **31,095 ₹** | factors according to investment rattio |
| **Variable operating costs (filter media exchange)** | 1,538 ₹ | 1 | **1,538 ₹** | 2 | **3,076 ₹** | explenation *1 |
| **Variable operating costs (WQ monitoring)** | 592 ₹ | 1 | **592 ₹** | 2 | **1,183 ₹** | explenation *2 |
| **pond lease** | 2,083 ₹ | 1 | **2,083 ₹** | | **2,083 ₹** | 25000 per year |
| **Total system O&M per month** | | | **48,000 ₹** | | **67,802 ₹** | |
| **O&M treatment + catchment** | | | **22,270 ₹** | | **29,207 ₹** | |
| **O&M only treatment** | | | **18,874 ₹** | | **24,457 ₹** | |

***1 media exchange:**

| ITEM | Unit price | Amount | Total price | Price per month |
|---|---|---|---|---|
| **Refill of media(sand) every three years** | 22 | 85 | 1870 | **52 ₹** |
| **Labour for sieving, washing and filling of media** | 250 | 40 | 10000 | **278 ₹** |
| **Refill of media (ACF) every 2 years** | 90 | 250 | 22500 | **938 ₹** |
| **Labour for sieving, washing and filling of media** | 250 | 6 | 1500 | **63 ₹** |
| **Washing of Gravel every 2 years** | 250 | 20 | 5000 | **208 ₹** |
| **per month expenses** | | | | **1,538 ₹** |

***2 Water Quality monitoring**

| ITEM | Unit price | Amount | Price per month |
|---|---|---|---|
| **Bacteria presence / absence by $H_2S$ vials every week** | 40 | 4 | **160 ₹** |
| **FAC test every week** | 3.75 | 4 | **15 ₹** |
| **Laboratory verification every six month** | 2500 | 0.17 | **417 ₹** |
| **per month expenses** | | | **592 ₹** |

*Table 54 Investment costs Advanced setup*

| Advanced Setup | |
|---|---|
| | Years |
| Lifetime | 30 |

| Investement: | Unit Price [INR] | No. / Amount | 14 KLD Total Price [INR] | No. / Amount | 60 KLD Total Price [INR] |
|---|---|---|---|---|---|
| Land [m²] | 47 ₹ | 30 | **1,413 ₹** | | **1,413 ₹** |
| AFM inkl RWT and CWT | 1,800,000 ₹ | 1 | **1,800,000 ₹** | | **1,800,000 ₹** |
| Mixed oxidants generator | 1,500,000 ₹ | 1 | **1,500,000 ₹** | | **1,500,000 ₹** |
| Online monitoring system | 1,000,000 ₹ | 1 | **1,000,000 ₹** | | **1,000,000 ₹** |
| OHT and pump house | 300,000 ₹ | 1 | **300,000 ₹** | **2.14** | **642,000 ₹** |
| Pumps and Piping | 100,000 ₹ | 1 | **100,000 ₹** | **2.14** | **214,000 ₹** |
| | | | | | |
| Total Investment all incl. | | | **10,191,691 ₹** | | **₹ 22,306,521.31** |
| investment treatment + catchment | | | **5,216,413 ₹** | | **₹ 6,314,556.31** |
| only treatment | | | **4,701,413 ₹** | | **5,157,413 ₹** |

*Table 55 O&M Advanced setup*

| Advanced Setup<br>Operating costs per month: | Unit Price [INR] | No. / Amount | 14 KLD<br>Total Price<br>[INR] | No. / Amount | 60 KLD<br>Total Price<br>[INR] | Remarks |
|---|---|---|---|---|---|---|
| **Fixed Labour costs (Treatment)** | 10,000 ₹ | 0.25 | **2,500 ₹** | 0.5 | **5,000 ₹** | skilled operator |
| **Fixed Labour Cost (Catchment Area)** | 5,000 ₹ | 0.25 | **1,250 ₹** | 1 | **5,000 ₹** | unskilled operator |
| **Fixed Labour Cost (Distribution and Waste Water)** | 5,000 ₹ | 1 | **5,000 ₹** | 2 | **10,000 ₹** | unskilled operator |
| **Variable operating costs (energy)** | 5 ₹ | 1135.5 | **5,678 ₹** | **4.29** | **24,356 ₹** | AFM (circulating pump 216 + compressor 792 + raw and clear water pump 67.5), MO (15), OM (45) kWh per month |
| **Variable operating costs (chemicals)** | 643 ₹ | 1 | **643 ₹** | **4.29** | **2,758 ₹** | AFM (408.- + 150.-)<br>MO (85.-) |
| **Variable operating costs (spares)** | 12,883 ₹ | 1 | **12,883 ₹** | **2.15** | **27,634 ₹** | AFM (283.- + 100.-)<br>MO replacement after 10 years (12,500.-) |
| **Structural O&M (5 % of Treatment)** | 19,589 ₹ | 1 | **19,589 ₹** | 1.10 | **21,489 ₹** | factors according to investment rattio |
| **Structural O&M (5% of Catchment)** | 2,146 ₹ | 1 | **2,146 ₹** | 2.25 | **4,821 ₹** | factors according to investment rattio |
| **Structural O&M (5% of Distribution and Waste Water)** | 20,730 ₹ | 1 | **20,730 ₹** | 3.21 | **66,633 ₹** | factors according to investment rattio |
| **Variable operating costs (WQ monitoring)** | 8,550 ₹ | 1 | **8,550 ₹** | **2.15** | **18,340 ₹** | OM replacement after 10 years (8300.-) SIM 250.- |
| **pond lease** | 2,083 ₹ | 1 | **2,083 ₹** | **1.00** | **2,083 ₹** | 25000.- per year |
| **Total system O&M per month** | | | **81,052 ₹** | | **188,116 ₹** | |
| **O&M treatment + catchment** | | | **55,322 ₹** | | **111,483 ₹** | |
| **O&M only treatment** | | | **51,926 ₹** | | **101,661 ₹** | |

*Table 56 O&M Advanced setup w/o replacement (lifetime 10 years)*

| **Advanced Setup**<br>**Operating costs per month (without replacement after 10 years):** | **Unit Price [INR]** | **No. / Amount** | **Total Price [INR] 14KL** | **No. / Amount** | **Total Price [INR] 60KL** | **Remarks** |
|---|---|---|---|---|---|---|
| **Fixed Labour costs (Treatment)** | 10,000 ₹ | 0.25 | **2500** | 0.5 | **5000** | skilled operator |
| **Fixed Labour Cost (Catchment Area)** | 5,000 ₹ | 0.25 | **1250** | 1 | **5000** | unskilled operator |
| **Fixed Labour Cost (Distribution and Waste Water)** | 5,000 ₹ | 1 | **5000** | 2 | **10000** | unskilled operator |
| **Variable operating costs (energy)** | 5 ₹ | 1135.5 | **5,678 ₹** | 4,871.30 | **24,356 ₹** | AFM (circulating pump 216 + compressor 792 + raw and clear water pump 67.5),<br>MO (15), OM (45)<br>kWh per month |
| **Variable operating costs (chemicals)** | 643 ₹ | 1 | **643 ₹** | 4.29 | **2,758 ₹** | AFM (408.- + 150.-)<br>MO (85.-) |
| **Variable operating costs (spares)** | 483 ₹ | 1 | **483 ₹** | 2.15 | **1,036 ₹** | AFM (283.- + 100.-) |
| **Structural O&M (5 % of Treatment)** | 19,589 ₹ | 1 | 19,589 ₹ | 1.10 | 21,489 ₹ | factors according to investment rattio |
| **Structural O&M (5% of Catchment)** | 2,146 ₹ | 1 | 2,146 ₹ | 2.25 | 4,821 ₹ | factors according to investment rattio |
| **Structural O&M (5% of Distribution and Waste Water)** | 20,730 ₹ | 1 | 20,730 ₹ | 3.21 | 66,633 ₹ | factors according to investment rattio |
| **Variable operating costs (WQ monitoring)** | 250 ₹ | 1 | **250 ₹** | 1.00 | **250 ₹** | SIM 250.- |
| **pond lease** | 2,083 ₹ | 1 | **2,083 ₹** | **1.00** | **2,083 ₹** | 25000.- per year |
| **Total O&M per month** | | | **60,352 ₹** | | **143,428 ₹** | |
| **O&M treatment + catchment** | | | **34,622 ₹** | | **66,795 ₹** | |
| **O&M only treatment** | | | **31,226 ₹** | | **56,974 ₹** | |

## U. BENEFIT MONETIZATION

***Table 57 Monetization of external benefits***

| Extend of investement involved | Benefits to be monetized | Suggestion for Monetization | Setups: Conventional Setup | Setups: Alternatve Setup | | Setups: Advanced Setup | | Calculation for the Monetization |
|---|---|---|---|---|---|---|---|---|
| | | | 112 | 140 | 280 | 140 | 600 | |
| | | | Gained benefit | Gained benefit | Gained benefit | Gained benefit | Gained benefit | |
| **1** | Time surplus for economic activities | Income gained due to additional working time as of access to clean water at household level per year (considering 8 hours working time and daily average wage 250 INR). With an estimated 0,5 hour for each household to acquire water daily, on an annual basis 30 days would be saved. This applies, of course only to the households with in-house access. | **840.000 ₹** | **1.050.000 ₹** | **2.100.000 ₹** | **1.050.000 ₹** | **4.500.000 ₹** | **(30 days surplus/year)*250 INR/day* household** |
| **123** | Health-related work productivity | Additionally earned income on extra working days per household per year as of averted diseases. Currently, we assume that a household succumbs to illness 110 days a year, of which we proposed 73 can be averted and additionally be used for working through access to clean water x(households)*x(days)*(daily income) **w/o catchment area only 75% of the water quality is achieved** | **2.044.000 ₹** | **2.555.000 ₹** | **5.110.000 ₹** | **2.555.000 ₹** | **10.950.000 ₹** | **(73 days averted /year)* 250 INR/day* households [*0,75 w/o catchment]** |
| **123** | Reduced costs from purchasing bottled water | To calculate the economic benefit for the reduced purchase of bottled water, the price per unit of bottled water (bottle of 20L=20INR) is multiplyied by the yearly consumption (only drinking water) of the respective number of households. It is assumed that each person drinks 2L of water per day. x(households)*x(yearly bottles consumed)*x(price of a bottle of water)**w/o catchment area only 75% of the water quality is achieved** | **408.800 ₹** | **511.000 ₹** | **1.022.000 ₹** | **511.000 ₹** | **2.190.000 ₹** | **5people*2L*365days/20L* 35INR* houshold [*0,75 w/o catchment]** |
| **123** | Cost savings from reduced medicine purchases and medicine and hospital visits | Average costs avoided per household per year as of averted diseases. It is assumed that prior to the intervention a household spends 10% (or at least actually needs to spend) of its daily income for medicine and visits to the hospital. It is proposed that, after the intervention only 5% has to be spent thus 5% reduction. Average salary of 60.000 INR per year, **w/o catchment area only 75% of the water quality is achieved** | **336.000 ₹** | **420.000 ₹** | **840.000 ₹** | **420.000 ₹** | **1.800.000 ₹** | **0,05*60000*household [*0,75 w/o catchment]** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **123** | Employment operator treatment | Income generated for the community due to new (permanent) employment. It is assumed that employment is created in operating the system (with a monthly salary of 5,000 INR). For the treatment plant alternative 1 advanced 0,25 | **0 ₹** | **60.000 ₹** | **60.000 ₹** | **15.000 ₹** | **15.000 ₹** | **no. of employees*yearly salary** |
| **12** | Employment operator catchment | for the catchment alternative 0,25, advanced 0,25 | **0 ₹** | **15.000 ₹** | **15.000 ₹** | **15.000 ₹** | **15.000 ₹** | **no. of employees*yearly salary** |
| **1** | Employment operator distribution and waste water | for waste water treatment alternative 1, advanced 1 | **0 ₹** | **60.000 ₹** | **60.000 ₹** | **60.000 ₹** | **60.000 ₹** | **no. of employees*yearly salary** |
| **12** | Biodiversity in catchment area | Additionally, it is assumed that the organic farming increases salary by 1 INR per square metre (the total area measures in average 25,000 m2) | **0 ₹** | **25.000 ₹** | **25.000 ₹** | **25.000 ₹** | **25.000 ₹** | **area *1 INR** |
| **123** | Increase in property value | Value enhancement of community land through access to drinking water by an estimated rise of 10 % per year (for 1 katha land present price 12000 INR assuming each family has 1 katha). | **134.400 ₹** | **168.000 ₹** | **336.000 ₹** | **168.000 ₹** | **720.000 ₹** | **1200*no. of households** |
| **12** | cost savings for leisure activities | Savings on travel costs by avoided trips to surrounding recreational sites per household per year. It is assumed that each household makes 10 trips per year, with an average costs of 60 INR to each of the five household members. | **112.000 ₹** | **140.000 ₹** | **280.000 ₹** | **140.000 ₹** | **600.000 ₹** | **20,-travel expenses * 5 people * housholds *10 trips** |
| **12** | Improved environmental quality | Costs for cleaning up the environment from visible waste, for example feces or plastic bottles. It is assumed that 35,000 m2 (maximum organic area) need to be cleaned up, and that 60 m2 can be cleaned up in one hour for an assumed per-hour-wage of 20 INR.*x(wage/hour) | **0 ₹** | **57.600 ₹** | **57.600 ₹** | **0 ₹** | **0 ₹** | **20 INR*8 hours*30days*12months** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **123** | Independent Maintenance treatment | Decreased maintenance costs: Of the maintenance costs (5 % of overall investment) approximately 30 % are labor costs. Local workers, trained in technical skills through the capacity building workshops, have 5 times lower salaries than personnel by external companies, costs that are saved hence. | | **0 ₹** | **54,358 ₹** | **54,358 ₹** | **0 ₹** | **0 ₹** | **0.30* yearly OM*80%** |
| **1** | Independent Maintenance full system | Decreased maintenance costs: Of the maintenance costs (5 % of overall investment) approximately 30 % are labor costs. Local workers, trained in technical skills through the capacity building workshops, have 5 times lower salaries than personnel by external companies, costs that are saved hence. | | **0 ₹** | **83,883 ₹** | **83,883 ₹** | **0 ₹** | **0 ₹** | **0.30* yearly OM*80%** |
| **123** | Better salaries for involved employees in construction of treatment system | Increase of salaries: unskilled labours with 200,- INR per month get training and are skilled and receive incomes on 300,- INR for alternativ: construction: 10, operation: 4; yearly benefit of (240days x 100INR x 14 people = 336 000 INR) | **336000** | **0 ₹** | **336,000 ₹** | **336,000 ₹** | **0 ₹** | **0 ₹** | **240 days *100INR * 14 people = 336 000 INR)** |
| **1** | Better salaries for involved employees in construction of distribution and waste water treatment system | Increase of salaries: unskilled labours with 200,- INR per month get training and are skilled and receive incomes on 300,- INR for alternativ: construction: 20, operation: 4; yearly benefit of (240days x 100INR x 24 people = 576 000 INR) | **576000** | **0 ₹** | **576,000 ₹** | **576,000 ₹** | **576,000 ₹** | **576,000 ₹** | **240 days *100INR * 24 people = 576 000 INR)** |
| **12** | Increased organic fish production | Reduced costs from purchasing well-tasting fish that is now produced in the local pond. It is assumed that the organic fish needs 6 times as long as the aquaculture fish and is only twice as valuable thus the added value is one third of the pond lease thus INR (2083/3 per month) | **694** | **0 ₹** | **8,332 ₹** | **8,332 ₹** | **8,332 ₹** | **8,332 ₹** | **(1/3* 2083 INR)*12 months** |
| | **Total benefits in monetary value** | | | **3,875,200 ₹** | **6,120,173 ₹** | **10,964,173 ₹** | **5,543,332 ₹** | **21,459,332 ₹** | |

**123** **benefits for all stages of investement**

**12** **only for all incl. And treatment + catchment**

**1** **only for all incl.**

*Table 58 Microeconomic Benefits (incomes) and calculation of losses with running O&M*

| Extend of investem ent involved | Benefits to be monetized | Suggestion for Monetization | Unit | Setups | | | | | | | Calculation for the Monetization |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Conven-tional Setup | Alternatve Setup | | Advanced Setup 30 years | | Advanced Setup 10 years | | |
| | | | | 112 | 140 | 280 | 140 | 600 | 140 | 600 | |
| | | | | Gained benefit | Gained benefit | Gained benefit | Gained benefit | Gained benefit | Gained benefit | Gained benefit | |
| 123 | Drinking water charge | Willingness to pay for a fixed water fee per year (independent of the volume used), a value that has been attained by a village-wide survey. As a result, each household would spend 600 INR per year (50 INR per month). It is assumed that only 80% of the 140 households receive clean water from the Conventional Setup, 140 and 280 households would be covered by the Alternative Setup and 140 and 600 households by the Advanced Setup. | 600 | 67,200 ₹ | 84,000 ₹ | 168,000 ₹ | 84,000 ₹ | 360,000 ₹ | 84,000 ₹ | 360,000 ₹ | 600 INR*households |
| 123 | Governmental support only treatment | The centre/State Government for piped water supply (user fee charges) covers 50% of O&M costs including minor repairs. | 50.0% | 165,315 ₹ | 113,246 ₹ | 146,741 ₹ | 311,556 ₹ | 609,968 ₹ | 187,356 ₹ | 341,841 ₹ | 0,5*O&M costs*12 months |
| 12 | Governmental support treatment and catchment | The centre/State Government for piped water supply (user fee charges) covers 50% of O&M costs including minor repairs. | 50.0% | | 133,621 ₹ | 175,241 ₹ | 331,931 ₹ | 668,896 ₹ | 207,731 ₹ | 400,770 ₹ | 0,5*O&M costs*12 months |
| 1 | Governmental support all inkl. | The centre/State Government for piped water supply (user fee charges) covers 50% of O&M costs including minor repairs. | 50.0% | | 288,002 ₹ | 406,814 ₹ | 486,313 ₹ | 1,128,695 ₹ | 362,113 ₹ | 860,569 ₹ | 0,5*O&M costs*12 months |
| 123 | Loss or Profit only treatment | Money missing for achieving payment of all O&M (O&M - fees - GOI contribution) in the only treatment customers would only pay 50% of the water fee as the water would not have the same quality | 50.0% | -98,115 ₹ | -71,246 ₹ | -62,741 ₹ | -269,556 ₹ | -429,968 ₹ | -145,356 ₹ | -161,841 ₹ | O&M - drining water charge (50%)- government support |
| 12 | Loss or Profit treatment and catchment | Money missing for achieving payment of all O&M (O&M - fees - GOI contribution) without the distribution and waste water treatment customers would only pay 75% of the water fee | 75.0% | | -70,621 ₹ | -49,241 ₹ | -268,931 ₹ | -398,896 ₹ | -144,731 ₹ | -130,770 ₹ | O&M - drining water charge (75%)- government support |
| 1 | Loss or Profit including all | Money missing for achieving payment of all O&M (O&M - fees - GOI contribution) | 100.0% | | -204,002 ₹ | -238,814 ₹ | -402,313 ₹ | -768,695 ₹ | -278,113 ₹ | -500,569 ₹ | O&M - drining water charge - government support |

## V. LCA INVENTORY

*Table 59 Alternative setup inventory data*

| | Alternative Setup: Inputs/Outputs [Inventory Indicators (Inventory Data)] | | | | | |
|---|---|---|---|---|---|---|
| **Life Stages** | **CONSTRUCTION** | **OPERATION** | | | | **DISPOSAL** |
| | | **Collection & protection** | **Water purification** | **Water distribution** | **Wastewater collection and treatment** | |
| **INPUTS** | 1-Participation of local community (both men and women) in the different phases of assessment, planning, design, construction and assembly operations<br>2-Water committee formation<br>3-Mechanical and manual construction of pond, silt trap, water storage tanks, filter units, solar system, distribution network , sanitation units and sewerage with waste water treatment plant<br>4-Use of local materials available in the region for construction (reinforcing steel, cement, bricks, wood, pipes, valves, pumps, PV cells, batteries, electrical equipment, etc.) | 5-land under controlled usage1 designated for the catchment area (25,000 to 35,000 m2 )<br>6-Precipitation input mostly during the months of April to October (appr. 1500mm/a)<br>7-Manual maintenance of bunds and harvesting channels, fencing<br>8-Energy: solar power pumping from pond to Raw Water Tank<br>(3 to 7 kWh/d)<br>9-Pump parts and spares acquisition<br>10- Manual replacement of spare parts of equipment<br>11-Offline manual monitoring of the water quality (Field test kit, laboratory) | 12-labour and material for general operation and maintenance of facilities and equipment<br>13- repair of system<br>14-Manual scrapping of top level of Slow Sand Filter<br>15- possibly cleaning of gravels of HRF after some years<br>16-Manual chlorination of water leaving the filtering system<br>17-Chlorine application (1.4-2.8 L/d )<br>18-Manual replacement of activated carbon every 1 to 2 years<br>19-Sand for the filter replacement every 3-4 years<br>20-Offline manual monitoring of the water quality (Field test kit, laboratory) | 21-labour and material for general maintenance and repair of pipe network<br>22-Energy: solar power pumping from Clear Water Tank to Overhead Tank<br>(3 to6.5 kWh/d)<br>23-Offline manual monitoring of the water quality (Field test kit, laboratory) | 24-labour and material for general operation and maintenance of facilities and equipment | 25-labour and equipment for destruction of constructions,<br>26-manual labour for handling disposal materials concrete, bricks, cast iron, etc. |

| | | | | | | |
|---|---|---|---|---|---|---|
| **OUTPUTS** | 27-Available sanitary dual pit latrines to protect the catchment area from nearby contamination<br>28- constructed pond, silt trap, water storage tanks, filter units, solar system, distribution network , sanitation units and sewerage with waste water treatment plant<br>29-Excavated soil used to construct bunds around the pond<br>30-Provision of electrical power from solar system<br>31-Promotion of gender equality between men and women in the community by compulsory involvement of 50% women in water committee | 31-Organic farming land free from open defecation (25,000 to 35,000 m2)<br>32-Evapotranspiration from catchment area and water reservoirs (ponds, tanks, etc)<br>33- Control of erosion, soil for repair of bunds<br>34-Mitigation in the ground and water sources contamination by less use of pesticides, fertilizers<br>35-Change in cultural and traditional practices for the land cultivation and agricultural production<br>36 Less space designated to ponds for aquaculture | 36- Inexpensive clean safe water production (between 14 and 28 KLD) 37-Top Scrapping material could be used as fertilizer<br>38-crossflush water from the Horizontal Rough Filter is recycled through the silt trap into the pond (2000 L/1-3d)<br>39- jobs<br>40- training (capacity building: workshops every 6 months for 2-4 committee members)<br>41- knowledge acquisition of involved stakeholders | 42-provision of safe water near to the household (63 households) | 43-Sewage sludges from the wastewater sedimentation tanks<br>44-Biogas production result of sludge anaerobic treatment<br>45-Source of Nitrogen and Phosphorous for fertilization of agricultural production | 46-debris and rubble material from installations and tanks (to be recycled, used for landfill, houses foundations, roads refill)<br>47-Hazardous materials from solar panels, batteries, transformer, etc., to be recycled or properly disposed |

*Table 60 Advanced setup inventory data*

| Advanced Setup: Inputs/Outputs [Inventory Indicators (Inventory Data)] | | | |
|---|---|---|---|
| **Life Stages** | **CONSTRUCTION** | **OPERATION** | **DISPOSAL** |
| | **description** | **Water purification** | **description** |
| **INPUT** | 48- provision of ready made treatment system imported from abroad<br>49-Construction of access road and concrete pads for the placement of equipment containers<br>50- setup and installation of equipment by technical experts<br>51-Installation of 25kW transformer to produce 220V single phase power for operation of equipment | 59-General maintenance of facilities and equipment<br>60- Energy:<br>disinfection of water leaving AFM filtering operation by dosing pump application of mixed oxidant (0,5 kWh/day)<br>55 electric power blower and pumping<br>(7.2 kWh/d)<br>Chemicals for AFM system: 6L APF/PAC Alum/ month<br>; 8.5kg MagPhlow / month;<br>61-Mixed oxidant components application( 4.5kg salt / month)<br>62-New dosing pump replacement every 5 years and accessory peristaltic dosing pump tube replaced every 6-12 months.<br>63-Online Monitoring system: every 10 years replacement<br>64-Energy: Online monitoring of water quality (1.5 kWh/day)<br>56-Pumps parts and spares acquisition<br>57- Manual replacement of spare parts of equipment<br>58-Water pump replacement approx. every 5 years | 68-manual labour of disposing materials<br>69-Disposal of construction materials mild steel, PVC, etc.<br>70-manual labour for handling disposal materials |
| **OUTPUTS** | 73- AFM, MO and online monitoring setup74-provision of electrical energy (220V single phase electrical power) | 78- inexpensive clean safe water production (between 2.5 and 50 KLD)<br>79-Backwash recirculation to Silt trap for retreatment (5000L/d)<br>93-water pollution possible by contamination with coagulant<br>92-training on the usage of an advanced treatment setup | 86-MS from installations and tanks can be sold for recyclinged 88-Hazardous materials from electric equipment, batteries, transformer, etc., to be recycled or properly disposed |

## W. DESCRIPTION OF LCA IMPACTS

### SOCIETY LEVEL – SOCIO-ECONOMIC

**Increased Grassroots Development**

The project as a whole empowers the community members to become more capable of organising their own issues independently, and also to build up their socio-economic resilience. As an effect, communities become less dependent on external parties such as big companies. By strengthening community based water supply and poverty alleviation, increased egalitarianism and gender equality can be achieved.

**Economic Value-add**

The increased individual productivity combined with other aspects of the project, which entail economic benefits (e.g. improved agriculture or a time-surplus for income-generating activities), lead to larger incomes on a household level; additionally, the village may be able to export food and other consumables at some point, thereby contributing to the regional economy. The same effect results when individuals, by means of better education and skills training, increase their productivity.

**Human Resources Developmen**

Families having more time and resources (especially due to averted waterborne diseases) can invest in the integrity of their families, in raising their children and enabling them more easily to attend school. In this way, the community produces individuals that may be healthier, better educated and more skilled as a labour force, which in turn comes as an advantage for many areas of society (e.g. when contributing to economic growth or participating in political processes).

**Business Opportunities for Regional Companies**

Constructing and running the system will not only generate employment within the community: Various steps require companies or individuals with different skills, both sporadically and permanently. In this way, the project creates employment as well outside the community.

**Use of renewable energy**

The alternative setup generates solar power for pumping water between different infrastructure components. Additionally, biogas can be generated from the treatment of wastewater. Both have a positive impact on the energy balance. Besides promoting the uptake of renewable energies in rural India, the project can serve as a full scale pilot model on how to set up integrated water-energy solutions.

### SOCIETY LEVEL – ENVIRONMENTAL

**Exploitation of Non-renewable Materials**

Especially for the construction of the water purification and wastewater treatment plant non-renewable materials such as sand, gravel, or cement are used. These are recyclable, if at all, only by difficult energy-intense procedures or when naturally decomposing. In addition, exploiting them often involves impacts inflicting ecological or social spheres at the mining site.

**Greenhouse Gas Emissions**

Building, operating and maintaining the water supply and wastewater treatment system necessitates energy along the entire value chain. Processes of the alternative system are generally not very energy-intense (e.g. much human labour instead of machines is deployed); in fact, given its ecosystem focus (gravity-based transport or plant-based treatment) carbon emissions are lower compared to centralized treatment plants or the supply by bottles. The alternative setup produces renewable energy, both through solar panels and a biogas reactor. Considering 6-13.5 kWh per day energy requirement of the alternative system and an average emission factor of 0.82 t $CO_2$ / MWh, the solar setup saves 1.8 to 4, whereas the advanced system generates 12.6 tons of $CO_2$ per year.

## COMMUNITY LEVEL – SOCIO-ECONOMIC

**Increase in Property Value**
The establishment of a well-functioning sanitary and water supply system is a capital-intensive infrastructure, in this way the project leads to an upgrading of public and private property value.

**Sludge-based Fertilizer Production**
Fertilizer resulting as an output from the wastewater treatment and the subsequent biogas production can be sold by the community to its member or neighbouring communities. Deployed in agriculture, it creates an additional indirect value by increasing the yielded harvests.

**Wastewater Reclamation for Agriculture**
The treated wastewater is designated to be used in agriculture for purposes of irrigation. Additional water will increase agricultural harvests especially during the spring months with prolonged dry periods. The treated wastewater can still be rich in nutrients, which allows the decrease of fertilizer usage.

**Cost Savings for Leisure Activities**
The villagers travel regularly to spend their time on recreational activities (like doing pick-nick) as they find the villages' environment too dirty (also due to open defecation). With the access to sanitation, it can be expected that people spend more time in the village and its surroundings, hence saving on travel costs.

**Skill Development**
Community members as part of the water committee as well as those involved in running the plant participate in capacity building workshops in which they learn about the basics on WASH-issues and acquire technical skills in masonry, plumbing and water treatment. Especially the technical skills may be valuable for other employments or for solving practical problems in the private context. The same benefit would also apply for villagers that join voluntarily, but are otherwise not participating in the project.

**Strengthened Community Integrity**
As the project is concerning the whole community (although not all members are participating in it), multiple occasions for exchange and common activities bring many members together. Apart from interactional aspects, the project is only shouldered when the community takes up the responsibility and works together. It can be anticipated that this enhances the sense of community.

**Strengthened Relationships with External Stakeholders**
The project involves several meetings where external public stakeholders from local, regional or even state level, but also NGO's and business people will visit the community and engage with its members. Therewith, there are various points to bring attention to other issues in the community, or to make business connections.

**Employment**
Across various stages of the project, work by community members is required, which directly and indirectly creates jobs. Running the plant will necessitate the employment of operators. More jobs indirectly issue from maintaining the system and in a further project state also exploiting and processing outputs like biogas or sludge.

**Increased well-being due to a cleaner environment**
There is strong scientific evidence that certain characteristics of the physical environment (e.g. the cleanliness or greened structures) affect its inhabitants psychologically. Installing sanitation in the community will decrease open defecation, so will a drainage system decrease waste water staging in the area. Together, these two will lead to a cleaner living environment, with positive health implications for the villagers.

**Awareness on WASH-issues**
The implementation of the project will be paired with workshops where awareness raising on WASH-issues is provided. Besides reducing the likelihood for the dissemination of diseases, people are trained to adapt their behaviour for dealing with issues around using water and sanitation facilities.

**Increased Community Resilience**
The combination of impacts, including better health conditions or generating savings resulting from higher incomes, will make the community more resilient against climate change and associated risks (e.g. drought-related harvest losses, flooding or tropical storms).

**Independent Maintenance**
As opposed to a system being built entirely by an external company, the participatory approach chosen in this project allows the community to independently operate and maintain the technology. This has not only economic benefits as less money is spent on O&M; in many development projects, foreign technology is often rendered dysfunctional soon after external support ends, not seldom causing the entire project to fail. Furthermore, the acquisition of skills enables the villagers to capitalize on their skills and replicate the system in other places.

**Noise Attenuation**
The supply of bottled water motorized vehicles, probably a few times per week, creates noise pollution for the inhabitants that live close to the distribution routes. Noise attenuation will be another result of the introduction of the localized water supply.

**Refunds for Land Use**
The catchment area will be altered in their land usage which may conflict with some income-generating activities, especially agriculture. The usage of land for the treatment plant causes a long-term loss for the respective land owner, either an individual or the community. This causes costs for the projects as the land owners need to be reimbursed.

**Decline of Income from Aquaculture**
Using the pond as a sedimentation tank to store and purify the rainwater implies to reduce the magnitude of fish farming in it. While a natural amount of fish has a positive impact on the water quality, intense fish farming including feeding the fish involves eutrophication of the water and reduction of source water quality. The pond owner has a reduced income for which the projects need to account by reimbursements.

**Increase of Domestic Water Filter Purchases**
It has turned out that the project as a whole, but especially the awareness raising on WASH issues, has prompted some better off villagers to buy domestic water filters. At the same time, they showed less commitment to participate in the project. This development is counterproductive as their contribution to the payment of water fees is required to cover the O&M expenses.

**Lowered Harvests through Organic Farming**
The replacement of conventional through organic farming may, on some occasions, produce fewer harvests given the (in conventional agriculture usually) intense deployment of artificial fertilizer and pesticides. Such a development can be countered though by using, for example, biological pest control or the sludge as fertilizer.

**Decline of Water Bottle Business**
Apart from the environmental benefits related to resource saving, noise and emission reduction, the bottles salesmen and suppliers' business may be negatively affected by the provision of clean drinking water through the project.

### COMMUNITY LEVEL – ENVIRONMENTAL

**Improved Environmental Quality**
The environmental quality may be improved by introducing access to sanitation and organic farming, while creating awareness on water pollution may result in ripple effects for other environmental issues such as solid waste disposal. Expectedly, most improvements will occur in the area around the pond, where the focus of environmental protection is set.

**Benefits for Biodiversity**
Curbing open defecation by providing latrines reduces nutrients as well as biologically toxic substances (e.g. antibiotics) contained in human faeces. Eutrophication is an important issue for plants that are used to only low inputs of nutrients and animals that inhabit low-nutrient ecosystems. In this way, the project may increase biodiversity. This effect may additionally be supported by the introduction of organic farming which, in contrast to conventional practices, makes less use of pesticides and other agro-chemicals.

**Improvement of Water Sources**
Surface water sources are protected from uncontrolled waste water discharge and runoffs of faeces, pesticides and fertilizers. The groundwater, which, in the village, is close to the earth's surface and therewith directly affected by open defecation and conventional agriculture. Pollution occurs when, for example, pathogens or pesticides infiltrate into the groundwater body with the event of rainfalls. By providing sewerage and a wastewater treatment plant, this effect can be minimized almost entirely.

**Soil Erosion**
The catchment area as well as the rainwater channels will likely transport water containing large quantities of soil flushed away from the surroundings by the forces of rain. At various points, the system has unit processes where sedimentation is enabled. In this way, the top soil often rich in nutrients stays in the system and can be reintroduced to the fields.

**Disposal of System and Spare Parts**
Disposal of system components will occur during the course of the entire life cycle. Spare parts (e.g. pumps, pipes, or filter media) need to be exchanged and disposed step-by-step. What distinguishes the system is the application of low-impact materials: Most of them are natural materials easily disposable or recyclable. This is an important aspect in remote rural areas where disposal for solid waste is rarely in place.

**Land Use Change**
The entire system induces a land use change in some areas of the village and its surroundings, with differentiated (and in part unforeseeable) impacts for the local environment. Some parts of the system like the treatment plant use up the space they are built on entirely. The catchment areas, the pond, or the reedbed filter may, on the other side, allow for the development of new ecosystems that could increase biodiversity or the environmental quality.

**Less Arsenic Contamination of Immediate Surroundings**
The arsenic, which is contained in the groundwater, has been brought up to the surface through tube wells. It has not only been consumed with drinking water but also for irrigation. Generally, the project creates awareness about the arsenic issue, so people retain from using it for drinking and irrigation.

## CONSUMER LEVEL – SOCIO-ECONOMIC

**Time Surplus for Economic or Educative Activities**
The access to both water and sanitation on a household level saves time as people do not have to walk to the public facilities. The time saved here can be put directly into income-generating activities or by investing it the children's education. For example, sending children to school instead of letting them work in the household will, in the long term, pay back with better education and eventually jobs. This benefits the whole family by a larger household income.

**Reduced Costs from Purchasing Bottled Water**
Currently, some households buy one 20L bottle of drinking water every two days. Those households spend a large deal of their income in this way. The provision of potable water through the community based supply has the potential to lower these costs and release money for other activities.

**Health-related Work Productivity**
Providing better access to drinking water and sanitation reduces waterborne diseases so that people become ill less often. A higher work productivity, manifesting both in a greater number of days to work and general performance, makes a household's income-generating activities more profitable.

**Cost Savings from Reduced Medicine purchases and Hospital visits**
As one of the major outputs, the safe drinking water, delivered through the stand posts and the taps in the households, leads to a reduction in diseases inflicting the community members. With the averted diseases, each community member consequently has to travel less often to the hospital and requires less medicine, which eventually results in cost savings.

**Averted Waterborne Diseases**
Safer sanitation and drinking water, as provided by the project, will cause less waterborne diseases among the participating households. Additionally, improved sanitation will reduce open defecation as a high-potential source for infection. The outcome of this contributes to better well-being and less disease related suffering. Deaths can be prevented, especially for infants and elderly people that are especially vulnerable to waterborne diseases.

**Time Surplus for Social Activities**
By achieving both cheaper access and time savings from domestic water supply, households and its members have ultimately more time to invest in social activities, for example into the family, educating the children or engaging with the project or the community.

**Lowered Consumption of Medicines**
The reduced exposure to waterborne diseases, both by access to sanitation and sufficient clean drinking water, will generally improve human health conditions. In this way, villagers will be less frequently forced to consume medicine. While medicine helps people to overcome diseases, disproportionately high doses subject people too adverse effects (e.g. weakening of the immune system); similarly, the viruses build resistances that render medication increasingly ineffective.

**Increased Privacy and Intimacy for Hygiene Practices**
Defecating openly in public places makes people visible to others when involved in an intimate and potentially shameful act. This is particularly relevant for women. The same applies to hygiene activities – though to a lower degree. The project contributes to solving these issues by making water and sanitation facilities private.

**Higher Comfort due to Indoor Facilities**
Having a toilet and tap installed in the house increases the convenience for the villagers. Walking away from the settlement to defecate openly, or to carry heavy containers of water several days a week, involves arduous work.

**Sufficient Safe Water for Hygiene and Cooking**
When ought to buy water that is relatively expensive compared to the income (while being probably insufficiently aware of the dangers involved with consuming low-quality water), people may be tempted to either use unclean water free of charge or minimize the amount for work in the kitchen or in hygiene. In both cases, the intention to safe costs on water may have negative health consequences. Offering water at a reasonable price, families can use sufficient water to avoid waterborne diseases.

**Gender Equality Advocacy**
Working together men and women advocates and promotes the equality of gender in the community. By increasing the women's participation in the different stages of the project's life, the community becomes more participative and women's work force is more appreciated and less restricted to gender standards that limit their potential and the things they are able to do for their community and families. In addition, with the active participation of the women in the project stages, the sustainability of the water treatment plant is reinforced as now it is a matter of not only men, but includes all members of the community that receive the benefit of clean water provision for their living.

**Equality Enhancement**
There is credible evidence of the correlations between access to water and sanitation and poverty. Poverty is a product of many cause but water and sanitation are key for alleviating it. The confluence of various impacts prompted by the project will ultimately lead to curbing poverty in the village. The equal access independent of income is an important step towards this direction.

## CONSUMER LEVEL – ENVIRONMENTAL

**Less Arsenic Contamination of Tube well Water**
By decreasing the extraction of groundwater further arsenic contamination of groundwater aquifers can be mitigated.

**Cleaner Household**

Connection to sewerage leads to cleaner household environments due to absence of stagnant waste water in the direct surrounding and also leading to less mosquito breeding, thus contributing to mitigating the transfer of deadly viruses such as Dengue fever or Malaria.

## X. MCA RESULTS

*Table 61 MCA Matrices*

| Sustainability Aspect | 1 | 10 | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | do not comply with permissible | comply with desirable | 3.5 | 7 | 5.8 | 9.3 | 6.9 | 9.5 |
| Final Output (working status) | unreliable | reliable | 7.5 | 7.5 | 7 | 9 | 3 | 10 |
| Construction and Installation Material | Hard to source | Readily available | 10 | 10 | 10 | 10 | 1 | 5 |
| Labour and time required for construction | laborous / time consuming | ready / quickly setup | 1 | 6 | 1 | 5 | 1 | 10 |
| Requirement for continuous operation | High consumption | low consumption | 10 | 5 | 7 | 9 | 3 | 6 |
| O&M procedures (qualification of staff) | Difficult | Easy | 10 | 5 | 8 | 9 | 2 | 6 |
| Socio-economic impacts | Negative | Positive | 1 | 5.9 | 7.8 | 10 | 3.1 | 6.4 |
| Environmental impacts | Negative | Positive | 1 | 0 | 9.1 | 10 | 0.5 | 0.5 |
| Adequacy of water price (O&M) | High | Low | 1.4 | 4.4 | 6.1 | 7.3 | 4.1 | 6.1 |
| Adequacy of water price (investment +O&M) | High | Low | 1.2 | 4.7 | 5.9 | 7.0 | 3.3 | 4.9 |
| Ratio of private benefits to costs (Loss and profit) | Low | High | 1.0 | 2.9 | 5.4 | 6.8 | 3.7 | 7.4 |
| Ratio of public benefits to costs | Low | High | 1 | 2.5 | 6.1 | 7.6 | 4.7 | 9.5 |
| **Total Score** | **12** | **120** | **49** | **61** | **79** | **100** | **36** | **81** |

View of Public Society

| Sustainability Aspect | | Weightage (0-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 2 | 7 | 14 | 11.6 | 18.6 | 13.8 | 19 |
| Final Output (working status) | | 3 | 22.5 | 22.5 | 21 | 27 | 9 | 30 |
| Construction and Installation Material | | 1 | 10 | 10 | 10 | 10 | 1 | 5 |
| Labour and time required for construction | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Requirement for continuous operation | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| O&M procedures (qualification of staff) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Socio-economic impacts | | 2 | 2 | 11.8 | 15.6 | 20 | 6.2 | 12.8 |
| Environmental impacts | | 3 | 3 | 0 | 27.3 | 30 | 1.5 | 1.5 |
| Adequacy of water price (O&M) | | 3 | 4.3 | 13.3 | 18.2 | 21.9 | 12.2 | 18.3 |
| Adequacy of water price (investment +O&M) | | 3 | 3.7 | 14.0 | 17.6 | 21.1 | 9.9 | 14.8 |
| Ratio of private benefits to costs (Loss and profit) | | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ratio of public benefits to costs | | 3 | 3 | 7.6 | 18.2 | 22.7 | 14.2 | 28.5 |
| **Total Score** | | **20** | **55** | **93** | **140** | **171** | **68** | **130** |

View of
Government

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 3 | 10.5 | 21 | 17.4 | 27.9 | 20.7 | 28.5 |
| Final Output (working status) | | 2 | 15 | 15 | 14 | 18 | 6 | 20 |
| Construction and Installation, Material | | 1 | 10 | 10 | 10 | 10 | 1 | 5 |
| Labour and time required for construction | | 1 | 1 | 6 | 1 | 5 | 1 | 10 |
| Requirement to assure continuous operation (energy, consumables) | | 2 | 20 | 10 | 14 | 18 | 6 | 12 |
| Operation and maintenance procedures (qualification of staff) | | 1 | 10 | 5 | 8 | 9 | 2 | 6 |
| Socio-economic impacts | | 2 | 2 | 11.8 | 15.6 | 20 | 6.2 | 12.8 |
| Environmental impacts | | 1 | 1 | 0 | 9.1 | 10 | 0.5 | 0.5 |
| Adequacy of water price (O&M) | | 1 | 1.4 | 4.4 | 6.1 | 7.3 | 4.1 | 6.1 |
| Adequacy of water price (investment +O&M) | | 2 | 2.5 | 9.3 | 11.7 | 14.1 | 6.6 | 9.9 |
| Ratio of private benefits to costs (Loss and profit) | | 1 | 1.0 | 2.9 | 5.4 | 6.8 | 3.7 | 7.4 |
| Ratio of public benefits to costs | | 3 | 3 | 7.6 | 18.2 | 22.7 | 14.2 | 28.5 |
| **Total Score** | | **20** | **77** | **103** | **131** | **169** | **72** | **147** |

View of
Community

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 2 | 7 | 14 | 11.6 | 18.6 | 13.8 | 19 |
| Final Output (working status) | | 2 | 15 | 15 | 14 | 18 | 6 | 20 |
| Construction and Installation, Material | | 2 | 20 | 20 | 20 | 20 | 2 | 10 |
| Labour and time required for construction | | 1 | 1 | 6 | 1 | 5 | 1 | 10 |
| Requirement to assure continuous operation (energy, consumables) | | 2 | 20 | 10 | 14 | 18 | 6 | 12 |
| Operation and maintenance procedures (qualification of staff) | | 2 | 20 | 10 | 16 | 18 | 4 | 12 |
| Socio-economic impacts | | 2 | 2 | 11.8 | 15.6 | 20 | 6.2 | 12.8 |
| Environmental impacts | | 2 | 2 | 0 | 18.2 | 20 | 1 | 1 |
| Adequacy of water price (O&M) | | 2 | 2.8 | 8.9 | 12.2 | 14.6 | 8.1 | 12.2 |
| Adequacy of water price (investment +O&M) | | 1 | 1.2 | 4.7 | 5.9 | 7.0 | 3.3 | 4.9 |
| Ratio of private benefits to costs (Loss and profit) | | 1 | 1.0 | 2.9 | 5.4 | 6.8 | 3.7 | 7.4 |
| Ratio of public benefits to costs | | 1 | 1 | 2.5 | 6.1 | 7.6 | 4.7 | 9.5 |
| **Total Score** | | **20** | **93** | **106** | **140** | **174** | **60** | **131** |

View of Consumer

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 3 | 10.5 | 21 | 17.4 | 27.9 | 20.7 | 28.5 |
| Final Output (working status) | | 3 | 22.5 | 22.5 | 21 | 27 | 9 | 30 |
| Construction and Installation, Material | | 1 | 10 | 10 | 10 | 10 | 1 | 5 |
| Labour and time required for construction | | 1 | 1 | 6 | 1 | 5 | 1 | 10 |
| Requirement to assure continuous operation (energy, consumables) | | 1 | 10 | 5 | 7 | 9 | 3 | 6 |
| Operation and maintenance procedures (qualification of staff) | | 1 | 10 | 5 | 8 | 9 | 2 | 6 |
| Socio-economic impacts | | 2 | 2 | 11.8 | 15.6 | 20 | 6.2 | 12.8 |
| Environmental impacts | | 2 | 2 | 0 | 18.2 | 20 | 1 | 1 |
| Adequacy of water price (O&M) | | 3 | 4.3 | 13.3 | 18.2 | 21.9 | 12.2 | 18.3 |
| Adequacy of water price (investment +O&M) | | 1 | 1.2 | 4.7 | 5.9 | 7.0 | 3.3 | 4.9 |
| Ratio of private benefits to costs (Loss and profit) | | 1 | 1.0 | 2.9 | 5.4 | 6.8 | 3.7 | 7.4 |
| Ratio of public benefits to costs | | 1 | 1 | 2.5 | 6.1 | 7.6 | 4.7 | 9.5 |
| **Total Score** | | **20** | **75** | **105** | **134** | **171** | **68** | **139** |

View of Private Operator

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 3 | 10.5 | 21 | 17.4 | 27.9 | 20.7 | 28.5 |
| Final Output (working status) | | 3 | 22.5 | 22.5 | 21 | 27 | 9 | 30 |
| Construction and Installation, Material | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Labour and time required for construction | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Requirement to assure continuous operation (energy, consumables) | | 3 | 30 | 15 | 21 | 27 | 9 | 18 |
| Operation and maintenance procedures (qualification of staff) | | 3 | 30 | 15 | 24 | 27 | 6 | 18 |
| Socio-economic impacts | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Environmental impacts | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adequacy of water price (O&M) | | 3 | 4.3 | 13.3 | 18.2 | 21.9 | 12.2 | 18.3 |
| Adequacy of water price (investment +O&M) | | 1 | 1.2 | 4.7 | 5.9 | 7.0 | 3.3 | 4.9 |
| Ratio of private benefits to costs (Loss and profit) | | 3 | 3.0 | 8.8 | 16.3 | 20.4 | 11.2 | 22.3 |
| Ratio of public benefits to costs | | 1 | 1 | 2.5 | 6.1 | 7.6 | 4.7 | 9.5 |
| **Total Score** | | **20** | **102** | **103** | **130** | **166** | **76** | **150** |

View of Private Investor

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 3 | 10.5 | 21 | 17.4 | 27.9 | 20.7 | 28.5 |
| Final Output (working status) | | 3 | 22.5 | 22.5 | 21 | 27 | 9 | 30 |
| Construction and Installation, Material | | 2 | 20 | 20 | 20 | 20 | 2 | 10 |
| Labour and time required for construction | | 3 | 3 | 18 | 3 | 15 | 3 | 30 |
| Requirement to assure continuous operation (energy, consumables) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Operation and maintenance procedures (qualification of staff) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Socio-economic impacts | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Environmental impacts | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Adequacy of water price (O&M) | | 2 | 2.8 | 8.9 | 12.2 | 14.6 | 8.1 | 12.2 |
| Adequacy of water price (investment +O&M) | | 3 | 3.7 | 14.0 | 17.6 | 21.1 | 9.9 | 14.8 |
| Ratio of private benefits to costs (Loss and profit) | | 3 | 3.0 | 8.8 | 16.3 | 20.4 | 11.2 | 22.3 |
| Ratio of public benefits to costs | | 1 | 1 | 2.5 | 6.1 | 7.6 | 4.7 | 9.5 |
| **Total Score** | | **20** | **67** | **116** | **114** | **154** | **69** | **157** |

**Overall**

| Sustainability Aspect | | Weightage (1-3, total 20) | Current | Conventional | Alternative (pilot) | Alternative (potential) | Advanced (pilot) | Advanced (potential) |
|---|---|---|---|---|---|---|---|---|
| Final Results (Water Quality as per IS10500) | | 2.6 | 9.1 | 18.2 | 15.08 | 24.18 | 17.94 | 24.7 |
| Final Output (working status) | | 2.8 | 21 | 21 | 19.6 | 25.2 | 8.4 | 28 |
| Construction and Installation, Material | | 1.2 | 12 | 12 | 12 | 12 | 1.2 | 6 |
| Labour and time required for construction | | 1 | 1 | 6 | 1 | 5 | 1 | 10 |
| Requirement to assure continuous operation (energy, consumables) | | 1.2 | 12 | 6 | 8.4 | 10.8 | 3.6 | 7.2 |
| Operation and maintenance procedures (qualification of staff) | | 1.2 | 12 | 6 | 9.6 | 10.8 | 2.4 | 7.2 |
| Socio-economic impacts | | 1.2 | 1.2 | 7.08 | 9.36 | 12 | 3.72 | 7.68 |
| Environmental impacts | | 1.4 | 1.4 | 0 | 12.74 | 14 | 0.7 | 0.7 |
| Adequacy of water price (O&M) | | 2.6 | 3.7 | 11.5 | 15.8 | 19.0 | 10.6 | 15.9 |
| Adequacy of water price (investment +O&M) | | 1.8 | 2.2 | 8.4 | 10.6 | 12.7 | 5.9 | 8.9 |
| Ratio of private benefits to costs (Loss and profit) | | 1.6 | 1.6 | 4.7 | 8.7 | 10.9 | 5.9 | 11.9 |
| Ratio of public benefits to costs | | 1.4 | 1.4 | 3.5 | 8.5 | 10.6 | 6.6 | 13.3 |
| **Total Score** | | **20** | **79** | **104** | **131** | **167** | **68** | **141** |