Sustainability of a Decentralized Wastewater Treatment System in Kathmandu Valley, Nepal - Technical and Social Challenges

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Preface

My motivation for choosing to write this thesis was my interest in water and sanitation in developing countries. This has been a very exciting project, I have been able to travel to a new country, meet interesting people, learn about the culture and, of course, learn about the water and sanitation conditions in Nepal. The field work was completed in January and February, 2011.

Many people have contributed to making this thesis what it is. First of all I would like to thank Roshan Shreshta at UNHABITAT and everyone at ENPHO for making it possible for me to come to Nepal and do the field work. Thanks to my translators who made it possible to do all my interviews. Thanks to Ingrid Nyborg for taking the responsibility of teaching me some social science. And of course I would like to thank my supervisors Petter Jenssen and Manoj Pandey.

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Abstract

In Southern Asia the proportion of the population without access to improved sanitation facilities (sanitation facilities that "ensure hygienic separation of human excreta from human contact") is below 50 % (WHO & UNICEF 2010). In Nepal, a country where only 31 % of the population has access to improved sanitation facilities, and 52 % practice open defecation, the situation is severe. Because of this, a location in the Kathmandu Valley, Nepal, was chosen for a case study for this thesis. The aim of this thesis is to give an overview of the condition of the treatment system at this location, and analyze the factors affecting sustainability, both from a technical and a social aspect.

Various approaches are used in the attempts to improve the sanitation challenges, but not all are equally sustainable as the approaches to implementation and choice of facilities are diverse, and not always adjusted to local conditions. Examples of site-specific factors to consider when choosing an approach to implementation might be: economics, water availability, local culture, management, operation and maintenance and so on.

The system studied in this thesis is a decentralized wastewater treatment system consisting of an ABR, two parallel horizontal flow constructed wetlands, and finally two parallel vertical flow constructed wetlands. In the constructed wetland the wastewater is treated by naturally occurring processes. Examples of such processes are; settling and straining of suspended solids and organic material, nitrification and denitrification of ammonia, die-out and predation of microorganisms. Among the advantages of a constructed wetland are low requirement of skilled labor for operation and maintenance and low construction costs.

In order to identify the factors affecting the sustainability of a decentralized wastewater treatment system in Nepal, several investigations concerning treatment efficiency, knowledge, operation and maintenance were carried out. The factors are, for simplicity, divided into technical and social factors. The technical investigations consisted of analyzing samples from different stages in the treatment process; the samples were collected since startup of the system. The social investigations consisted of interviews with key persons connected to the system.

The results from the technical investigations show that the treatment efficiency is fairly high, but the effluent values are not according to neither Nepali nor EU standards. The treatment system is not being operated and maintained in the optimal way, and some simple improvements may give better treatment efficiency. From the interview it is clear that there is great potential of improving knowledge and involvement of the user's committee as well as the community.

Abbreviations

ABR – Anaerobic Baffled Reactor

BOD – Biological Oxygen Demand

CBS – Community Based Sanitation

CDD – Community Driven Development

CLTS – Community Led Total Sanitation

COD – Chemical Oxygen Demand

CW – Constructed Wetland

DEWATS – Decentralized Wastewater Treatment System

EcoSan – Ecological Sanitation

HFW – Horizontal Flow Wetland

O&M - Operation and Maintenance

P – Phosphorus

SDB – Sludge Drying Bed

SSFW – Subsurface Flow Wetland

TP – Total Phosphorus

TSS – Total Suspended Solids

VFW – Vertical Flow Wetland

Contents

1. Introduction

Worldwide the lack of appropriate sanitation is a huge threat to human health; according to the WHO (2010) as many as 2.6 billion people around the world do not have access to improved sanitation (sanitation facilities that "ensure hygienic separation of human excreta from human contact"). Most of these people live in Southern Asia where less than 50 % have access to improved sanitation facilities (WHO & UNICEF 2010).

In September 2000 the UN-Summit came to an agreement on the Millennium Development Goals. Target 7.c is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" (UN 2010). Nevertheless, on world basis we are off track to meet this target, and with the current progress the goal will be missed by 13 % (WHO & UNICEF 2010). Most of the countries off-track to meet the target are situated in Sub-Saharan Africa and Asia (WHO & UNICEF 2010). The most extreme case of poor sanitation is open defecation, which is practiced by 17 % of the people worldwide. However, in certain countries the number is much higher, like Nepal where 52 % of the population practices open defecation (WHO & UNICEF 2010).

Development agencies throughout the developing world strive to improve the sanitation situation, and many different design solutions and approaches to implementation have been developed. However, experience has shown that not all solutions are sustainable in the environment where it is implemented.

In this thesis the terms *sustainability* and *sustainable sanitation* are used for sanitation systems which are adjusted to the economic, social and environmental conditions, the three pillars of sustainability defined by the Brundtland commission in Our Common Future (World Commission on Environment and Development 1987). A more detailed definition may be found under section *Sustainability criteria* on p 8.

In the strive to improve sanitation in Kathmandu, Nepal, a DEWATS (Decentralized Wastewater Treatment Systems) approach has been implemented in a small community in Thimi Municipality in the outskirts of Kathmandu Valley. This treatment system is a "community based" system where the ones responsible is a user's committee consisting of representatives from the local community. The treatment system consists of a pretreatment component, a hybrid constructed wetland (CW), a biogas reactor and a sludge drying bed. Each component is designed to be functional and support sustainability of the system. The constructed wetlands ensure that the pollution caused by the wastewater is minimized, and the sludge drying bed provides fertilizer for farmers. However, there are some operational challenges connected to the system and a central issue in sustainability is how the system is being operated and maintained. The idea is that, in order to achieve optimal use, adequate knowledge and understanding of the system is required from all parties involved.

In this thesis, the author attempts to give an overview of the condition of the treatment system and identify and analyze the factors affecting sustainability, both from a technical and a social aspect. In order to study sustainability of the Sunga treatment system, sampling of the effluent of different stages in the treatment system and interviewing of locals and key persons connected to the treatment system was performed. Since the CWs are the key components of the treatment system the processes occurring here are carefully explained in the *Background* chapter.

2. Background

2.1 Sanitation, health and environment

According to the World Health Organization (WHO) the definition of sanitation is "the provision of facilities and services for the safe disposal of human urine and faeces" (WHO 2011b). The lack of adequate sanitation causes spreading of disease agents and is a major cause of diarrhea worldwide. The WHO estimates that diarrheal diseases alone causes about 1.8 million deaths every year (WHO 2011a).

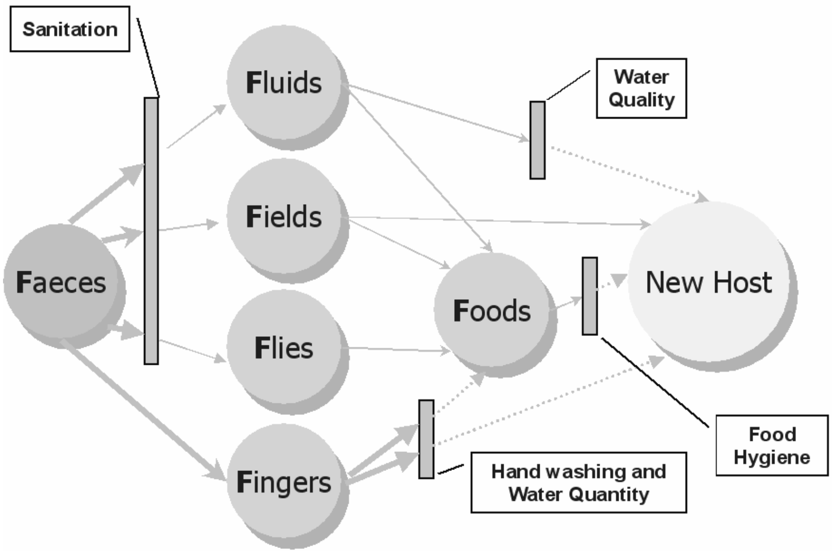

Figure 1: The F-diagram shows pathways of fecal-oral contamination (UNICEF 2008).

As shown in figure 1, pathogens from feces can spread to other humans through different transmission routes. One of the most important pathways is water (represented by fluid in the figure), and protection of water sources from fecal contamination is crucial for preserving the quality and protecting health. Fingers is also an effective transmission route but can be hindered through hand hygiene. Other transmission routes are fields and flies, both causing spreading of pathogens through contamination of food. The most effective way of preventing pathogens to spread is, regardless, to prevent them from entering the environment in the first place; through sanitation.

Inadequate disposal of human wastes may also have severe effects on the environment. Human wastes contain significant concentrations of plant nutrients like nitrates and phosphates. When released to water bodies these nutrients may cause excessive plant production and organic matter accumulation. Subsequently the water and habitat quality is degraded due to oxygen depletion, this process is also termed eutrophication (Cloern 2010).

2.2 Sanitation in Nepal

According to the WHO and UNICEF Joint Monitoring Programme, the coverage of improved sanitation was in 2008 at 31 % of the Nepalese population (WHO & UNICEF 2010). As many as 52 % of the inhabitants practice open defecation (WHO & UNICEF 2010). There is a gap between the rural and urban areas; in the cities 51 % have access to proper sanitation, while only 27 % in the rural areas experience the same (WHO & UNICEF 2010).

In the urban areas sewers are often present but the sewage treatment is lacking. The sewers dispose of the wastewater from the houses directly into the river or stream, causing high levels of contamination. Especially in the dry season some rivers are like open sewers. During the rainy season the rivers pose a threat to health of the populations of urban areas in the lowland as the rivers flood and consequently spread the contaminants into inhabited areas. As urbanization increases, further pressure is put on these areas.

The inadequate or nonexistent sanitation facilities are the cause of about 13,000 deaths, among children under the age of five, every year (International Year of Sanitation 2008 in Nepal 2008). The economy is also suffering from the lack of sanitation in terms of "health expenses, loss of productivity and adverse effects on tourism" (International Year of Sanitation 2008 in Nepal 2008). As mentioned by International Year of Sanitation in Nepal one of the main barriers for progress in sanitation is the lack of priority within the national budget and investment in water and sanitation sector.

According to UNICEF in their annual report in the Water and Sanitation Trust Fund Impact Study Series Nepal is not on their way to meet, neither the Millennium Development Goal, nor the goal of national universal access to sanitation by 2017, but are estimated to be 81 % with current investment levels (Nycander et al. 2011).

2.3 Some approaches to sustainable sanitation

> *"The main objective of a sanitation system is to protect and promote human health by providing a clean environment and breaking the cycle of disease. In order to be sustainable, a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources." (SuSanA 2011)*

This is how the Sustainable Sanitation Alliance (SuSanA) defines sustainable sanitation. SuSanA is a network of more than 134 partners whose objective is to promote sustainable sanitation approaches (SuSanA 2011).

When choosing sanitation technology, sustainability is rarely considered, and it is often assumed that centralized water-based sewer system is the best option in all urban and peri-urban areas. However, there may be factors such as water scarcity, need for fertilized in agriculture, lack of technical skills, and other “institutional and socio-economic barriers” to consider (SuSanA 2009). The implementation of sewer systems without considering water availability can cause severe environmental damage and the populations living downstream of the discharge point may be at health risk. Often the lifespan of the waste inputs and the products are not considered (SuSanA 2009).

There are several examples where sewer systems have been implemented without consideration of water availability and treatment technology, and without acknowledging the limitations in geological, groundwater and climatic conditions (SuSanA 2009). One such example is from rural areas of South Asia where pour flush latrines have been widely promoted but the wastewater treatment system is absent (SuSanA 2009).

Latrines have in many cases been shown to be dysfunctional or malfunctioning due to the lack of simple corrections in basic design to make adjustment to site-specific conditions (SuSanA 2009). Also there is too much focus on the toilets and not on the collection, transport and treatment of the fecal sludge (SuSanA 2009).

There are many different approaches to sanitation in developing countries with the aim of making the facilities appropriate considering economics, culture, environment, resources etc. A variety of approaches may be sustainable when implemented and followed through in the right way. Many experiences have been made in this field, some approaches are presented beneath.

Decentralized Wastewater Treatment Systems

Decentralized Wastewater Treatment Systems (DEWATS) is a technical approach to sanitation where the focus is on locally adjusted solutions and keeping costs low. Through constructing treatment system with low maintenance requirements, no electricity inputs, and using only locally available materials, costs can be kept at a minimum and the community members will be able to operate and maintain the system without hiring technical assistance from outsiders (BORDA 2011b). When constructing a treatment facility close to the place of waste generation sewers covering large areas are not needed and the high cost that this would cause is avoided.

Ecological Sanitation

One approach to sustainable sanitation is Ecological Sanitation (EcoSan) which, instead of considering human waste as something that needs to be disposed of, considers it to be a useful resource (GIZ 2011). Human wastes are rich in nutrients and may be used as fertilizer. Ecosan is not one, or a set of technologies, but rather the paradigm that recognizes human excreta and wastewater as resources that can be reused for fertilizing purposes in agriculture once properly treated. There are several benefits; the soil quality is improved, hence food security is also improved. In addition water resources are not stressed or polluted, lastly it opens for the possibility of biogas production (GIZ 2011). As for technical solutions there are many options like urine-diversion dehydration (UDD) toilets, composting, rainwater harvesting, CWs, vacuum sewers, biogas reactors and many others (GIZ 2011).

In EcoSan the limited need of resources, low water consumption, recycling of nutrients and cost efficiency makes it highly applicable in developing countries where financing opportunities are scarce and water availability low (Jenssen et al. 2004). EcoSan promotes the use of local resources and labor as opposed to conventional wastewater infrastructure which depends on imported goods. This way the local communities can reuse their own nutrients and will reduce spending on fertilizer as well as keep implementation costs low (Jenssen et al. 2004).

Community Based Sanitation

According to BORDA (BORDA 2011a) the most successful way of implementing CBS is by sharing the responsibilities among the different stakeholders such as organizations, the community, government, departments and donors etc. Financing is by means of "private or public development agencies" but implementation and management can be facilitated by either the provider or the community. It is essential that the users contribute with fees to cover operation & maintenance (O&M) costs.

Within BORDA an important principle is that the stakeholders are willing to "promote, finance and manage CBS infrastructure" (BORDA 2011a). Some conditions to be met are; participatory planning, information to the users about the different options, professional design and workmanship, and that the community themselves cover costs of O&M (BORDA 2011a).

The Asian Development Bank has published a report on "Community based development", which compares Community Based Development and Community Driven Development (CDD). CDD is defined as an approach to development of communities where the funds are transferred directly to the communities. Through the help from government, organizations, donors, consultants and technical advisers the community members themselves decide how the money is to be spent (Hill 2009). The idea behind this is that "communities know what is best for them, and if properly guided and educated, will act collectively to advance their interests when given control of the resources and decision making" (Hill 2009). This method is opposed to the top-down method where parties involved in planning and managing are not the ones directly affected by the decisions made. CDD is believed to give more effective and efficient, and thus more sustainable outcomes (Hill 2009).

The main key characteristic of CDD projects is community focus; the implementing agent is always a representative of the community. Other characteristics are participatory planning and design, and that the control of resources, implementation, monitoring and evaluation are all based in the community. It was found, for projects in the "rural water supply and sanitation sector", that the CDD projects were more successful and had a higher probability of cost savings (Hill 2009).

Examples of successful sanitation projects

The Orangi Pilot Project

In 1980 the Orangi Pilot Project started working on an informal settlement on the outskirts of Karachi, Pakistan. The town of 1.2 million inhabitants was overcrowded, and suffered from huge social challenges. The main challenge was identified to be sanitation infrastructure (Pervaiz et al. 2008). A model was evolved of low-cost sanitation where the residents of the community were responsible for building the household sanitation infrastructure, and the municipal authorities were responsible for constructing the secondary infrastructure such as disposal and treatment systems (Pervaiz et al. 2008).

The approach was quickly accepted by the community (Pervaiz et al. 2008) and within a few years the community members themselves had managed to turn the Orangi Pilot Project into a movement where the funding, and the administration was all ensured by the community itself (Zaidi 2001).

Through the use of local materials and skills they were able to construct hundreds of kilometers with "extremely low-cost" sewage line (Zaidi 2001). By April 2001 the sewage system served as many as 90 % of the families in Orangi, and as much as Rs. 82.141 million (£924,000) had been invested in the project by the community members themselves.

As a consequence of the installation of sewage lines the town was changed from a filthy condition of open sewers to a healthier environment where the infant mortality rate was reduced by more than 70 % within the period 1982 to 1991 (Zaidi 2001). In addition mobility was improved for the traders as well as for the women (Zaidi 2001).

This project demonstrates the people's ability to change their own situation even when it comes to implementation of advanced infrastructure, and it is an important counterbalance to the dominant development paradigms which "generally treated poor communities as simply the objects of, rather than the central force of, development" (Zaidi 2001).

After the success with the sanitation project the OPP continued to start other programs within health, education, low-cost housing, and credit. The OPP kept criticizing non-governmental organizations which relied on highly technical solutions that required foreign funding and consultants, instead of looking into the community and exploiting the resources available there (Zaidi 2001).

Community Led total Sanitation

Another example of successful sanitation projects where the community is in focus, and responsible for decision making, is Community Led Total Sanitation (CLTS). The program started in Bangladesh where it spread quickly; today it is represented in more than 20 countries in Asia, Africa, Latin America and the Middle East.

This is an approach where the community members themselves analyze and assess open defecation in order to completely eliminate the practice and make the village open defecation free (IDS 2011). The idea behind the approach is that providing toilets for a community does not necessarily mean that they will be used; instead CLTS has a focus on "behavioral change" and "community mobilization" in order to obtain sustainable improvements. By enhancing knowledge and awareness of how open defecation puts everyone in the community at health risk the inhabitants are motivated for change and to finding appropriate solutions for their community. Through involving the entire community in analyzing the sanitation situation it is believed that they will see what needs to be done and find the solutions suitable for themselves (IDS 2011).

Sustainability criteria

There are many factors affecting sustainability and the mechanisms of understanding them can be complex. Nevertheless, certain key factors can be mentioned; the economic, the environmental and finally the social factors – the three pillars of sustainability defined by the Brundtland commission (World Commission on Environment and Development 1987).

As for sustainable sanitation the choice of technical solutions need to be based on all of these factors. The facilities should be economic feasible in the sense of construction and O&M. An extra contribution to sustainability would be reuse of the products of the sanitation facilities such as sludge for fertilizer. In addition the environmental conditions need to be evaluated; the status on water availability and what would be the consequences of discharging the wastewater to the nearest stream. Finally the social issues; the sanitation facilities needs to be adjusted to fit the needs and wishes of the community, thus the community needs to be involved in decision making. In order to do this they need to be informed and educated on the matter of sanitation and the available technical options. After implementation the system needs to be carefully followed up, not just by the caretaker who ensures proper O&M, but also by the community.

2.4 Constructed wetland as an approach to sustainable sanitation

A CW is a decentralized treatment system based on natural processes; it can be built of local materials and it has, as opposed to conventional systems, a low requirement for skilled labor for O&M. CWs are not just an option for developing countries but are also used for wastewater treatment in developed countries; one example of a successful project is the Klosterenga ecological housing project in Oslo where all graywater from 35 apartments is treated in a CW (Jenssen 2005).

Components of a CW

A CW system may be found in different varieties, with both surface flow and subsurface flow. In this thesis only subsurface flow wetland (SSFW) are included, as this is what is of interest in relation to the treatment system studied. SSFWs can be divided into horizontal flow wetland (HFW) and vertical flow wetland (VFW), the two types of SSFWs can also be combined to create a hybrid system (further explainer under *Hybrid CW* on p17)

A HFW is a wetland where the water flows horizontally through the system, as opposed to a VFW where the water flows vertically. These two flow regimes generates different treatment processes as will be explained in the section *Removal processes in CWs* (p 11). Wastewater normally needs to receive some treatment prior to entering the CW. The pretreatment is further explained under *Pretreatment* (p 10).

The effluent from a CW should be of a quality that can be discharged to waterways. However, there is another product to consider; the sludge collected from the pretreatment facility. The sludge needs to be disposed of safely or treated properly to ensure minimum content of infectious agents, thus making it safe for reuse by humans.

Pretreatment

Due to excessive contents of suspended solids (later defined under *Suspended Solids* p 11) the wastewater needs to be pretreated. Suspended solids that are not removed in the pretreatment step will quickly settle or be filtered out once the wastewater is in the CW and may within a few meters from the inlet the suspended solids may cause clogging of the bed material (Álvarez et al. 2008). Clogging leads to reduced infiltration capacity of the wetland; in a HFW clogging will lead to ponding on the bed surface, in a VFW the clogging would hinder oxygen transfer and hence the treatment ability of the system is reduced (Álvarez et al. 2008).

Because the wastewater is pretreated clogging is delayed or prevented from occurring, thus enhancing sustainability of the system. There are several different types of pretreatment, among the most common are septic tanks and also Imhoff tanks (Álvarez et al. 2008). The option chosen for the treatment system studied in this thesis is, however, an Anaerobic Baffled Reactor. This is a unit quite similar to a septic tank but where certain functions are improved (Akvopedia 2011). The reactor has several baffles hindering to retain both floating and settling sludge. The baffles are, as shown in figure 2, constructed to manipulate the flow of water in upward and downward direction,

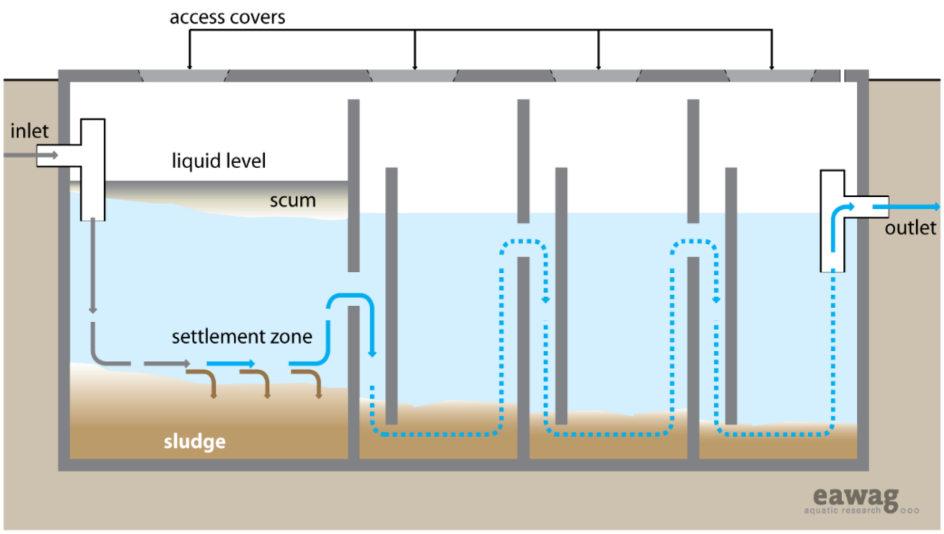

Figure 2: Anaerobic baffled reactor (Akvopedia 2011)

Any of these pretreatment options need to be desludged regularly; the interval of desludging depends on the size of the tank, and the volume and suspended solids levels of the influent wastewater.

Removal processes in CWs

In general there are two different removal mechanisms in a wetland; first there is the liquid/solid separation which includes gravity separation, filtration, adsorption, ion exchange, stripping, and leaching (USEPA 2000). Secondly there is transformation of constituents such as chemical transformation, including oxidation/reduction reactions, flocculation, acid/base reactions, and precipitation (USEPA 2000). These reactions are what we call removal mechanisms but they actually often just detain the contaminants over a period of time (USEPA 2000).

Another removal mechanism is biochemical transformations of organic compounds creating gases like carbon dioxide (CO_2) and methane (CH_4) (USEPA 2000). However, these processes also produce biomass and organic acids that may affect the level of contamination in the effluent (USEPA 2000). As for the biomass it can be transformed to volatile suspended solids or change further through bacterial reaction which may cause leakage of soluble carbon compounds to the water (USEPA 2000).
This section gives an overview of the most important factors to be removed in wetlands and the removal processes for each factor.

Removal of Suspended Solids

Suspended solids are defined as “those solids retained on a standard fiber filter that typically has a nominal pore size of 1.2 µm” (USEPA 2000). The suspended solids measured in wastewater are normally termed Total Suspended Solids (TSS) and the particle size ranges from about 1 µm to greater than 100 µm. The effluent from a septic tank will normally hold suspended solids with origin of fecal matter and food wastes (USEPA 2000), which often has associated organic matter and phosphorus (P) (USEPA 2000), thus making TSS removal essential for removal of organic matter and P.

For fine grained media the mechanisms of “inertial deposition” and “diffusional deposition” are dominant for TSS removal (Kadlec & Wallace 2009). Inertial deposition represent particles moving in such speed that they impact bed particles (Kadlec & Wallace 2009). Diffusional deposition represent random processes which causes particles to move and hence possibly interact with a submerged surface (Kadlec & Wallace 2009). In a gravel bed the TSS removal process is mainly "flow line interception" which is the mechanism of particles moving with the water and being captured in biofilm (Kadlec & Wallace 2009).

In a deep bed (> 40 cm) the roots of plants and their associated biofilms in the upper part will limit flow and can cause blockage, while the lower zone will have better flow (Kadlec & Wallace 2009).

Biofilms form as organic matter settle and is intercepted in the wetland. These biofilms contribute to further entrapment of other solids and form biomats (Kadlec & Wallace 2009). As the water flows through the wetland the amount of organic matter in the water is reduced and less biomat formation will occur further out in the bed (Kadlec & Wallace 2009).

A suspended particle will settle if the time it takes to travel through the bed is greater than the time it takes to fall and hit a surface (Kadlec & Wallace 2009). Removal efficiency is relatively high in a HFW because of low velocity and high surface area of media allowing for TSS to be removed by gravity sedimentation, straining and physical capture and adsorption to media and root biofilm (USEPA 2000).

Normally the TSS entering the wetland is removed quickly, and the effluent values of TSS is not determined by influent values, but by "internal biological processes" (decomposition and resuspention) in the wetland (Kadlec & Wallace 2009).

In the intermittently loaded VFB the process of biomat formation is the same as for HFW. During resting, oxygen is allowed to enter the bed and will help decomposition of organic matter resulting in less biomat formation (Kadlec & Wallace 2009)

Removal of Organic matter

There are several different ways of measuring the organic content in the wastewater, most common are Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (USEPA 2000).

BOD is a measure of oxygen consumption of microorganisms in the oxidation of organic matter, normally over five days (BOD_5), while COD is the amount of chemical oxidant (usually potassium dichromate) required to oxidize the organic matter (Kadlec & Wallace 2009). Wetlands show excellent reductions of BOD and COD. The background concentrations of BOD and COD are non-zero and depend on type and status of the wetland (Kadlec & Wallace 2009).

Degradable carbon compounds from the wastewater are rapidly utilized in wetland processes and the decomposition processes produce available carbon (Kadlec & Wallace 2009). Organic carbon is cycled in the wetland through growth, death and partial decomposition. In this process atmospheric carbon is being consumed and gases, dissolved organics and solids are produced (Kadlec & Wallace 2009). When litter is decomposed carbon is returned to the atmosphere and waters (Kadlec & Wallace 2009).

Particulate organic matter removal in HFW is somewhat similar to removal of suspended solids. The solids will undergo decomposition through hydrolysis and will be transformed to soluble organic matter (USEPA 2000). These organics, together with dissolved organic matter from the influent, can sorb to biofilm surfaces attached to bed media and plant roots, as well as accumulated plant litter (USEPA 2000). The oxygen transfer to the HFW is limited and consequently anaerobic metabolism will be predominant (USEPA 2000). Thus the BOD removal will be caused by methanogenesis, sulfate reduction or denitrification, which all produce gases (USEPA 2000). Clogging may occur because slowly degradable compounds may accumulate in the bed (USEPA 2000). The role of plants in HFW is controversial; the root surfaces may provide space for biofilm growth, and they might contribute some oxygen, but this would be unreliable in parts of the year due to plant senescence (USEPA 2000). In many cases the roots don't penetrate all the way to the bottom and there is a significant amount of flow underneath the root zone (USEPA 2000).

Through intermittent loading of VFW, air can penetrate and enhance aerobic decomposition of organic matter (Kadlec & Wallace 2009). The majority of the microbial biomass is located in the top cm of the bed and it is likely that most BOD removal takes place in this region due to filtration, oxygen availability, and greater microbial mass (Kadlec & Wallace 2009). Treatment performance is dependent on influent BOD load (Kadlec & Wallace 2009).

Removal of Nitrogen

There are several forms of nitrogen which are interesting in waters and wastewaters: nitrate, nitrite, ammonia and organic nitrogen (USEPA 2000). Organic nitrogen exists in both soluble and particulate form, while all other nitrogen species are only in the soluble form (USEPA 2000). Discharging nitrogen to surface and ground waters is undesirable for several reasons; it can lead to eutrophication, it can be toxic to fish and other aquatic life, nitrate and nitrite may reduce quality of drinking resources, and ammonia may deplete oxygen levels through nitrification (USEPA 2000).

In the influent, nitrogen is mostly present as either organic nitrogen or ammonia (60% and 40%) (Kadlec & Wallace 2009). The organic nitrogen in the influent is transformed to ammonia through biological processes, this occurs in both aerobic and anaerobic conditions (Kadlec & Wallace 2009). The process is not instantaneous but may continue through several steps in the treatment system. Ammonia can, due to its positive charge, potentially sorb to both organic and inorganic material. The bond will, however, be loose (Kadlec & Wallace 2009). The ammonia may also be removed through plant uptake. However, the amount taken up by plants is small compared to the influent nitrogen load, and for the ammonia to be removed from the system, the plants need to be harvested. Another limitation is that the uptake will only occur during the growth period of the plants (USEPA 2000). If the ammonia is not absorbed by plants, it will follow the water through the treatment system (USEPA 2000).

The ammonia can be converted to nitrite and further to nitrate through nitrification, a biological process where the bacteria require aerobic conditions and a low carbon : nitrogen ratio (Kadlec & Wallace 2009). Nitrite is not chemically stable and only found at low concentrations in wetlands (Kadlec & Wallace 2009).

Denitrification, where nitrate is converted to di-nitrogen (nitrogen gas) by bacteria, is a reaction which requires anaerobic conditions and an organic substrate in order to happen (Kadlec & Wallace 2009). The nitrogen gas is transferred to the atmosphere and is subsequently removed from the treatment system.

The transfer of oxygen into HFW is low and the nitrification will be limited to areas close to the surface or around the roots (USEPA 2000). The media is constantly saturated and no air is allowed to enter, the environment in a HFW is consequently poorly suited for nitrification. HFW may be good facilitators for denitrification as they have anaerobic environments, however, an organic carbon source is also needed and this may be a limiting factor (USEPA 2000). Organic carbon is supplied through decomposing plant litter on the surface which may leach into the anaerobic zone by the help of rainfall, or through decomposing organics within the bed (USEPA 2000). The carbon availability will vary with the season.

A VFW is normally intermittently loaded, allowing air to enter after the water has percolated through the media. This ensures a high oxygen transfer rate and subsequent nitrification of ammonia compared to HFW (Tsihrintzis & Stefanakis 2009).

Removal of Phosphorus

Phosphorus can occur in wastewater and natural waters in the form of phosphates such as orthophosphates, condensed phosphates and organically bound phosphates, and can be found in either particulate form or in solution (USEPA 2000). Organic phosphorus will be present in the wastewater as residues of food and human waste, while inorganic phosphorus may originate from cleaning products (USEPA 2000). P is present in wetlands normally in the form of orthophosphate.

In the environment P is usually the "limiting nutrient in freshwater systems" (USEPA 2000) and P in effluent wastewater can lead to eutrophication in the recipient.

Removal mechanisms of P in wetlands are sorption, settling of TSS and associated P, filtration, interception and uptake by plants (Kadlec & Wallace 2009). However, all of these removal mechanisms only ensure temporal removal (Kadlec & Wallace 2009). P storage in plants is temporal in the way that it follows the growth cycle (Kadlec & Wallace 2009), and the influent loading is much larger than what the plants can take up (USEPA 2000). When the influent has a high concentration of suspended solids, large amounts of P can easily be removed and stored through particulate settling, but the accretion of P is not sustainable due to loss of porosity and hydraulic conductivity in the bed (Kadlec & Wallace 2009).

Sorption to media is dependent on properties of the media and inlet concentrations of P (Kadlec & Wallace 2009). Surface chemistry is the most important media property and is made up by presence of aluminum oxides, iron oxides and calcium carbonates. Other factors such as organic matter content, pH, temperature and redox conditions will also affect sorption (Kadlec & Wallace 2009). The surface chemistry of the soil changes over time as the media is weathered (Kadlec & Wallace 2009). Larger surface area gives more sorption, but the removal is limited by lower hydraulic conductivity (Kadlec & Wallace 2009). Some removal can also be caused by accretion of decomposing plant litter (USEPA 2000).

After some time of operation the system will reach equilibrium in P-removal. Once the retention capacities are exhausted, P-values in the effluent will be equal to values in the influent, and more sorption can only occur if inlet values rise (Kadlec & Wallace 2009). Only a small portion of the potential sorption sites in field can be utilized because influent values are lower than the values needed to fill the sorption sites. If high P-removal is to be expected, an appropriate P-sorbing media with the right surface chemistry and surface area, must be chosen (Kadlec & Wallace 2009).

The removal, or retention, of P in HFW is found to be a function of the bed area, hydraulic loading and influent concentrations. However, the media is also an important factor; in order to sorb P the media needs certain chemical properties, but the sorption will be limited to a period of time until the sorption capacity of the media is exhausted (Kadlec & Wallace 2009).

As the loading rate for the VFW is higher than the HFW, the short term storage mechanisms, like sorption and biomass uptake, is less prevalent and subsequently the P removal in VFB is lower than in HFB. However, the long-term mechanisms are similar for both VFW and HFW (Kadlec & Wallace 2009).

Removal of Pathogens

The term pathogens includes helminthes, protozoan, fungi, bacteria, and viruses (USEPA 2000), and are unwanted in the environment due to their negative effect on human health.
One of the most common ways of testing for human waste contamination is by fecal coliform bacteria. These bacteria are, however, not necessarily of human origin but can come from any warm blooded animal (USEPA 2000).

Pathogens can be suspended in the water or attached to TSS. These will be removed from the water by the same mechanisms that remove TSS, like sedimentation, interception and sorption (USEPA 2000). Pathogens in suspension can be removed by the following mechanisms; straining and attachment to biofilm, or due to competition with other microorganisms better suited for the prevalent conditions (USEPA 2000). Another removal mechanisms is predation by other microorganisms (USEPA 2000). The removal efficiency will vary amongst the different pathogens. Viruses and protozoan are more resistant, and the removal mechanisms might also vary among the different types (USEPA 2000).

Removal of pathogens from the water does not always mean that they are "no longer viable" (USEPA 2000). They may later be released into the water from the media and become available "as infectious agents" (USEPA 2000).

Bacteria can sorb to clay particles through cat-ion bridging. Both the cell and the clay surface are negatively charged but the cell surface may be neutralized through "the accumulations of positively charged counter-ions such as K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe^{3+} and Al^{3+}" (Maier et al. 2009).

Removal mechanisms of parasites are settling, filtration, interception and predation (Kadlec & Wallace 2009). In HSSFW the removal rates of parasites range from 79 to 100 % (Kadlec &

Wallace 2009). For VFW sufficient data does not exist, but the removal rates of parasites are expected to be much higher than for bacteria and virus as the size is significantly larger (Kadlec & Wallace 2009).

Viruses are difficult and costly to monitor and have not been carefully studied. But because they have the potential of causing disease at low exposure doses and show high endurance in natural environments, their fate in wetlands is subject to great concern (Kadlec & Wallace 2009).

No generalizations can be made about HFW and VFW, as the "flow paths and conditions" are very different (Kadlec & Wallace 2009).

Hybrid CW

In order to enhance treatment different types of wetlands can be connected treating the same wastewater. In the Sunga treatment system there is a horizontal flow bed followed by a vertical flow bed. However, many researchers would rather recommend the wetlands to be connected the other way around; vertical prior to horizontal (Haberl et al. 1995).This way denitrification is enhanced, through high levels of nitrification in the VFW and latter denitrification in the HFW (Haberl et al. 1995). When the wetlands are put in the sequence of HFW prior to VFW this is to improve nitrification; in the HFW organic matter is removed and the wastewater is more effectively oxidized in the VFW and, as a result, nitrified. The reason one would choose this option is to avoid oxygen depletion caused by ammonia discharge to the stream.

3 Methods

3.1 Sunga Treatment System

The Sunga Treatment System is a hybrid system consisting of two different types of wetlands. It is located in a peri-urban area in the Kathmandu Valley, Nepal. It is a DEWATS solution designed to serve 80 households (average flow is $10m^3/d$) where the wastewater produced per capita is as low as 25-30 l/day (Singh et al. 2009). The system was implemented through a community based approach meaning there is a locally based User's Committee responsible of the system.

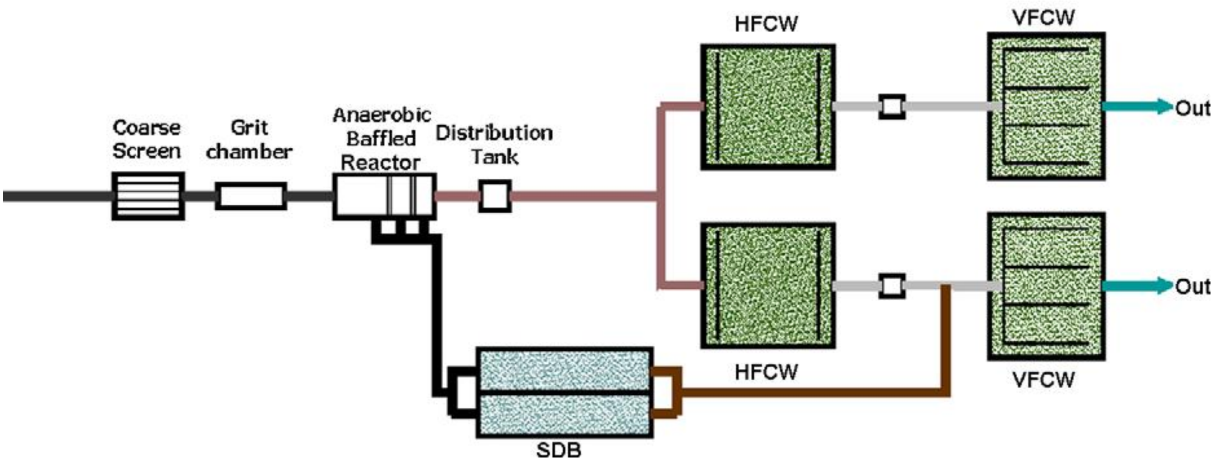

Figure 3: sketch of the treatment system showing all the different components (Singh et al. 2009).

As shown in figure 3 the system has preliminary treatment consisting of a coarse screen and a grit chamber. If the screen blocks, the pit will fill and the wastewater is diverted to a different pipe and bypasses the system.

The pretreatment consists of an Anaerobic Baffled Reactor (ABR) with an effective volume of 42 m^3 (Singh et al. 2009) with an average flow of 10 m^3/d the Hydraulic Retention Time will be 4.2 days. The water is distributed to the two HFW through pipes with holes along the side.

The next treatment step is two parallel HFWs with a total area of 150 m^2, effective depth of 0.4 – 0.5 m (Volume is 60 – 75 m^3) (Singh et al. 2009) and a subsequent hydraulic retention time of 6 days.

The wastewater is collected in tanks and is intermittently fed to the VFW by tipping buckets. Two parallel VFWs also with a total area of 150 m^2 and depth of 0.55 m (Volume is 82.5 m^3) form the last treatment step before effluent is collected in a tank with overflow to a nearby stream (Singh et al. 2009).

When the ABR is desludged the effluent goes to a sludge drying bed (SDB) with an area of 70 m^2. The excess fluid from the SDB is led to one of the VFWs for further treatment. To ensure sufficient pathogen reduction before use it is supposed to dry for six months before taken out of the bed.

A biogas reactor was built after construction of the other components and receives effluent from the grit chamber. It has an inlet pit where other organic wastes can be added. The effluent of the biogas reactor goes straight to the sludge drying bed. As it is not part of the actual treatment system it is given little attention in this thesis.

According to an engineer representing the municipality of Thimi, there was initially a plan to build a treatment system at another location in Thimi, but as it turned out the locals of that area did not welcome a wastewater treatment system in their neighborhood. The focal person of Sunga, and later to be president of the user's committee, heard of this project and suggested it to be built in the Sunga locality instead. A community meeting was arranged where a user's committee was formed.

According to WaterAid's report on the project the treatment system was built after the community had showed interest in handling their wastewater (Rajbhandari 2007). Several organizations came together to plan and fund the system. ENPHO provided technical assistance and funding together with WaterAid, Asian Development Bank and UN-HABITAT, and the municipality of Madhyapur Thimi provided the land and the funding for O&M (Rajbhandari 2007). The finalized project was a community based reed treatment system for municipal wastewater.

> *"The main objective of this demonstration project is to promote a simple but effective, community based, urban wastewater treatment technology to improve sanitation, improve water quality of rivers, provide alternate water uses other than for drinking purposes, and to link with livelihood opportunities for poor communities and finally demonstrate the successful application of a community managed wastewater treatment plant." (Rajbhandari 2007)*

Operation of the system started in October 2005. The user's committee is responsible for supervision, and ENPHO provides technical assistance (Rajbhandari). After the effluent values of the treatment plant were tested, and the values found to be within the Nepalese standards the system was handed over to the User's Committee from ENPHO on 1-Sep-06 (Rajbhandari 2007).

3.2 Technical Investigations

For this thesis two rounds of sampling was conducted to collect primary data. In addition the past performance records from March 2006 until December 2010 were obtained from ENPHO. Another round of sampling was conducted by another master student (Prajowl Shreshta) in March 2011. Both the primary and secondary data were considered for the performance evaluation of the system.

Grab samples were collected after each step in the treatment process, this was done on February 7th 2011 and March 7th. The sampling was started at 9 am. At this time the screen was clean and the water was going to the treatment system, this was also checked the day before at 3 pm.

The flow was measured using a 2.2 L container. The container was held under the pipe feeding the inlet pit and filling was timed. The procedure was repeated four times; from this an average filling time was calculated.

Samples were collected from the treatment plant at four different points in the treatment process:

1. Inlet – open pit where the flow goes through a screen and to the grit chamber. The sample bottle was filled under the flow from the pipe.
2. Outlet ABR – collection tank between ABR and HFW. Sample bottle was filled by dipping it in the tank.
3. Outlet HFW – collection tank with tipping bucket between HFW and VFW. Water was collected using bucket and rope, sample bottle was filled with water from bucket.
4. Outlet VFW (final effluent) – collection tank with outlet to stream. Water was collected using bucket and rope, sample bottle was filled with water from bucket.

Samples were taken using 1L plastic bottles and smaller glass bottles for preserving samples in refrigerator. The bottles were labeled prior to the sampling. For BOD samples the bottles were filled completely full to avoid contact with air and possible oxidation of contents.

All samples were collected with few minutes apart; each sample thus represents a different batch of wastewater. After the samples were collected they were transported directly to the lab (this took approximately 30 min to 1 hour) where testing began the same day. Laboratory test were conducted at the ENPHO lab according to ISO 17025 set by the International Organization for Standardization.

The following parameters were tested:

- Biological Oxygen Demand (over five days)
- Chemical Oxygen Demand
- Total suspended solids
- Ammonia
- Nitrate
- Fecal coliform bacteria
- Total Phosphorus (TP)

These parameters were chosen on the basis of them being among the most common parameters to consider for wastewater (Kadlec & Wallace 2009). Other common parameters to test for would be heavy metals and organic chemicals (Kadlec & Wallace 2009) but since the Sunga Treatment system only receives domestic wastewater these parameters are not considered to be interesting. Additionally these parameters were the ones monitored prior to this thesis work.

Possible sources of error in technical investigations

There are several sources of error in both sample collection and laboratory tests that may cause the test results not to be representative for the actual situation. During sampling, air might have been able to enter in BOD-bottles, causing some organic matter to be oxidized, thus giving too low values for BOD, or the bottles may have been contaminated before use. In the laboratory many different human mistakes may have been made, examples could be incorrect measures of chemicals, incorrect counting of bacteria colonies and so on.

3.3 Social investigations

Objective and hypothesis

In order to get an overview of the knowledge and perceptions of the people in the community interviews were carried out within different groups and individuals. Before interviews were planned some hypothesis were made:

Main Hypothesis: the lack of community participation and knowledge diminishes sustainability.

Hypothesis 1: poor knowledge and involvement from the user's committee causes poor O&M and poor performance of the treatment system.

Hypothesis 2: lack of female involvement has a negative impact on the user's committee.

Hypothesis 3: reuse options are not being exploited properly because of lack of knowledge in community.

The two groups to be interviewed were the user's committee and the community where random members were picked. Individuals who were interviewed included a representative from the municipality, the president of the user's committee and the caretaker of the treatment system.

Research questions

The research questions formulated for social investigations are:

- What are peoples knowledge and perceptions of the wastewater treatment plant?
- What do the farmers know of the positive and negative impacts from using wastewater and sludge in their farming? Are they positive to using it?
- What was the initial plan for the treated water and the sludge and did things work out the way it was planned?
- In what way are women involved in the user's committee?
- What are the drivers for, and barriers to, a sustainable sanitation system in this community?

Method of data collection

Primary data was collected using open ended questions. The interviews were in a semi-structured form, thus allowing for the questions to be adjusted to each respondent, and letting the respondent elaborate on what he or she thought to be important.

Semi-structured interviews have general questions that do not need to be asked in the same way or in the same order to every respondent (Bryman 2008). A semi-structured interview also allows for further questions to be asked if the respondent has some interesting information on a specific area. This allows the interviewer to adjust the interview to each respondent, by changing the way questions are asked and what questions are asked, thus focusing on the more interesting information this respondent has.

The questions in the interviews were in an open form, thus letting the respondents answer in their own words instead of giving them a limited set of answers. This method lets the respondent give a more true answer, but it makes the analysis more complicated, as it needs to be coded to be interpreted quantitatively. This is much work and opens up for errors in both coding and analysis (Bryman 2008). This is also a more complicated approach during interviews as the interviewer needs to note as much as possible of what is being expressed by the respondent, this could be a source of error. On the other hand there are many advantages to open questions as it lets the respondents answer in their own way. In many cases the researcher does not know of all the possible answers to a question and letting the respondent answer on her or his own terms opens up for unexpected answers to be included in the study. This is especially useful when the researcher has limited knowledge on the field of study. Especially questions concerning knowledge will give a more true answer when no options are suggested (Bryman 2008). In comparison the closed questions may cause "loss of spontaneity" in the answers and the respondents might not find an answer they feel is appropriate for them (Bryman 2008).

Planning and preparation for data collection

A structured form of interviewing was first planned to easily compare answers. After further investigation and advice a semi-structured form was chosen.

The interviews were prepared by making questionnaires (see *Appendix*). The questions were mainly open ended but also closed questions were included such as "did you have a toilet before construction of the wastewater treatment system?" or "would you consider buying vegetables produced using sludge?". These questions were specific things that were needed to give the entire picture of the situation and to allow for comparison between different respondent's answers.

The lists of questions were structured with some main questions, many with additional questions that were to be asked if the respondent did not elaborate on this after being asked the main question. The main questions were mostly open ended and additional questions were non-open ended.

The following groups and individuals were chosen for interviews:

- User's committee members
- User's committee president
- Community members
- Farmers (when a community member answered that he or she did farming this list of questions was asked, thus the farmers are not a separate group)
- Representative from municipality

A specific list of questions was made for each group or individual.

Three different translators were used, all of them university students. To minimize misunderstanding during interviews it was crucial to use translators who spoke the local language, Newari. Two of the translators grew up in the area and spoke Newari. The third, an ENPHO volunteer, translated only during the interview with the president of the user's committee who was fluent in Nepali, and the language is not believed to be a barrier in this specific case. None of the translators had any previous experience. The translators were given the questions in advance of the interviews, and during interviews the questions were asked in English and translated on the spot to Newari. If the interviewee had any trouble understanding a question, it would be explained more thoroughly. Before the interviews started, the interviewee was explained the purpose of the interview, and the terms such that the answers would remain anonymous.

Possible sources of error in survey research

In an interview situation there are many factors that can cause misunderstandings or may affect the answer of the respondent, thus causing error in the collected data. Examples of such factors may be a poorly worded question, the way the question is asked, misunderstandings, memory problems on the part of the respondent and finally the way the information is recorded and processed by the interviewer (Bryman 2008).

There are also other factors that might affect the outcome of the interview when a respondent needs help to understand a question or an early question might affect answers on later questions (Bryman 2008). Questions concerning opinions and attitudes are thought to be sensitive and should be asked before questions concerning behavior and knowledge (Bryman 2008). Suggesting possible answers for the respondent can affect the answers and was completely avoided in this survey.

In this study translation and cultural differences may also be a cause of misunderstandings and errors. In order to minimize this source of error local interpreters were used in all interviews, the only exception being the interview with the president of the User's Committee as it was not possible to obtain a local translator at that time.

4 Results and Discussion

4.1 Performance of the treatment system

Treatment results presented are calculated as a mean of all values measured throughout the observation period of the treatment system, excluding the very first set of measurements which are considered to not be representative as they were collected few months after startup of the system, a SSFW needs about three to six months for the microbial biomass in the media to be developed (USEPA 2000). In all eleven observations have been carried out.

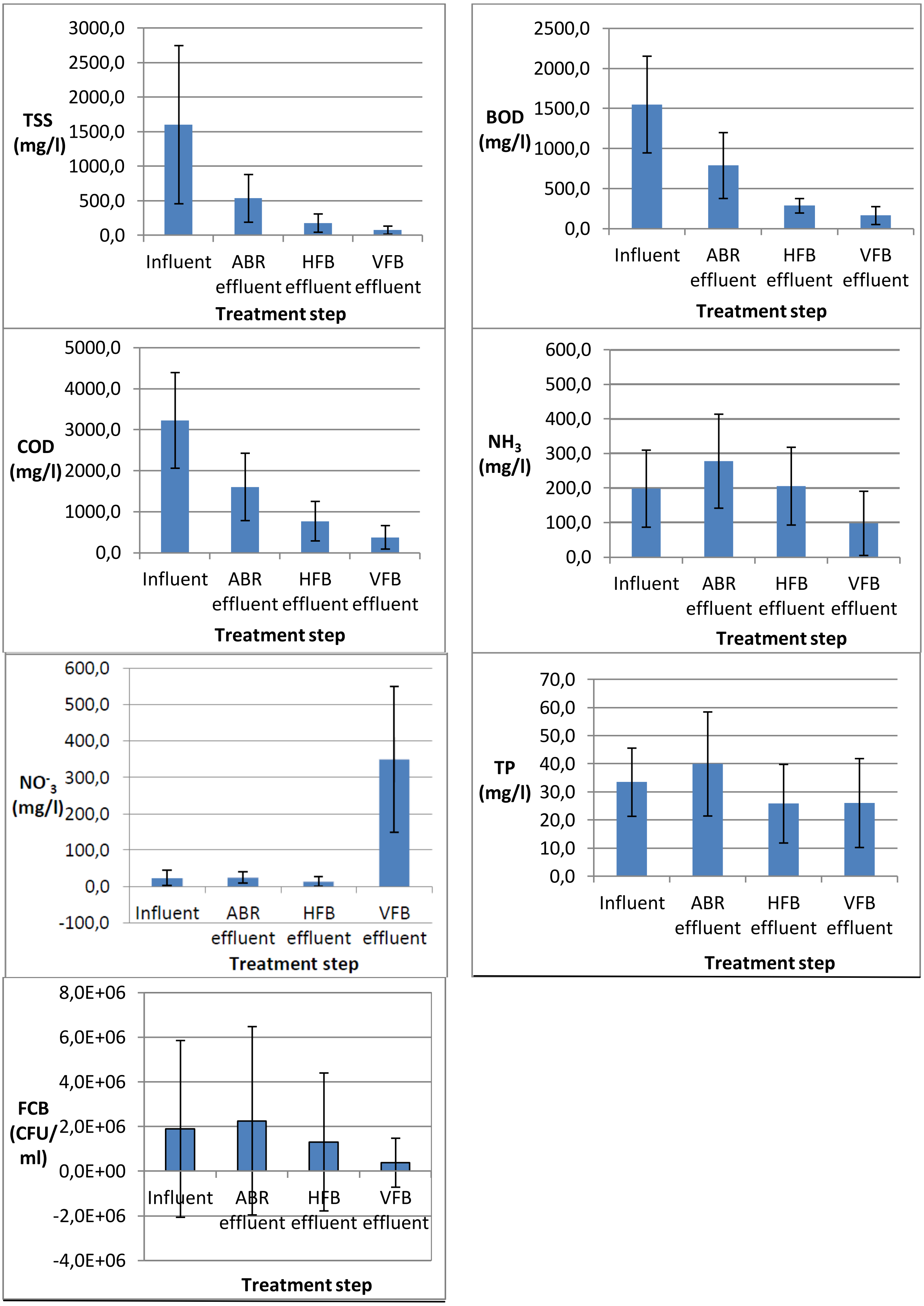

Figure 4: Mean pollutant values for all steps in the treatment process of the Sunga Treatment system (TSS-Total Suspended Solids, BOD – Biochemical Oxygen Demand, COD – Chemical Oxygen Demand, NH_3 – Ammonia, NO_3^- - Nitrate, TP – Total Phosphorus, CFU – Colony Forming Unit (of fecal coliform)).

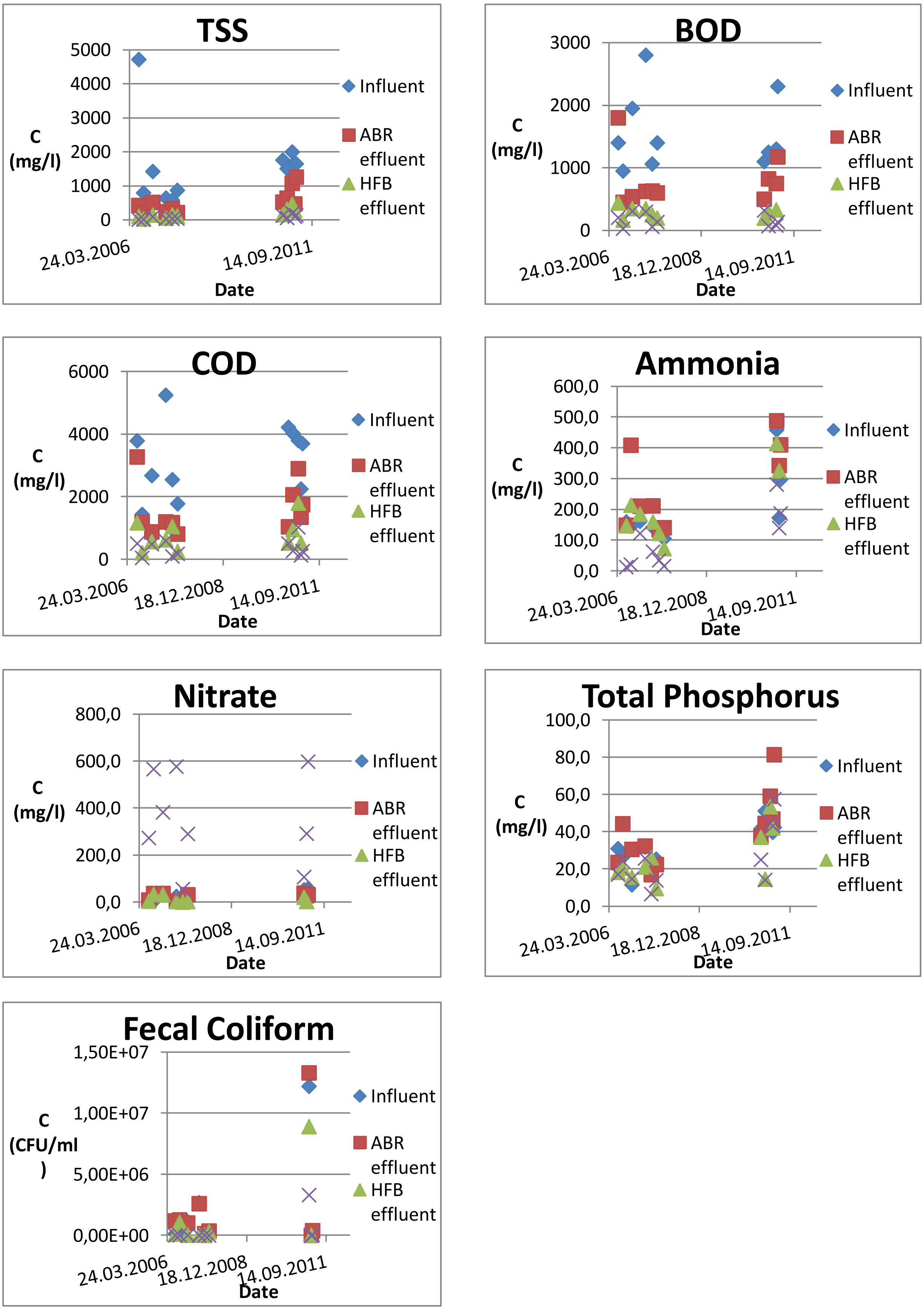

Figure 5: change in pollutant values for all steps in the Sunga treatment system over time (TSS- Total Suspended Solids, BOD – Biochemical Oxygen Demand, COD – Chemical Oxygen Demand, NH_3 – Ammonia, NO_3^- - Nitrate, TP – Total Phosphorus, CFU – Colony Forming Unit (of fecal coliform)).

Table 1: Mean treatment efficiency for each parameter

Parameter	Treatment efficiency (%)	Mean effluent values	Nepali standards (mg/l)	According to standards (% time)	EU standards (mg/l)	According to standards (%)	EU standards (%)	According to standards (% time)
TSS	95	77	50	46	35	27	90	100
COD	89	374	250	36	125	18	75	91
BOD	89	165	50	10	25	0	70-90	100
Ammonia	57	98	*Nonexistent*		*Nonexistent*		*Nonexistent*	
Nitrate	-3341	349	*Nonexistent*		*Nonexistent*		*Nonexistent*	
P	21	26	*Nonexistent*		1-2 mg/l	0	80	0
FCB	95	3,8E+05	*Nonexistent*		*Nonexistent*		*Nonexistent*	

TSS- Total Suspended Solids, BOD – Biochemical Oxygen Demand, COD – Chemical Oxygen Demand, NH_3 – Ammonia, NO_3^- - Nitrate, TP – Total Phosphorus, FCB –Fecal Coliform Bacteria

TSS

As illustrated in Figure 4, TSS has a steady decline for each step in the treatment system. TSS is mainly removed in the ABR through settling but also in the following steps settling and straining occurs (see section *Removal of TSS* p 11 for explanation of settling and straining) and the values are lowered further. There has been a quite large increase in the influent TSS values since startup of the system, as shown in figure 5. The effluent values have increased along with the influent wastewater, the increase has, however, been much smaller for the effluent values. When comparing the effluent values, as shown in Table 1, they are higher than both Nepali and EU standards in less than 50 % of the time but when looking at the removal efficiency of TSS it is 95 % as compared to 90 % which is the EU standard.

Organic Matter

Both COD and BOD values drop steadily throughout the treatment process. According to Figure 4 the ABR is the most efficient step where about 50 % of both BOD and COD are removed. Figure 5 shows how both the influent and effluent values have increased slightly for both BOD and COD throughout the operation period of the treatment system. The effluent BOD values are according to standard values only 10 % of the time, as can be seen in Table 1. The effluent values are, however, never as low as the EU standard value, but for percentage reduction the standard is always reached. For COD the results are somewhat better.

Nitrogen

The ammonia values increase between the inlet and the ABR as shown in Figure 4, the reason for this might be that the organic nitrogen is being converted to ammonia. As explained under *Removal of Nitrogen* (p 13), the conversion of organic nitrogen to ammonia is not an instantaneous process, so it will most likely proceed through several treatment steps, both in aerobic and anaerobic environments (Kadlec & Wallace 2009). This may be the reason why the ammonia values increase from one treatment step to another. In the HFW the ammonia values drop as the ammonia is being nitrified. However, there is no increase in the nitrate concentrations in the effluent of the HFW, this can be explained by denitrification directly following nitrification (see *Removal of Nitrogen* p 13 for further explanation). Another explanation can be that the ammonia is volatilized, but it seems unlikely that such a large removal of ammonia can be explained by this mechanism. In the VFW the ammonia drops further, and there is a significant increase in Nitrate as seen in Figure 4. In this step the wastewater is exposed to air and is thereby also exposed to oxygen which ensures nitrification (see *Removal of Nitrogen* p 13 for further explanation). Simultaneous ammonification can be the reason for the somewhat modest fall inn ammonia value.

For ammonia, both the influent and effluent values have increased significantly throughout the operational period as according to Figure 5. For Nitrate, the values do not vary much.

Overall there is a 57 % reduction of ammonia throughout the treatment process, given in Table 1. Nepali effluent standards for Nitrogen are nonexistent; EU standards are only given for total nitrogen, thus making it impossible to make a good comparison with the effluent values. The nitrate values have, as expected due to nitrification explained in *Removal of Nitrogen* (p 13), an extreme increase throughout the system.

Phosphorus

Figure 4 shows that the TP values increase in the ABR, this increase in values was tested for statistic significance through a T-test, and the result showed that the rise was not significant ($P = 0.17$). P is mainly removed in the HFW, and increases slightly again in the VFW according to Figure 4. This rise is also not significant ($P = 0.49$). The largest removal happens in the HFW. As mentioned in section *Removal of Phosphorus* (p 15), the media needs to be selected specifically for P removal in order to achieve high removal rate. P removal is, as expected, not very high, but for three out of the eleven measurements the effluent value is higher than the influent. This signifies occurrence of dissociation of P from the media. The media of the wetlands consist of gravel and sand that are not expected to have high P sorption capacity; consequently sorption is expected to be of little significance as a removal mechanism for P. It is, however, expected that some is taken up by plants, which are later removed. This would give a permanent removal but only small amounts are removed in this way (see *Removal of Phosphorus* p 15). P associated with suspended solids is, however, expected to be removed in the wetland.

According to Figure 5, the P values show an increase since startup of the system, both for influent and effluent values.

Nepali effluent standards for P are non-existent. EU standards are 1-2 mg/l or 80 % removal efficiency; the effluent values are in this case much higher than the EU requirements, also for treatment efficiency as shown in Table 1.

Fecal coliform bacteria

As seen in figure 4, the concentrations of Fecal Coliform Bacteria increase in the ABR, although this increase is not statistic significant (P = 0.43). In the subsequent steps the values decline. The values of fecal coliform bacteria show very large variance between each measuring throughout the treatment process. The influent values are also very varying, and is partly the reason for the large variations in effluent values. There are most likely other reasons as well for the large variations. The mechanism of sorption of bacteria is most likely negligible in this case, as the media is not chosen for its chemical properties. Main removal mechanisms will be filtration and straining, especially in the sections where biofilm is well developed; in addition die-out and predation would be contributing factors. As inflow wastewater is sometimes diverted due to blockage of inlet screen the wetlands will sometimes not receive flow. This might harm the biofilm in the wetland, and the following treatment will show lower removal rates of fecal coliform bacteria both due to less straining in biofilm.

Figure 5 shows that the values are somewhat stable over time except for one set of measurements which has extremely high values compared to the other measurements.

Nepali effluent standards for fecal coliform bacteria are, as shown in table 1, non-existent.

Removal Rate Constant

The Reaction Rate Constants (K) used for design of the HFW was 0.13 m/d, with a subsequent removal efficiency of 70 % for BOD_5, and 0.15 m/d for the VFW (Singh et al. 2009).

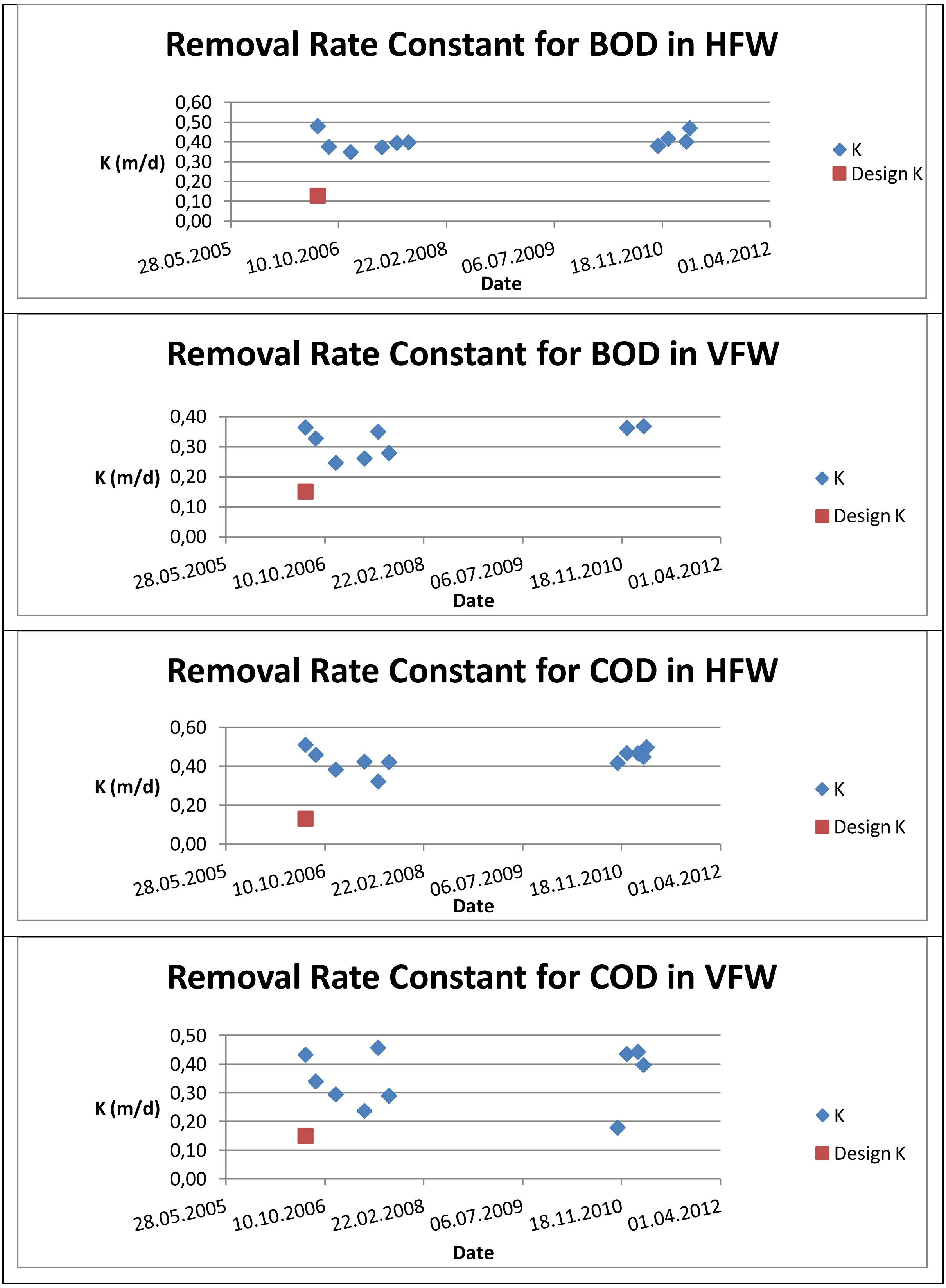

Figure 6: Removal rate constant for BOD and COD in HFW and VFW (BOD – Biochemical Oxygen Demand, COD – Chemical Oxygen Demand, HFW – Horizontal Flow Wetland, VFW – Vertical Flow Wetland).

As shown in figure 6 the actual K values are much higher than the design values for all measurements. There are quite some variations in the actual K values.

Overall results and discussion

Results from all parameters show large variations, and in particular fecal coliform bacteria show extreme variations. Variations in influent pollutant concentrations may be due to variations in water availability for toilet flushing, when there is poor availability of water little is used for flushing and the concentration of pollutants in the wastewater rise. The variations of effluent values are not quite as large, showing that the system does handle increased pollutant values well.

The results throughout the operational period show that the treatment efficiencies (measured in percentage) are mostly according to EU standards, although the effluent values are mostly not. The effluent values are mostly higher than both EU and Nepali standards. The influent wastewater has very high concentrations of pollutants compared to normal wastewater and thereby needs more treatment. This could be done in the form of improved pretreatment; the ABR could be made larger, giving the water longer retention time, thus allowing more solids to be separated from the water column. Values of K are much higher than expected. Even though the system is designed for 70 % removal efficiency for BOD, the actual value is almost 90 %.

During a visit to the treatment plant on 25-Jan-2011, some observations were made on the state of the treatment system and the O&M of it (see *Appendix*). One of the observations made, was that the inlet screen was blocked due to large presence of organic matter and other wastes in the influent. If the screen is blocked for a longer period of time, this would cause large amounts of untreated wastewater to overflow to the stream, and it may temporarily weaken the treatment ability of the system as the biofilms and the plant growth is dependent on the incoming water and organic matter. Another interesting observation was the presence of sludge in the pipes discharging to the HFWs, below the pipes on the bed itself there was a thick dark sludge. The pipes were in a somewhat poor condition causing several leakages. In the VFW the pipes were not leveled and the distribution of wastewater was not even, certain part of the wetland received large amounts of wastewater, while other parts received no flow.

It is alarming that the inlet screen blocks so easily, and that the wastewater is consequently discharged directly to the stream without any treatment, and the system does not receive any flow. It seems likely that if the caretaker is prevented to come for a few days, this would affect the biofilms in the wetlands and the following treatment would suffer from this.

The ABR was emptied on an interval of 3 – 30 days, dependent on the caretaker's observation of the amount of organic matter in the influent. According to the caretaker, the SDB had never been completely emptied, and only small parts of the sludge were taken out to dry further on the side of the bed. Most likely the frequent emptying of the ABR was making it hard to dry the sludge properly, and it was not treated sufficiently in order to ensure safe reuse.

The daily operation seems to be quite well functioning, except for the cleaning of the inlet screen. It would, however, be a better solution to put in a larger screen that is not dependent on such high frequency cleaning. The system is, nevertheless, in need of some maintenance as pipes need to be emptied of sludge, leveled, and tightened.

The effluent sampling has not been performed often enough to give a true image of the treatment efficiency. Also, the samples collected in one day do not represent the same batch of wastewater, because of this the result need to read skeptically. But there seems to be an increase in many of the pollutant values in influent wastewater.

4.2 Findings of social investigations

User's committee

The user's committee is made up of a president and 17 members, two of which are women. Four members plus the president were interviewed. None of the members, including the president, have any relevant education within engineering, environment or wastewater treatment.

In preparation for the interviews some general questions were noted:

- To what extent are women taking part in the user committee, the decision making and the O&M? How does women's involvement influence the result?
- What is the role of the committee? Are they actively making sure the system runs properly? Are they involved in O&M?
- Was the possibility of reusing the wastewater considered before implementation of the treatment system?

Female participation

As for the question on how involved the women in the committee are, it is hard to comment as only one was interviewed. It seemed though, that she was dedicated and engaged in the role as a member of the user's committee. How much influence she had is hard to say.

Member involvement

It was confirmed by one of the members and the president that there were no regular meetings. In the initial phase there were regular meetings, but it seems to be about two years since they had an official meeting where all members were invited. This was confirmed by the president. Thus, there is little involvement by the user's committee at the time of research, though the president visits often, and will be notified by the caretaker if there are any issues to be resolved on the technical part of the system. One of the respondents still point out that he/she thinks the caretaking is not sufficient.

Knowledge

There is a general lack of knowledge among the members on how the system works. It could be a great benefit if the members had more knowledge and could spread this to the rest of the community. More knowledge would also increase the chances of satisfactory O&M. Of course it cannot be expected that the members have a detailed understanding of how the system works, they are not educated for this and their role is primarily to be a link between their community and the project.

All respondents state that the O&M is of great importance, and two out of four interviewed members say they have participated in maintenance of the system, and three states to have been involved in decision making on maintenance. Still it seems that more involvement should be expected at this point as the system needs close follow up.

Reuse

From the answers it seems like the option of reuse has somewhat been part of the planning all along, though it seems like it has never been thoroughly followed through. The two members who are doing farming have tried to use the sludge and among all respondents none state to have any contradictions to buying food produced using treated wastewater for irrigation or sludge for fertilizer.

Drivers and barriers as identified by respondents

When it comes to the benefits of having such a system all respondents from the user's committee say that the overall impact from the system is positive for both the environment and the community, although they cannot see any direct benefits for themselves. Some positive effects are still mentioned.

Drivers:

- No landslides
- Treatment of wastewater, less pollution of the river
- Option of reuse
- No, or less smell
- The people are happy
- The environment is improved
- OD free environment

The comments on prevention of landslides are somewhat surprising; this is not a direct benefit from constructing a WWTP, but the consequence of building it in this exact spot.

Barriers:

- No one has knowledge or experience of wastewater treatment, engineering or environment
- No regular meetings
- No or inadequate training given for members of committee and caretaker
- Possible benefits such as sludge and treated water not in use
- Lack of involvement in O&M
- No O&M plan or manual

One respondent answer that "there are no direct benefits, most people do not know if the system is running".

Community

Ten respondents from the local community were randomly chosen and were interviewed. Some general questions asked to the respondents from the community were:

- Do the people of the community have any general knowledge of the system?
- What kind of effects do they see?
- Are they involved in the project?
- What are their perceptions of sludge use?

Knowledge and involvement

Only six people were asked about involvement in community meetings regarding the treatment system, half said they had never been informed of such meetings, and two said they had participated. Among the respondents, five out of ten said they had been to see the system and had been explained how it works. Of the five who had not visited, three had no knowledge and two had some knowledge of the treatment system. Three of the respondents reported to have no knowledge of the treatment system. There is a large potential for involving the community in the project, giving them information on sanitation and the purpose and functions of the system. Only when having some knowledge they will be able to engage and have opinions on the matter.

Reuse

When asked if they were willing to buy food produced using treated wastewater or sludge, none of the respondents were negative. Out of 10, two had neither any knowledge nor an opinion on the matter, while eight of the respondents were positive to buying this food.

Drivers and barriers as identified by respondents

Drivers:

- Water treatment removes germs, diarrhea prevalence is lower, people are healthier
- Removes smell
- The school receives gas
- Improved/cleaner environment
- Outsiders visit and recognize the place
- Water is purified
- Improved health
- Cleaner environment
- Reuse of water
- Reuse of sludge
- Easy indoor access to a toilet

Barriers:

- It is costly and there is some smell (the respondent later adding that the smell was even worse without the treatment plant)
- Financial support not sufficient
- The system is not working properly

Improvements

Throughout the interviews a few suggestions for improvements were mentioned:

- Improved biogas production
- Improved sludge quality
- Wider pipes connecting the houses to the plant

Note that the actual cause of pipe clogging could be that they don't use enough water when flushing, and not that the size of the pipes.

Farmers and sludge users

Reuse

An interesting aspect of the reuse issue is whether the inhabitants of the community had received and perceived the information on the possibilities of using sludge and treated wastewater from the treatment system as a means of increasing yield in their farming. The people who stated to do some farming were asked some questions on this issue. When asked if they had been informed of the possibilities of using the sludge, all of the six respondents had a negative answer, but many had found out in other ways such as seeing others use it, or hear from others. For the treated wastewater three out of five stated to have been informed of the possibility of reuse. Out of the six respondents who were doing farming, five were willing to consider using sludge, but only two out of six respondents stated to have already tested the sludge for themselves.

Hygiene behavior

All who stated to be farmers were asked about hygiene. Percentage of respondents who answered positive to the questions of whether they washed their hands and feet, and whether they changed their clothes after working in the field, are shown in the diagram below.

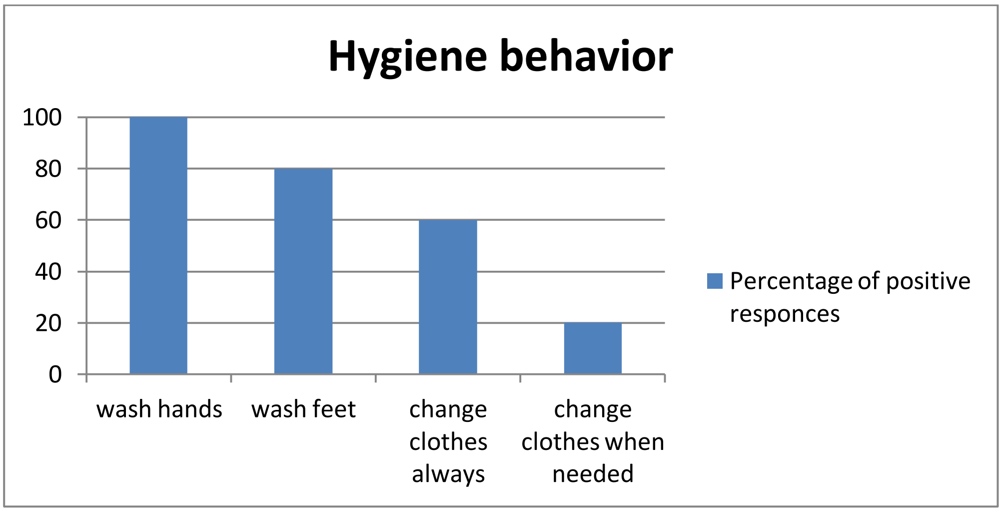

Figure 7: Respondents were asked about hygiene behavior, the diagram gives the percentage of respondents who confirmed to perform the given hygiene actions.

Sludge contents

When asked if the sludge could contain any harmful substances, two out of six responded that they did not know. One said that no, the sludge did not contain any harmful substances. The three remaining respondents knew, or at least thought that the sludge might be harmful to human health. One respondent added that she thought it was safe as long as she washed her hands and changed her clothes after working with it. When asked about sludge contents it was clear that not all had any actual knowledge in the field.

When asked if the sludge might contain substances harmful to crops, three people did not know, one said it might, but wasn't sure, and two didn't know.

The more interesting question was whether they thought the sludge was actually helpful for crop yield. To this question four people answered "yes", and the remaining two respondents did not know.

One respondent compares the sludge to the traditional fertilizer made of ashes and urine, and says they are quite the same.

Irrigation water

To understand the need for irrigation, the six farmers were asked about what kind of water they were using for irrigation and whether they had access to sufficient access to water for irrigation. Three respondents stated to be using ground water, and tree were using stream water. Only two said they had access to sufficient irrigation water throughout the year. A couple of the respondents who stated to not have enough irrigation water mentioned that the deficiency of water occurred only in summer.

Caretaker

The caretaker is employed by the municipality, and does not represent the user's committee. He is a part of the local community and is one of the neighbors of the treatment system. The purpose of interviewing him was mainly to learn more about the O&M. In preparation for interviewing, the caretaker the following questions were noted:

- What training has he received?
- What does he understand of the system?
- Does he have an O&M plan?
- What does he do when he encounters a problem he doesn't know the solution for?

He told that he only received a brief explanation of the system when he started in his job as a caretaker, but he still feels he fully understands how it works. He confirms that he has never been given a plan or manual for O&M. He says he thinks the system is operating satisfactory, and that he has never encountered a problem he did not know the solution for. When technical failures occur, and he needs assistance, he contacts the president of the user's committee who then contacts the engineer.

Sludge use

As the sludge drying bed fills he takes out sludge and leaves it on the side of the bed to dry it further. From there anyone can pick it up and use it. He says that no recommendations are given to the sludge users on how to treat or handle the sludge, but that it is common to treat it with ashes before use. This was not confirmed by anyone else.

From the information given by the caretaker it is clear that there is no minimum drying time for the sludge before it is being used.

Drivers and barriers as identified by respondent

Barriers:

- No manual
- Poor training
- No regular sludge removal/ does not ensure sufficient drying
- No information or recommendations given to sludge users

Overall results and discussion

General impressions were that most people had received information about the treatment system and understood its purpose. Some on the other hand stated not to have any knowledge of what the system is for, despite of living at a distance of less than 100 m away from it. None showed any negative attitude towards the project, but there seemed to be room for improvement on informing the public about the system and its functions as well as the options of reuse.

When asked about the advantages of having such a treatment system many people would mention the prevention of landslides, as the locality of the treatment system was severely affected by landslides prior to construction of the system. It was earlier considered unsafe to go there, but at the time of investigation, the landslides were prevented by the treatment system itself as this was constructed down throughout the hillside.

Among the people who did not have a toilet before construction and practiced open defecation, the access to toilets seemed to have high value. Before construction the site of the WWTP was the common spot for open defecation with separate areas for women and men. At the time of investigation they do not have to leave their houses to defecate; this was by many given as the main advantage. Others also mentioned that the environment was cleaner after the WWTP was installed.

Most people stated that they would be willing to buy food produced using sludge, but as there is no actual experience these answers cannot be trusted. It seems likely that some might change their mind once they are actually offered the food, or when they have their own experience using sludge. The possibility of contamination of food was never mentioned, and there is a possibility that some people might be opposed to buying the food grown using sludge or treated wastewater if they learned about the risk of contamination of the food by human feces.

A few people mentioned the resemblance between sludge and the traditional fertilizer made from urine and ashes; this should make it easier for the sludge to be accepted as a common fertilizer.

Experiences while interviewing

While interviewing people in the community, the author of this thesis often got the impression that the respondents were telling things they thought they were expected to say, or they would repeat things they had been told from implementers. When being asked about the benefits of having the treatment system they would mention the reuse of water and the use of sludge, but when asked if this was actually being used or if they had any personal experience with it, the answer was mostly no.

Drivers and barriers for the project

Drivers and barriers, as mentioned by the respondents and defined by author, are summarized below.

Drivers:

Environmental:

- Clean-up of the site, no garbage dumping
- Reduced risk of land-slide
- No open defecation
- Reduced pollution of the stream
- Nutrient recycling

Social:

- Toilets in the houses
- Dignity
- User friendly compared to open defecation
- Reduced health risk
- Access to sludge
- Access to treated wastewater

Financial:

- Low construction costs
- Low O&M costs
- Possibility of financial support through sale of sludge

Barriers:

Environmental:

- Treatment of the wastewater has little significance for the quality of the stream water as it is already extremely polluted.

Social:

- Little involvement from community/user's committee
- Little knowledge

Financial:

- Expensive compared to no-treatment

Testing of hypothesis

Hypothesis 1: *poor knowledge and involvement from the user's committee causes poor O&M and poor performance of the treatment system.*

The user's committee has a large potential of being more involved. The O&M is in need of improvements and follow-up, but there are no regular meetings within the user's committee and there seems to be no plans for improvements.

Hypothesis 2: *lack of female involvement has a negative impact on the user's committee.*

There were two female members of the user's committee, and only one was interviewed, and she seemed to be well involved. However, it is not possible to draw any conclusions from such a small amount of information.

Hypothesis 3: *reuse options are not being exploited properly because of lack of knowledge in community.*

It was found through the investigations that there was a general lack of knowledge on the treatment system, its functions and the options of reuse. Some people had found out by themselves, or through others, that it was possible to reuse the sludge and treated water, however, there is great potential in instructing them and demonstrating the actual use. Thus increasing the possibilities of the sludge and treated wastewater to be reused properly.

Main Hypothesis: *the lack of community participation and knowledge diminishes sustainability.*

It is impossible to know exactly what the effect would be of involving the community more, but is seems likely that if they were educated to understand the purpose and see the advantages the treatment system gives, they might be more engaged. Through more engagement the treatment system would be closer monitored and the people would better exploit its benefits.

It is clear that there is a lack of both community participation, and knowledge, in this case. It seems obvious that the sustainability must be affected by this. There are most likely other factors not mentioned in this study that may also have an influence on the outcome of O&M and sustainability.

4.3 Improvements

As the effluent values from the treatment plant are not according to standards, certain improvements might be helpful. First of all continuous flow through the system must be ensured. Today this flow is interrupted whenever the screen in the inlet pit is blocked, and the water is diverted to an overflow pipe and bypasses the system. There may be different solutions to this problem like increasing the size of the screen so it will not block as easily. In addition one could make the inlet pit larger and allow for a larger amount of wastewater to collect before water overflows and bypasses the treatment system. Another option is to increase cleaning interval but this will require more involvement from the caretaker and might not be feasible.

There is some sludge following the effluent of the ABR and entering the wetland where it collects in the pipes and on the bed surface. This may be caused by different factors. The ABR needs to be emptied on regular basis but not too often, the optimal time needs to be found and the caretaker needs to be informed. However, the problem with the ABR is probably caused by the very large quantities of organic matter and suspended solids in the influent.

O&M might be improved if there was made an O&M manual explaining the system and its functions and possible problems, and how to solve them. There should also be a maintenance plan and maybe regular check-ups by an engineer. But also more training for the caretaker would be very helpful.

When it comes to the user’s committee, the main functions and priorities should be the administration of the WWTP. They should meet to discuss present problems and find appropriate solutions or contact ENPHO in the case of technical challenges. Another important task is to engage and inform the community of what the system is for, its importance for the community and environment, the possibilities of reuse and maybe even the importance of sanitation.

As of today very little sludge is being used, and no treated water is collected for irrigation purposes. This may be changed if the community members were better informed of the benefits from using both the sludge and the treated water, however, it is important to also inform on the possibilities of catching different diseases and the care that needs to be taken to avoid this. The sludge could also be made more readily available. If sludge and treated wastewater is to be promoted as fertilizer and irrigation water the users will need to be taught further about the importance of protecting oneself from the pathogens present in the sludge and the water. This is to ensure that it is safe for them to use these resources.

5 Conclusions

The aim of this thesis was to get an overview of the condition, and secondly, identify and analyze the factors affecting sustainability, of the Sunga wastewater treatment plant in Thimi, Nepal.

From the results it can be determined that the all over effluent values do not show as good treatment results as desired according to Nepali and EU standards. Nevertheless, the system does remove on average as much as 80 – 90 % of all parameters. And when considering the high concentration of pollutants in the wastewater, the treatment results are not bad. There is some increase, throughout the operational period, in many of the pollutant values of the influent wastewater. Nevertheless, the effluent values do not rise as much as the influent values, this shows that the system is capable of higher treatment efficiency at higher loading of pollutants.

From the social research it can be concluded that there is a lack of community participation, both from the general community and the user's committee, consequently the O&M must be affected by this. In general there is a large potential of educating all involved parties, like the members of the user's committee, the caretaker, and the community members. The user's committee should have some basic knowledge of the treatment processes and requirements for a well functioning system. But detailed knowledge and understanding cannot be expected as they are not professionals in this field.

The system is not operated and maintained in the best manner, not giving maximum treatment efficiency, and not giving best usage of sludge and treated water. The system has great potential of long lasting operation on certain conditions, like stronger involvement and engagement from the community and user's committee, which subsequently could ensure adequate caretaking. There are also many possibilities of improvements in the technical part of the project; however, involving the community more could be the key to a more sustainable system.

Water is not available in large quantities, sometimes there is no water in the tap for several days and water needs to be saved and wisely used, thus as little as possible is used for flushing and the pollutant concentrations and TSS content is extremely high compared to western wastewater. The highly concentrated wastewater is difficult to treat. Unless water availability is improved, the most sustainable solution might be one where water is not needed.

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Appendix

Observations made during visit on 25-Jan-11

At a visit to the Sunga Treatment System on 25-Jan-11 some observations on the state of the systems were noted and are given below:

- Inlet pit
  - Screen is currently blocked and influent wastewater is overflowing and bypassing the treatment steps
- ABR
  - Lids are too heavy to lift
- HFW x 2
  - Vegetation is dry
  - Pipes are turned with holes up, causes water and sludge to collect
  - Pipes are not tight
  - Sludge on beds
- VFB x 2
  - tipping bucket seems to be working
  - Distribution system poor, pipes not leveled, leakages
- SDB
  - Has never been totally emptied according to caretaker
  - ABR emptied during visit
    - Maintenance responsible says the reason is that he is afraid the ABR will overflow
- Collection tank for effluent had a water level much lower than the outlet pipe

Interviews

Questionnaire for community

1. What is your knowledge of the system?
   a. Have you visited?
   b. Have your been explained the system?
2. What is your perception of it?
   a. Were you positive when you first heard about the implementation of the system?
   b. What impact has the system had on:
      i. Community

ii. Environment

c. Why?

d. Overall positive or negative?

e. Do you think the plant is operating well?

f. If you could make any improvement what would it be?

3. What contribution would you be willing to give to keep the system?

   a. Are you currently paying any fees?

   b. Would you be willing to pay to be connected to the system?

4. Are you interested in any of the products from the system? Treated water/ sludge/ biogas

   a. Do you do any farming?

   b. Do you use sludge in your farming?

   c. Would you consider using sludge?

5. Would you buy vegetables/food produced using treated wastewater?

6. Would you buy vegetables/food produced using dried sludge?

Questionnaire for user committee

1. How did you become part of the committee?

   a. How was the user committee formed?

2. Please describe your role in the group?

   a. Are you satisfied with your role in the group?

   b. Do you feel that your opinions have been heard?

7. What was the situation before the implementation?

   a. Did you have a toilet?

      i. If no: how far did you have to walk to get to a toilet/OD?

3. Has the treatment plant in any way affected your way of life?

4. What information/training was given/ required when entering the committee?

   a. Have you received any training about this system?

   b. Do you feel that you understand the system?

   c. Do you have any education related to wastewater treatment, engineering or environment?

5. Operation and maintenance

   a. Have you experienced any problems with the system?

      i. If YES: Did you participate in solving the problem?

   b. Is there an Operation and Maintenance plan for the system?

c. Is there an Operation and Maintenance manual for the system?
d. Have you participated in Operation & Maintenance?
e. Have you been involved in making decisions on maintenance?
    i. If NO: Why not?
f. Do you feel the system is operating satisfactory?
    i. If NO: Why not?
g. Do you feel the operation/maintenance role is important?
h. How often do you go see the system?

6. How many meetings for the user's committee have been arranged?
    a. How many meetings did you attend?
        i. If NONE: Why?
7. Have you participated in meetings/discussions with the community?
8. Financing
    a. Have you been involved in money contribution or collection of money for maintenance?
    b. Have you payed any fees?
    c. Would you be willing to pay a fee to keep the WWTP?
9. Reuse options
    a. Was reuse of wastewater considered before implementation of the system?
        i. If YES: what kind of reuse? For garden/ irrigation/ washing/ don't know
    b. Do you know of any reuse going on at the moment?
        i. If YES: What kind of reuse? Irrigation/ washing/ flushing toilets
10. Impact from system
    a. What impact has the treatment system had on:
        i. community
        ii. environment
    b. Why?
    c. Overall positive or negative?
11. Are you interested in any of the products from the system? Treated water/ sludge/ biogas
    a. Do you do any farming?
    b. Do you use sludge in your farming?
    c. Would you consider using sludge?
12. Would you buy vegetables/food produced using treated wastewater?
13. Would you buy vegetables/food produced using dried sludge?

Questionnaire farmers

1. Have you been informed of the possibility of reuse of wastewater from the Sunga system?
    a. If YES: Who informed you? Someone from the user's committee/ another farmer/someone from the community/ other
    b. Are you using wastewater from the Sunga treatment system?
2. What are your irrigation practices?
    a. What kind of irrigation water are you using? Water from wells/ stream water/ treated wastewater/untreated wastewater/ other
    b. How/where do you divert the wastewater? How (channel, pipe)?
    c. Is the treated wastewater easily accessible?
    d. How do you apply water? drip irrigation/flood/spray/bucket/other
3. Do you have access to sufficient irrigation water?
    a. What months do you require more water than easily available?
4. Working conditions
    a. Do you wash your hands after working in the field?
    b. Do you wash your feet after working in the field?
    c. Do you change clothes after working in the field?
5. Contents of treated wastewater
    a. Do you think the treated wastewater contains anything that may be harmful to your health?
    b. Do you think the treated wastewater contains anything that may be harmful to your crops?
    c. Do you think that the treated wastewater contains substances that are helpful for crop yield?
6. Contribution
    a. Do you pay for water for irrigation?
    b. Would you pay for treated wastewater?
    c. Would you pay contribution to the maintenance costs of the treatment plant to ensure good quality discharge?
7. Fertilizer
    a. Do you use chemical fertilizer?
8. Do you have any personal constraints on using wastewater for irrigation?

Questionnaire for sludge users

1. Have you been informed of the possibility of use of sludge from the Sunga system?
    a. If YES: Who informed you? Someone from the user's committee/ another farmer/someone from the community/ other
    b. Are you using sludge from the Sunga treatment system?
    c. When did you learn about the possibility of using sludge?
    d. Why did you not start using it earlier?
2. Hygiene
    a. Do you wash your hands after working in the field?
    b. Do you wash your feet after working in the field?
    c. Do you change clothes after working in the field?
3. Sludge contents
    a. Do you think the sludge contains anything that may be harmful to your health?
    b. Do you think the sludge contains anything that may be harmful to your crops?
    c. Do you think that the sludge contains substances that are helpful for crop yield?
4. Do you use chemical fertilizer?
5. Would you pay be willing to pay for sludge?
6. Do you have any personal constraints on using sludge?

Questionnaire for caretaker

1. Do you feel that you understand how the system works? YES/NO
2. Have you been given any contact info for an engineer? YES/NO
3. Have you been given a manual for operation and maintenance? YES/NO
4. Do you feel the system is operating satisfactory? YES/NO
5. If NO: what are the main problems?
6. Have you ever encountered a problem you didn't know the solution for? YES/NO
7. If YES: What did you do?
8. If NO: what will you do if it happens?
9. How often do the members of the user's committee visit?
10. Are the members of the user's committee involved in the O&M?
11. If YES: in what way?
12. How often is the ABR emptied?
13. For how long is the sludge dried before it is being used?

14. Is the sludge taken out to dry further somewhere else before ABR is emptied again? YES/NO
15. Do you give any recommendations for the farmers who collect sludge at the plant? YES/NO
16. If YES: What are the recommendations?
17. On what interval do you send the water through the biogas reactor?
18. How often is the screen in the inlet pit cleaned?
19. Do you have any former experience/education related to wastewater treatment/ sanitation/ engineering/ environment?
20. Do you have any former experience/education related to wastewater treatment/ sanitation/ engineering/ environment?