Norwegian University
of Life Sciences

Master's Thesis 2017 30 ECTS
Faculty of Environmental Sciences and Natural Resource Management

# Wetland treatment of hospital wastewater in Far Western Nepal including a Knowledge Attitude and Practice (KAP) study on sanitation

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# Preface

First of all, I wish to thank my supervisors Manoj K. Pandey and Petter D. Jenssen for presenting this interesting study, which gave me the opportunity to travel to Nepal and learning about constructed wetlands and the sanitation situation in and around Geta. My motivation for this thesis is my interest in travelling, experiencing new countries and cultures and combining this with my interest for water and sanitation. Special thanks go to Ramesh Chandra Bhatta, Bikash Pathak and Mahesh Ojha along with the rest of the staff at Geta Eye Hospital for taking such good care of me and helping me with my thesis work during my stay in Geta. I would like to thank Iswar Man Amatya with the Institute of Engineering at Tribhuvan University for helping me in Kathmandu and for providing me with necessary testing equipment and making the lab available for analyzing the wastewater samples. I am also grateful to Amit Kumar Maharjan and Kenta Shinoda for helping me with the analysis of the samples.

Norwegian University of Life Sciences,15.05.2017

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# Abstract

Decentralized wastewater treatment systems are a technological approach to sanitation that often is easy to operate, cheap to construct and require little maintenance. Combining this with ecological sanitation which consider human waste as a resource and not something that needs to be disposed of is essential to provide sustainable sanitation solutions and reduce the number of people without access to improved sanitation. These systems are especially suited for rural and semi-urban areas in developing countries where centralized conventional system are absent and too expensive to build and operate. The decentralized wastewater treatment system studied in this thesis is a newly built system at Geta Eye Hospital that consist of pretreatment in an existing septic tank, biofilter and a subsurface horizontal flow constructed wetland. Final construction of the system was observed and some constructional errors are presented, with high loading rate and potential clogging of the system as the major issues. Performance evaluation of the treatment system was conducted by taking wastewater samples at strategic points and see how different parameters reduced throughout the system. The treatment efficiency of the system is based on analyses of Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN) and Total Solids (TS). The treatment efficiency of this newly constructed, immature, system is rather poor compared to more mature systems operating in Nepal, but will most likely improve as the system matures. The new treatment system at Geta Eye Hospital shows their willingness to improve their sanitation situation, but there is still need for further improvement. The improvements should be sustainable and ecological, and can include sludge drying beds, biogas reactors, urine diverting toilets as well as some technical issues. These new interventions not only improve the environmental conditions at the hospital, but might also work as a showcase for the local community to observe and learn from. Therefore, a Knowledge, Attitude and Practice (KAP) survey was conducted among households in Bijaura village, adjacent to Geta Eye Hospital, to map the baseline sanitation situation there and see how the interventions at the hospital can benefit the local community. No one in the village knew of anyone that practiced open defecation. The households have a good knowledge about and attitude towards the value and reuse of excreta and urine as fertilizer. Over half of the households use biogas reactors that produces gas for cooking. Knowledge about safe use of sludge in agriculture is lacking for many of the households as they do not store the sludge long enough before application.

# Abbreviations

| | |
|---|---|
| BOD | Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| CW | Constructed Wetland |
| DDC | District Development Committees |
| DEWATS | Decentralized Wastewater Treatment Systems |
| DVUD | Double Vault Urine Diverting toilet |
| EcoSan | Ecological Sanitation |
| KAP | Knowledge, Attitude and Practice |
| MLD | Million Liters per Day |
| NBSM | Nepal Bureau of Standards and Metrology |
| SDG | Sustainable Development Goals |
| SDRB | Sludge Drying Reed Beds |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| TS | Total Solids |
| TSS | Total Suspended Solids |
| UDDT | Urine Diverting Dry Toilet |
| UDWT | Urine Diverting Wet Toilet |
| VDC | Village Development Committee |
| WHO | World Health Organization |

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# 1 Introduction

## 1.1 General introduction

Today 2.4 billion people are living without access to improved sanitation facilities, 663 million people are living without access to safe drinking water and 946 million people are practicing open defecation (UNDP 2015). More than 80 percent of the worlds wastewater is discharged untreated into rivers or the sea. Nearly 1000 children die every day due to sanitation-related diarrheal diseases which are easily preventable. Trying to improve the state of the world, the United Nations came up with a set of Millennium Development Goals in 2000 to be met by 2015. Goal number 7 included two crucial points on water and sanitation; ñhalve the proportion of the population without improved drinking water between 1990 and 2015ò and ñhalve the proportion of the population without basic sanitation between 1990 and 2015ò. The ambition of access to improved drinking water was met five years ahead of schedule in 2010. However, the target on access to basic sanitation was not met; as one in three people worldwide still use unimproved sanitation facilities. There is a huge difference between access to improved sanitation in urban areas (82%) and rural areas (50%) (Rose 2015).

In 2015 the Sustainable Development Goals (SDG) were adopted by heads of state all around the world. The SDG are built on the Millennium Development Goals. The SGD consist of 17 goals and 169 specific targets to be met by 2030. Goal six states ñensure availability and sustainable management of water and sanitation for allò and include targets such as ñby 2030, achieve universal and equitable access to safe and affordable drinking water for allò and ñby 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situationsò. A designated goal for water and sanitation shows the importance of this issue and realizing goal number six would also go a long way towards achieving the other SDG (UNWater 2015).

Conventional treatment systems were introduced in industrialized countries to improve public health in urban areas. Because of the technical complex and financially expensive construction, many communities in developing countries cannot afford to implement conventional treatment systems. Therefore, simple, affordable and environmentally friendly treatment systems should be adopted for these communities (UN-HABITAT 2008). Several studies and field experience shows that implementation of new technology is less likely to be successful or sustainable without educational, behavioral, motivational and participatory activities and without considering socio-cultural aspects. For goal number six in the SGD to be met, initiatives in sanitation must include behavioral modification, education and community participation. The new technology should also be adapted to site-specific conditions (Sobsey 2002). In this thesis, constructed wetlands are presented as a decentralized wastewater treatment system as one possible solution to access to sanitation for all.

## 1.2 Main objectives of the study

The main objectives are:

1. Evaluate the performance of the constructed wetland (CW) at Geta Eye Hospital by measuring key parameters before and after the CW and analyzing for TP, COD, TN, TS, temperature and pH.

2. Social aspects concerning water and sanitation in the communities around Geta Eye Hospital. Get an overview of the water and sanitation situation in the village and what knowledge they have about improved sanitation, hygiene and the importance of proper water and sanitation facilities. Perform KAP studies (knowledge, attitude and practice) in the community. Find out the weaknesses and strengths in the sanitation situation in the villages adjacent to the hospital area.

3. Make a proposal for further improvement of the sanitation situation in Geta Eye Hospital. Discuss different technologies for source separation and nutrient recovery, including urine diverting toilets, grey water treatment and sludge stabilization.

# 2 Background

Nepal is a landlocked country wedged between China to the north and India to the east, west and south. It is about 855 km from east to west and 241 km at its widest. Nepal covers an area of 147,181 square kilometers and with a population of 26.66 million (2011) the population density is 181 people per square kilometer. Nepal is divided into five development regions; Far-western, Mid-western, Western, Central and Eastern. These are again divided into 14 zones, 75 District Development Committees (DDC), 58 municipalities and 3915 Village Development Committees (VDC) (SACOSAN 2013).

## 2.1 Water and sanitation in Nepal

In Nepal 3.27 million people are without access to safe drinking water and 17.39 million people are without access to improved sanitation facilities (WHO 2015). In 1990 the sanitation coverage was 6% and had reached 62% by 2011 (SACOSAN 2013). The Department of Water Supply and Sewerage (DWSS) is the lead department in sanitation and water supply in Nepal have set a very ambitious target of achieving universal water and sanitation coverage by 2017. This target will most likely not be met. Open defecation free (ODF) is used for measuring the nation-wide sanitation movement and districts, municipalities and VDCs can achieve ODF status. 6 municipalities and 748 VDCs had been declared as ODF areas by March 2013. Five districts had also been declared as ODF districts and had achieved 100% sanitation coverage. The urbanization growth is at 3.38% which is more than the annual 1.35% national population growth (SACOSAN 2013). This puts an extra stress on the water and sanitation demand in the cities. By estimations only 12% of urban households are connected to a sewer line and treatment of this sewage is virtually none existent. 370 million liters of sewage is produced every day in Nepal, but installed treatment capacity is only at 10% of this (37 MLD). Of the 37 MLD installed only 17.5 MLD is in operation meaning only 5% of total demand is treated (WaterAid 2008b). This means that there is a critical need for proper treatment of wastewater in Nepal.

### 2.1.1 Different approaches to sustainable sanitation in Nepal

The two most common wastewater management and sanitation are either waterborne conventional treatment systems (developed world) or dry pits (developing world). In both systems, the excreta are viewed as waste and are disposed of. In the conventional waterborne end-of-pipe system large amounts of water is used to transport the excreta and the idea is to treat the wastewater at the end of the pipe. This does not happen in most cases as more than 80% of wastewater does not receive any treatment at all. Untreated wastewater discharge to surface waters poses a serious health risk to people living downstream, using this water. These systems are also very expensive, energy demanding and does not favor recycling of resources. In the dry pit system, liquid infiltrates into the ground and solids are retained. Although this toilet does form a barrier between excreta and human contact, the liquid infiltrating into the ground contains nutrients and pathogens which might pollute surface or groundwater (SSWM 2012).

Sustainable sanitation aims to be socially acceptable, economically viable, environmentally friendly and institutionally and technically appropriate. The main objective of sustainable sanitation is to provide a clean environment to protect and promote human health. To break the cycle of disease, the sanitation system must prevent exposure that can affect public health by working as an effective barrier between the environment and the user. The environment and natural resources should be protected by reducing the required energy to run the system and limit the water consumed when using it. Recognizing excreta and wastewater as a resource instead of waste is an important principle. The system should be easy to construct and operated by the local community and must be resilient and robust. Furthermore, the system should be built meeting the financial capacity of the household; not only construction, but also for operation and maintenance. When designing the system, socio-cultural aspects must be considered it to be accepted. Many systems are designed using these aspects, but are failing due to some of the criteria not having been met. It is nearly impossible to achieve absolute sustainability, and the concept of sustainable sanitation are more guidelines than a goal to actually reach (SuSanA 2008).

Sustainable sanitation is an approach with certain principles rather than a specific technology as there are several different technologies that can be used to make wastewater management and sanitation more sustainable. Some of these will be explained later in the thesis. One must consider local factors such as climate, water availability, local materials available, socio-cultural preferences, agricultural practices etc. to find the most adequate solution from case to case (SSWM 2012).

### DEWATS

Decentralized Wastewater Treatment Systems (DEWATS) is not just a technical package but a technical approach to sanitation. DEWATS application are based on the principle of low-cost and low-maintenance because most materials for construction are locally available and most parts of the system works without technical energy inputs. DEWATS can treat both domestic and industrial wastewater with flows ranging from 1-1000 $m^3$ per day. The system is also tolerant towards fluctuation in flow. DEWATS does not require sophisticated maintenance and are long lasting and reliable. DEWATS can include resource recovery through biogas production or wastewater re-use (BORDA 2010).

### Ecological Sanitation

Ecological sanitation (EcoSan) recognizes the value and reuse of excreta and wastewater as a resource that can be recovered, treated and reused safely. EcoSan is a holistic approach to economic and ecological sanitation and is an attitude as well as a systemic approach. EcoSan can come in the form of many technologies, from composting toilets to natural treatment, and from household use to larger decentralized systems (Poudel & Adhikari 2015). EcoSan is based on three fundamental aspects: preventing pollution rather than trying to control the pollution after it has taken place, rendering human excreta safe and using safe products from this for agricultural purposes. This makes a sustainable closed-looped system (Esrey et al. 1998). The nutrients found in domestic wastewater could in theory be enough to fertilize all the crops needed to feed all the whole world. Most of nutrients in wastewater comes from toilets and contain as much as

80-90% of nitrogen, phosphorus and potassium which are the major plant nutrients. By using hygienically safe pathways, these nutrients can be reclaimed and used locally as fertilizer. Urine is basically sterile and only needs storage before it can be used safely as fertilizer. Urine can easily be collected by using urine diverting toilets which are explained later in the thesis. Infrastructure for wastewater handling is absent in many developing countries and water, money and fertilizers are scarce resources. This makes ecological sanitation more appropriate in low-income countries as the system is low-cost, locally managed, has minor requirements for water and values the reuse of nutrients. Another benefit is that the system can be built onsite and do not require much piping, which is the biggest cost in conventional wastewater facilities. Ecological sanitation saves water, reduces the amount of blackwater which contains disease causing organisms, produces energy, reuses excreta for fertilizer production or soil amendment and can be adapted to local conditions  (Jenssen et al. 2004).

### 2.1.2 Sanitation technologies used in Nepal

**Pit Latrine**

One of the most widely used sanitation technologies is the pit latrine due to its easy and low-cost construction. It is also easy to operate and maintain and meets the definition of improved sanitation set by UNICEF and WHO. The pit latrine usually consists of a dug hole of around one meter in diameter and varying depth. A slab with a hole in it should be used to cover the pit to prevent people from falling in, reduce odor and increase convenience of the toilet. To avoid flooding of the pit by surface water, the slab is mounded above ground level by using the excavated soil. A shelter is built by local materials around the slab to provide cover. Urine, faeces and cleansing material is disposed of into the pit where the solids accumulate and the liquid percolates into the walls and bottom of the pit. Therefore, the pit should be constructed where permeable soil is available. If the infiltration is slow, stagnant water in the pit might lead to breeding of insects. Microbiological activity degrades some of the organics and reduces the accumulation rate. The pit latrine does not need any water to function and is advantageous in water scarce areas. The treatment process however is limited. There is risk of groundwater contamination from the leachate and the bottom of the pit should be at least 2 meters above the groundwater table and 30 meters from the nearest source of drinking water. A pit can last for 20 years or longer depending on how deep it is and how many people use the toilet. Operation and maintenance usually only consist of cleaning the toilet to avoid odor and flies. After the pit is full the contents can be dug out and used for agricultural purposes if it is properly stored and dried to limit the number of pathogens. By alternating between two pits, one can be stored for one year before it is dug out while the other one is used. The content still needs proper handling as it might contain pathogens. The pit can also be covered when it is full and the slap and superstructure relocated to a new spot. This is only recommended where land is available. Space for infiltration can be limited and emptying of the pit difficult in urban areas. The pit latrines should therefore only be used in rural or semi-urban areas (SSWM 2014b). By adding a ventilation pipe from the pit to the outdoors you will get a ventilated improved pit latrine which reduces odors from the pit (WaterAid 2008a).

### Pour flush latrine

The only difference between a pit latrine and the pour flush latrine is that instead of a hole in the slab you have a water sealed squatting pan. The optimal depth of the water seal is 2 cm to minimize flushing water needed. This prevents odors and flies from coming up from the toilet. The user of the toilet usually pours 2-3 liters of water when flushing. The squatting pan can be connected to a soak pit, septic tank, biogas reactor or other types of preliminary and primary treatment. One of the drawbacks to this system is that it needs a constant supply of water which also increases the amount of contaminated sewage from the toilet. Recycled water and collected rainwater may be used (SSWM 2014a).

### Septic tank ï  soak pit system

In a septic tank ï  soak pit system the wastewater is pretreated in a septic tank. The septic tank consists of a big tank that can be divided into different compartments. The easily settleable solids will sink to the bottom by gravity and scum will float to the top. The accumulated sludge and scum must be emptied periodically to avoid high solids content effluent. The septic tank should be emptied when the sludge and scum makes up more than 30% of the total liquid volume of the tank (UN-HABITAT 2008). From the septic tank the wastewater goes into the soak pit. The soak pit is usually a covered pit with porous walls and bottom that allows wastewater (or greywater or stormwater) to slowly infiltrate into the ground. This is a relatively safe way of discharging wastewater and low-cost partially treatment. The wastewater is treated by microorganisms digesting organics and the soil matrix filters out particles. The soil should be permeable and with absorptive properties so that the wastewater will infiltrate easily and not clog the soil. The wastewater runs through the soil pores in horizontal and vertical direction until it reaches the groundwater and can contribute to groundwater recharge. The soak pit should be constructed no less than 2 meters above the groundwater level and at least 30 meters from the nearest source of drinking water. The pit should be between 1.5 and 4 meters deep and can be lined with concrete or filled with larger rocks to prevent the pit from collapsing. The soak pit is a low-cost alternative to direct discharge in rural or semi-urban settlements where soil allows for infiltration. Biomass and particles will eventually clog the soak pit and must be cleaned out or moved. A soak pit should last 3-5 years before any maintenance is required. The soak pit should be covered so that humans and animals do not have contact with the effluent. If the pretreatment works as it should and the pit is not used for raw sewage, health concerns are minimal (Tilley et al. 2014).

### Biogas sanitation

Instead of going into a soak pit, the excreta from the pour-flush latrine can go into a biogas digester made from brick and cement. In addition, there is also an inlet for feeding the system with cattle dung. Almost all the biogas plant in Nepal are fixed dome plants with a volume of 6 $m^3$. The gas produced by anaerobic digestion can be used for cooking or lighting while the slurry can be used as compost. Since compost and renewable biogas is produced, biogas attached toilets are excellent systems for sanitation and can be considered as ecological sanitation. The system is not suited for the poorest households as the system needs cattle dung and the investment cost is high. The cattle dung must be mixed with equal amount of water before it can be fed into the biogas digester and the system is therefore not suited in water scarce areas. 157,675 domestic biogas plants had been built in Nepal by 2006 and it is estimated that 65% of these were attached to a toilet (WaterAid 2008a).

### Urine diverting dry toilet

Based on the ecological sanitation approach the urine diverting toilet was introduced in Nepal in 2002 and comes in urine diverting dry toilet (UDDT) and urine diverting wet toilet (UDWT). In a UDDT a squatting pan with separate holes for urine and faeces is used to collect and store the different fractions separately. There is also a separate hole for anal cleansing water which is diverted into a soak pit or a constructed wetland. The first UDDT to be introduced in Nepal was a double vault urine diversion toilet (DVUD) based on a Vietnamese model. This system consists of two watertight vaults made of brick plastered with cement or mortar for storage of faeces and are ventilated with a pipe to the outdoors. The two vaults alternates feeding and resting. The vaults are constructed above ground level to avoid groundwater contamination. The size of each vault is usually 0.35 cubic meters and are accessed through a vault door for easy removal of the content.  Urine is diverted from the bowl in a 50-mm polyethylene pipe to a collection tank, usually a 100-liter plastic tank but can also be made from brick plastered with cement or mortar. After the urine has rested for one week and the fecal matter for six months it can be used for agricultural purposes (WaterAid 2008a). Tilley et al. (2014) states that urine should be stored for at least one month when application at the household level and for six months if it is for larger scale (Tilley et al. 2014).

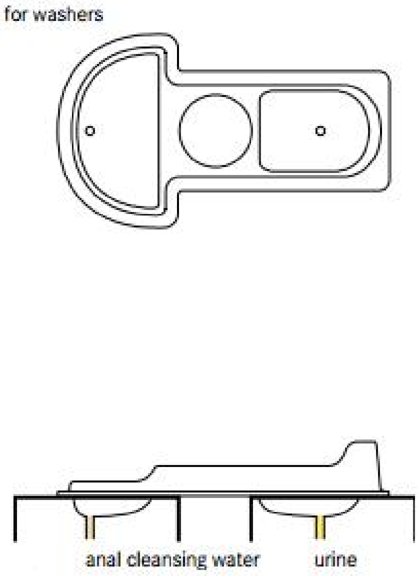

*Figure 1: Sketch of a UDDT with separate hole for anal cleansing. In a UDWT faces, cleansing water and water for flushing goes into the same hole (Tilley et al. 2014)*

**Urine diverting wet toilet**

UDWT is basically a pour-flush latrine with a urine diverting squat pan instead of a conventional one. The urine is collected and stored in plastic tanks just like in the UDDT but the faeces together with anal cleansing water and flushing water is collected in two alternating pits made of precast concrete rings. Liquid percolates into the bottom and walls of the pit and when one pit is full it is left for decomposing for six months while the other pit is used. Eventually the pits will have to be emptied (WaterAid 2008a). Since anal cleansing is common in Nepal the transition to the UDWT has been easier for the Nepali because there is no separate hole for cleansing water (Poudel & Adhikari 2015).

The urine from both the UDDT and UDWT are nearly sterile and can easily be handled safely after storage. Urine contains roughly 88% of nitrogen, 74% of potassium and 61% of the phosphorus excreted from the body. The high nutrient content in urine makes it a good liquid fertilizer. One person produce on average 1.5 liters of urine per day and this can be received by 1 $m^2$ of farmland, which means 300-400 $m^2$ can be fertilized by the urine from one person every year (Tilley et al. 2014).

### 2.1.3 Sludge handling and treatment

Septic tank for pretreatment is common in developing countries but sludge treatment facilities and proper disposal of sludge is often lacking. The sludge is therefore dumped into rivers, open spaces or drains illegally. Sludge drying reed bed (SDRB) is a sludge treating method that requires minimal maintenance and little or no electricity to operate and is well suited for developing countries for both small scale and larger treatment plants. SDRBs can reduce the sludge volume by increasing the dry matter content in sludge if the bed is correctly designed. The SDRB can be loaded with sludge for 8-10 years before the sludge must be taken out and can be safely used on green areas or in agriculture. Sludge drying beds can be planted or unplanted. Several authors have pointed out that planted beds perform better than unplanted ones in terms of longer life span, higher loading, quicker drying and enhanced mineralization (Pandey & Jenssen 2015).

The SDRB works as a vertical flow constructed wetland and usually consist of multiple beds to alternate feeding of sludge and resting for the biological and physical processes to take place in the resting period. The beds are filled with porous media to allow the liquid in the sludge to percolate into the media. The porous media consist of one or multiple layers of finer-textured layers of sand, gravel, or soil. The top layer is planted with wetland vegetation, often the common reed. The sludge is usually fed onto the bed by a vertical standpipe and distributed passively across the whole surface of the bed. The solid content of the sludge is retained on the top of the bed while the liquid is infiltrating into the bed. At the bottom of the bed there is a drainage system to dewater the sludge efficiently and transport the liquid back to the wastewater treatment facility. Depending on site conditions the beds can be excavated into the ground or built on top of the soil with concrete walls. These walls should be high enough to allow sludge to build up for 10 years. In the startup of the system the loading should be less than designed capacity for the plants to grow. After the startup period the loading should be at design capacity. At the end of the operating (8-12 years) the sludge is left to dry for some months in the dry season to further increase the dry matter content of the sludge. A study showed that a resting period of 3-4 months after the last loading of sludge was sufficient to reduce the number of pathogens to be safely used as a fertilizer agriculture. When the beds has been emptied the process can start over again (Brix 2017).

A combination of physical and biochemical processes secures the treatment of sludge in the SDRB. The plants in the bed reduces the moisture content in the sludge and the sludge volume by evapotranspiration in addition to transferring oxygen into the sludge layer through the rhizomes thus promoting aerobic degradation and nitrification. Nutrients and heavy metals are removed by plant uptake. The root system and the natural movement of the plants in the wind leads to improved drainage. Plants also provides surface area for microbial growth, stabilizes the bed and prevents clogging and erosion. Mineralization is done by biochemical degradation of organic material in the sludge and releases inorganic nutrients which are biologically available and improves fertility of the plants. Mineralization requires oxygen and primarily occurs in the resting periods since oxygen is less available in the saturated conditions when the system is loaded. In the resting period, cracks will form in the drying sludge which allows oxygen transfer into the sludge layers. SDRBs in temperate climates have shown greater treatment performance in the summer than in the winter months when it comes to solids reduction, water removal and increased oxidation. This makes the SDRB system ideal for tropical climates where the temperature is high the whole year. The design and performance of the bed is also dependent on media type and size, sludge characteristics, hydraulic loading rate, solids loading rate, loading frequency and maturity of the bed (Kengne & Tilley 2014). The solids loading rate varies greatly between 17-28 kg TS/$m^2$/year in colder climates to 250 kg TS/$m^2$/year in warmer climates. A study from a SDRB loaded once a week with 250 kg TS/$m^2$/year produced residual solids with TS content of 30% to 60%. The area required for this treatment was 0.03 $m^2$/p.e. compared to 0.3-0.6 $m^2$/p.e. needed in cold climates (Pandey & Jenssen 2015). This makes the SDRB well suited in warm climates.

Possible design and construction issues with the SDRB include too few beds which can cause to short resting period, damaged draining pipes causing insufficient drainage and drying of the sludge, wrong composition of the growth layer can cause clogging or not being able to hold back the solids and wrong planting techniques casing the plants to not thrive in the bed. Operational issues include not letting the plants settle in the startup period, overloading the system, no or not long enough resting periods and variations in sludge quality (Brix 2017).

## 2.2 Constructed wetlands

According UN-HABITAT (2008): ñConstructed Wetlands (CWs) are a natural, low-cost, eco-technological biological wastewater treatment technology designed to mimic processes found in natural wetland ecosystems, which is now standing as the potential alternative or supplementary systems for the treatment of wastewaterò. Constructed wetlands are decentralized wastewater treatment system that are relatively inexpensive to build and easy to operate and maintain which makes them a viable alternative for developing countries. Constructed wetlands have been used for treatment of wastewater since the early 1950s and are now in operation all over the world. The potential for constructed wetlands technology in developing countries is enormous, but little knowledge of constructed wetland design and management limits the adoption. A constructed wetland consists of a shallow lined basin filled with filter media in which the wastewater flows through or over. The bed is vegetated by plants that can survive in saturated conditions. Outlet and inlet structures control the flow of water and the water level in the system (UN-HABITAT 2008).

### 2.2.1 Different types of Constructed wetlands

In nature, you will find naturally occurring wetlands such as bogs, marches and swamps. Constructed wetlands are built where natural wetlands do not normally occur, specifically for the treatment of wastewater and pollution control. Categorized by flow pattern, we generally divide constructed wetlands into free water surface wetlands and subsurface flow wetlands. Both these types of constructed wetlands utilize emergent aquatic vegetation (Reed 1993). In the free water surface wetlands, water flows at a shallow depth horizontally over media which support the roots of the vegetation. The flow is above the substrate which makes the top layer of flow aerobic and the lower layers can be anaerobic. In addition to treating wastewater, free water surface wetlands can be aesthetically pleasing as they look like natural marshes and may provide wildlife habitat. Subsurface flow wetlands are made up of pretty much the same components as the free water surface wetlands. The difference is that the flow of wastewater is designed to remain below the top of the media in the subsurface flow wetlands. Because the flow of wastewater is subsurface, odor and pest problems are minimized. Wastewater will also have more contact with the porous media because the flow runs through the media and not over it. This can make the subsurface flow wetlands smaller in size compared to a free water surface wetlands treating the same amount of wastewater (Davis 1995). Free water surface wetlands can become potential mosquito breeding grounds if not properly designed. Subsurface flow wetlands are therefore preferred in tropical and subtropical climates (Pandey et al. 2013). Since Geta has a tropical climate and the studied constructed wetland is a subsurface flow wetland, the free water surface wetland will not be discussed any further.

There are two main directions of flow in the subsurface flow wetlands; horizontal flow and vertical flow. Both has certain advantages and limitations. By combining horizontal and vertical flow you get a hybrid system that complements each other (UN-HABITAT 2008).

### Horizontal Flow Wetlands

In horizontal flow wetlands, the wastewater flows from the inlet in the bed to the outlet of the bed in a horizontal path. As the wastewater moves slowly through the porous substrate, the wastewater will encounter anaerobic, aerobic and anoxic zones. While most of the bed will be anaerobic or anoxic, aerobic zones will occur around the roots and rhizomes of the vegetation planted in the bed. Organic pollutants are effectively removed in horizontal flow wetlands by microbiological degradation and by physical and chemical processes. The removal of nutrients is limited in horizontal flow wetlands due to lack of oxygen in the bed. Nitrates are however removed (UN-HABITAT 2008).

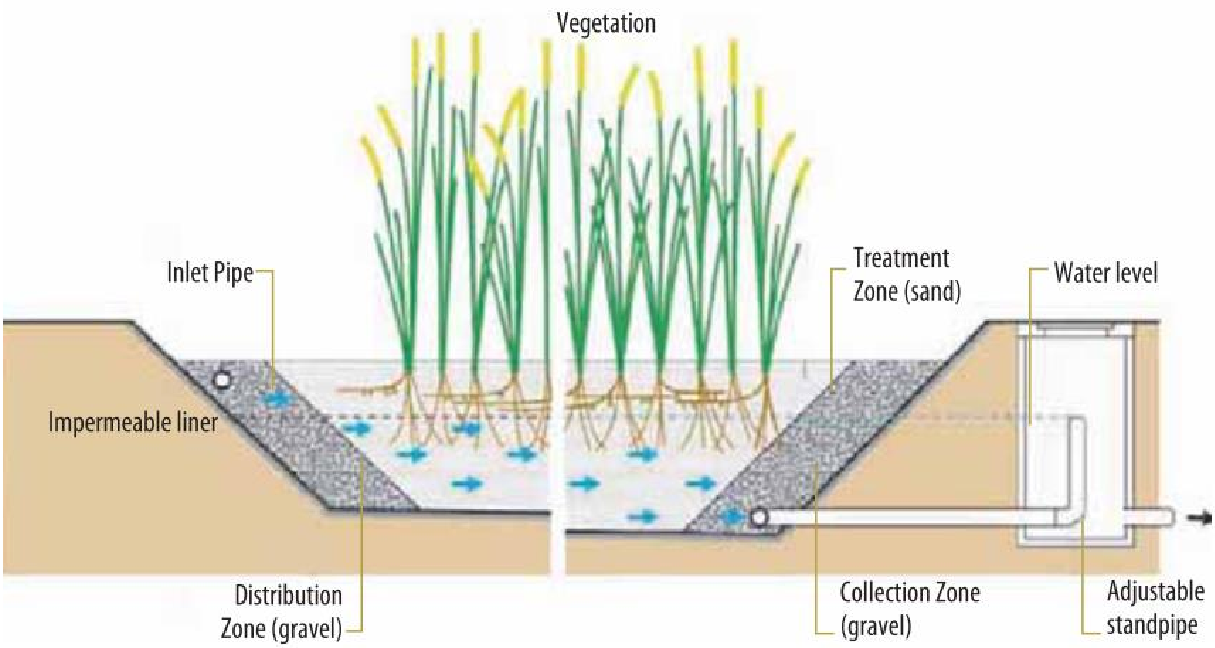

*Figure 2: Schematic cross-section of a horizontal flow constructed wetland (UN-HABITAT 2008).*

### Vertical Flow Wetlands

In vertical flow wetlands, the wastewater is fed intermittently over the bed so that it floods the top of the bed. The wastewater then moves vertically through the substrate before it is collected in drainage pipes at the bottom. Between loadings the bed is drained free of wastewater which allows air to fill the bed again. The next loading traps the air inside the bed and leads to good transfer of oxygen which allows nitrification. Vertical flow wetlands removes organic matter and pathogens efficiently and takes up less space than a horizontal flow wetland (UN-HABITAT 2008).

### Hybrid Systems

There are limitations and advantages to both the vertical and horizontal flow wetlands. Horizontal flow wetlands are better when it comes to removal of solids and removes organic matter efficiently, but it takes up more space. Vertical flow wetlands have better oxygen transfer, hence the ability to nitrify, but can become clogged if the selection of media is wrong. By combining both vertical and horizontal flow wetlands you get what is referred to as a hybrid system. There has been a growing interest in these hybrid system as they complete each others advantages and disadvantages. In a hybrid system, horizontal flow wetland can be followed by vertical flow wetland or vice versa, depending on the purpose of treatment (UN-HABITAT 2008).

### 2.2.2 Treatment processes in constructed wetlands

The treatment performance of a constructed wetland depends on many factors including physical characteristics for the system, influent wastewater quality, hydraulic and pollutant loading and climate. Constructed wetlands are very complex systems which transform or separate pollutants by chemical, biological and physical mechanisms. Constituent transformation and liquid/solid separation are the two major treatment mechanisms in constructed wetlands. Both of these mechanisms may remove contaminants but usually only detain them for a period of time (USEPA 2000a).

## Removal of organic matter

Organic compounds may occur as both settleable and soluble matter. Settleable organics are removed much in the same way as suspended solids, by filtration and deposition. Soluble organics are removed by attached and suspended microbial growth and are degraded both aerobically and anaerobically. Oxygen for the aerobic degradation is supplied by the plant roots or directly from the atmosphere by diffusion in the top layers of the wastewater. The aerobic bacteria consume oxygen to transform the organic matter to $CO_2$. But the concentration of dissolved oxygen is low so most of the degradation is done by anaerobic bacteria. Organic matter is removed by anaerobic bacteria by breakdown to methane. There is also uptake of organic matter by the vegetation planted in the bed but this is negligible compared to biological degradation (Vymazal 1998). There are discussions about the significance of planted beds, but the plant roots do contribute to more surface area where biofilm can form. Soluble compounds will be generated by hydrolysis and will most likely sorb to the biofilm formed on the plant roots and the rest of the media in the bed. Some of the organic matter removal mechanisms are temperature dependent and will likely slow down or cease when temperatures go down (USEPA 2000a).

## Removal of phosphorus

In wastewater phosphorus occurs primarily as phosphates such as organically bound phosphates, condensed phosphates and most importantly as orthophosphates. These may occur in soluble or particulate form. Organic phosphates usually come from food residue and body waste as they are primarily formed by biological processes. Inorganic phosphates usually come from cleaning products (USEPA 2000a). Removal of phosphorus is important as it can cause eutrophication in receiving water bodies (Norton 2007). Phosphorus is one of the most significant nutrients for ecosystems, but it usually moves to the sediment sink in nature and is therefore scarce. One of the primary removal mechanisms for phosphorus in constructed wetlands are accretion of phosphates in the sediment (USEPA 2000a). Besides physical mechanisms, phosphorus is also removed by biological and chemical processes.

Microbial removal occurs to some extent, where bacteria take up and store phosphorus. This is a reversible removal mechanism as the die-off and decay of these bacteria releases most of the assimilated phosphorus back to the water. Plant uptake of phosphorus is also of little significance. Different studies have shown between 1.5 and 13% plant-uptake (Garcia et al. 2010). However, plant uptake of phosphorus may be more significant in tropical climates where standing crops are taller and no translocation occurs during the fall. Harvesting the plants accounts for less than 10% of phosphorus removal, but if not harvested the phosphorus will be partially released back to the system when plant decay (Garcia et al. 2010).

Phosphorus can also be removed by adsorption to the granular media of the bed and plants. The adsorption rate is dependent on the surface area and texture of the media. Gravel is the most used media in constructed wetlands, but has low adsorption capacity as it has coarse texture and low Fe and Al content. The adsorption pathway for phosphorus removal is also limited by the fact that the binding sites on the media becomes saturated a short time after start-up of the system (Garcia et al. 2010).

Phosphorus can be chemically removed by phosphates precipitate as insoluble ferric, calcium and aluminum phosphates. However, the phosphates may be released back into the water under anoxic conditions. Over time some of the bound phosphate will be trapped in the sediments and lost to the system (USEPA 2000a).

Phosphorus removal in constructed wetlands is rather poor. A review of removal rates shows an average of 32% reduction and an effluent value of 5.15 mg/L which is above discharge limits. The low reduction can be explained by low uptake by plants, depletion of adsorption sites and the temporal removal by microbial activity (Garcia et al. 2010).

### Removal of Nitrogen

Nitrogen may occur in wastewater as organic nitrogen, ammonia, nitrite and nitrate. Removal of nitrogen from wastewaters is important because it may have bad effects on waters receiving the effluents. High nitrogen content in surface waters may cause eutrophication which involves excessive plant growth and oxygen depletion. High concentrations of unionized ammonia are toxic to fish and other aquatic life. Nitrate and nitrite in high concentrations in drinking water may cause serious health problems to humans (USEPA 2000a).

Physicochemical and biological mechanisms are the two major processes in which nitrogen removal is achieved. This includes microbial interaction with nitrogen, plant uptake, sedimentation and chemical adsorption. The biological treatment mechanisms most prevalent in constructed wetlands are ammonification, nitrification and denitrification. In ammonification, organic nitrogen is biologically converted into ammonia. This process happens in both aerobic and anaerobic zones in the bed. The inorganic ammonia is then removed mainly by nitrification-denitrification processes. Nitrification happens under aerobic conditions and use bacteria such as Nitrosomonas and Nitrobacter. Ammonia is first oxidized to nitrite and then oxidized to nitrate. Denitrification bacteria, such as Bacillus and Pseudomonas, converts nitrate and nitrite into nitrogen gas, thus leaving the system. The process of denitrification only occurs under anaerobic and anoxic conditions and needs a supply of organic carbon (Lee et al. 2009). Plant uptake as a biological process is usually insignificant compared to the loading of nitrogen to the wetland. The vegetation must also be harvested to remove the nitrogen accumulated in plants, otherwise it will return to the water when the plants wilt (USEPA 2000a).

The physicochemical mechanisms include ammonia adsorption and sedimentation as the major processes. Particulate organic nitrogen will usually be removed by sedimentation and will settle on the floor of the bed or adhere to plants. Ammonium will adsorb to substrate with loose bonds. The amount of ammonia adsorbed to substrate can quickly change if chemistry of the water change (Lee et al. 2009).

Since the concentration of oxygen is low and most of the nitrogen will be in the form of ammonia which requires oxygen to be nitrified, subsurface flow wetlands do not represent a reliable treatment system for ammonia removal. The system can be improved by low loading or well-nitrified influents (USEPA 2000a). Factors that can influence the nitrogen removal are mostly temperature, pH and hydraulic residence time. The biological removal of nitrogen is most efficient at temperatures between 20-25 ºC, pH range between 6.5 and 8.5 and longer residence time in the system will increase nitrogen removal accordingly (Lee et al. 2009).

**Removal of suspended solids**

Subsurface flow wetlands have proved effective to remove suspended solids due to low velocity of the flow and large surface area of the substrate. The suspended solids are removed by gravity settling, adsorption to media and straining. 60-75% of the suspended solids are removed already in the first third of the bed. Clogging of the filter media is a concern when it comes to subsurface flow wetlands. When the solids pass through the media it can clog pores and reduce the hydraulic conductivity of the wetland. This can be minimized by using different kinds of media and suspended solids removal is optimized (Norton 2007).

### 2.2.3 Vegetation in constructed wetlands

The vegetation in constructed wetlands is an important factor as they have many roles in the treatment process and gives the constructed wetland an aesthetic appearance. Emerging aquatic macrophytes is the dominating life form in natural wetlands and marshes and is also used in constructed wetlands. These plants are adapted to growing in saturated soil and have extensive root and rhizome systems which transport oxygen from the atmosphere through large internal air spaces in the plant. The oxygen around the roots stimulates growth of nitrifying bacteria and decomposing of organic matter. The physical effects of the plants are the most important regarding the treatment process and include filtration and surface area for microbiological growth. The biofilm formed on plant surface and the media in the bed makes up most of the microbial processes in the system. The plants metabolism, such as plant uptake and oxygen release, can contribute to the treatment in some extent depending on the construction of the wetland. Wetland vegetation is very productive and needs nutrients to grow and reproduce. These nutrients are taken up by the roots of the plants. If harvested, these nutrients will be removed from the system. Otherwise they will return to the water when the plants decompose. The amount of nutrients you can remove by harvesting is however insignificant compared to the amount of nutrients entering the system (Brix 2003).

When choosing vegetation for constructed wetlands it is important to choose locally dominating macrophytes that has massive fibrous roots, strong rhizomes and deep root penetration to provide maximum surface area for microbial growth. The plants must be able to transport oxygen into the root zone to support the large rhizosphere and reduce toxic metals. High stem densities or considerable biomass is necessary to achieve assimilation of nutrients and maximum evapotranspiration of water (UN-HABITAT 2008). There are many different plants that can be used in constructed wetlands. Among plants that are available in Nepal suitable for use in constructed wetlands we find spike-rush (*Efeocharis*), rushes (*Juncus*), bulrushes (*Scipus*), cattails (*Typha*), other sedges (*Cyperus*) and common reed (*Phragmites karka*). Common red (*Phragmites karka*) has been used in all of the existing constructed wetlands in Nepal and has performed efficiently (Pandey 2015). In addition to being one of the most productive wetland plants, common reed is also one of the most variable and wide spread. It is the most predominant wetland species due to its rapid growth and climatic tolerance (UN-HABITAT 2008).

### 2.2.4 Design of a constructed wetland

To avoid the constructed wetland to be filled up with grit, debris and solids from raw waste water preliminary/primary treatment is necessary to remove these settleable solids. Preliminary treatment of wastewater usually includes a grit chamber and screens. A grit chamber removes grit, sand, gravel and other solids heavier than organic solids. A screen has openings used to retain solids and coarse materials in the influent wastewater. From the preliminary treatment, the wastewater goes to the primary treatment. The primary treatment usually consists of settling of suspended solids in quiescent conditions. This will reduce the loading of suspended solids to the wetland. Primary treatment is usually done in a septic tank of an anaerobic baffle reactor (improved septic tank). Septic tanks are the most widely used primary treatment in the world before small-scale constructed wetlands. An anaerobic baffle reactor is an improved septic tank (UN-HABITAT 2008)where the wastewater floats over and under baffles inserted in the tank. This allows more contact with the active biomass in the accumulated sludge and enhances the removal efficiency of solids and organic pollutants (UN-HABITAT 2008).

The sizing of the bed can be done by using an equation or based on specific area requirement per population equivalent. This first order plug flow model is used for designing constructed wetlands in Nepal:

$$A_h = \frac{Q_d(lnC_i - lnC_e)}{K_{BOD}}$$

Where $A_h$ is the surface area of the bed ($m^2$), $Q_d$ is the average daily flow rate of sewage ($m^3/d$), $C_i$ is the influent BOD concentration (mg/l), $C_e$ is the effluent BOD concentration and $K_{BOD}$ is aerial rate constant (m/d). $K_{BOD}$ is determined from the expression $K_T dn$, where $K_T$ is $K_{20}(1.06)^{(T-20)}$, $K_{20}$ is the rate constant at 20 ºC ($d^{-1}$), T is the operational temperature of the system (ºC), d is the depth of the water column (m) and n is the porosity of the media (percentage as fraction). The cross-sectional area can be calculated by using Darceyô s law (UN-HABITAT 2008).

The depth of a horizontal bed is usually restricted to the depth of the rooting of the vegetation on the bed. This is to ensure that the wastewater flows through the roots and not under them. Hydraulic retention time should also be considered when choosing the depth of the media. Most constructed wetlands in Europe are 60 cm deep, but a study conducted in Spain showed that shallow beds of 27 cm perform better than deeper ones at 50 cm. However, 40 cm of media is recommended to account for the effects from precipitation which could cause surface flow. The media has several important functions including filtering, trapping particles, rooting material for the vegetation, evenly distribute/collect flow at inlet/outlet and provide surface for microbial growth. Small sized media reduce hydraulic conductivity and can easily clog. Large media has high hydraulic conductivity but small surface area per volume unit for microbial growth. Gravel is the compromise between the two with its intermediate size. The media around the inlet and outlet should be greater in size to minimize clogging. In the treatment zone, there appears to be no significant difference in treatment efficiency of media in the 10-60 mm range. For easier planting and routine maintenance, the top layer of the media should be level. The slope of the bottom of the bed is usually between 0.5 and 1% for proper drainage and easier construction (UN-HABITAT 2008).

To avoid groundwater contamination by wastewater leaking from the constructed wetland it is important to have it properly sealed. This can be done by using impermeable soil, cement or plastic liners. When using plastic liners, it is crucial that the subgrade is prepared and is free from materials that could puncture the liner (UN-HABITAT 2008).

The inlet to the constructed wetland can either be on the surface or subsurface manifolds and are usually perforated pipes. The main function of the inlet is to distribute the wastewater evenly across the entire width of the bed. This is to avoid ñdead zonesò in the bed where exchange of water is slow and could result in shorter detention times for the wastewater. The inlets should be designed to minimize clogging and short-circuiting. For easy operation and maintenance of the inlet structure it should be installed on top of the media instead of subsurface. The outlet structure help managing the water level and uniform flow of wastewater through the bed. For easy operation and maintenance of the system, the outlet should be adjustable to be able to change the water level in the bed if desired. It should be possible to raise the water level to 15 cm above the media to control weeds and foster plant growth. The wastewater is usually collected at the bottom of the bed in perforated pipes before it is discharged through the outlet (UN-HABITAT 2008).

### 2.2.5 Start-up phase of a constructed wetland

To let the vegetation related to the treatment process to establish, a start-up period is necessary. Since the performance of subsurface flow wetlands is less dependent on the vegetation, the start-up period is less critical. But the vegetation adds to the aesthetic appearance of the bed and needs to root. In the beginning the subsurface flow wetland is filled with wastewater to the surface of the media. The water level can gradually be lowered towards the operating level once the plants have started to root (UN-HABITAT 2008). Subsurface flow wetlands require more than one growing season to achieve plant densities normal for a wetland. It normally takes three to six months for the microbial biomass to develop in the media (USEPA 2000a).

### 2.2.6 Operation and maintenance of constructed wetlands

Constructed wetlands can be a low energy, low-cost process that requires minimal operational attention. Because of practical application and extensive research, there is good information about performance, design, operation, and maintenance of constructed wetlands for treatment of wastewater (Davis 1995). Constructed wetlands require little operator intervention and the routine operation is mostly passive because this is a ñnaturalò system. But monitoring of the system is necessary and the operator must take appropriate action when problems occur (UN-HABITAT 2008).

Usually the only operational variable that significantly impacts the performance of the constructed wetland is flow control and the water level in the bed. Changes in water level can be caused by clogging of inlet or outlet pipes, leaks or other causes and should be investigated immediately. This is because changes in water level will affect the hydraulic residence time in the bed and might have negative effects on the performance of the system. It is also very important to maintain uniform flow across the constructed wetland to achieve expected treatment performance. To achieve uniform flow in the bed, the inlet and outlet should be checked and cleaned regularly. Uniform flow also prevent flooding on the surface of the bed which could have caused odor. Suspended solids will accumulate near the inlet of the constructed wetland and will require removal if the hydraulic detention time is reduced. It is also important to maintain the walls of the constructed wetland. If any leaks or cracks is noticed this should be fixed immediately (UN-HABITAT 2008).

Over time it will be easier for the operator to predict potential problems in the bed and act accordingly. For long term operations, it might be necessary to take out the substrate of the bed and clean it. To avoid sludge coming into the constructed wetland, the primary treatment must be desludged when necessary. Samples should be collected to check the treatment performance of the constructed wetland from time to time. The following parameters need to be analyzed (UN-HABITAT 2008):

- Total Suspended Solids (TSS)
- Biochemical Oxygen Demand ($BOD_5$)
- Chemical Oxygen Demand (COD)

- Ammonia
- Nitrate
- Phosphorus
- Fecal Coliforms

### 2.2.7 Constructed wetlands in Nepal

Several constructed wetlands have been built and are now in operation in Nepal. The first CW in Nepal was built at Dhulikhel Hospital in 1997 by the Environment and Public Health Organization (ENPHO). Dhulikhel Hospital is a community-based hospital situated in Dhulikhel Municipality. The treatment system was built to treat all the wastewater generated within the hospital and to ensure nearby farmers access to safe water for irrigation. The CW was designed using plenty of safety margin and conservative assumptions as this was the first CW in Nepal. The system was originally built to treat 10 $m^3$ per day, but is now treating four times that amount with success due to the conservative design of the system. The system at Dhulikhel has a septic tank as pretreatment and a horizontal flow bed followed by a vertical flow bed. The vertical bed is 1.05 meters deep of sand and gravel and covers an area of 120 $m^2$. The horizontal bed has an area of 140 $m^2$ and is 0.6 meters deep with sand and gravel. Both are planted with Phragmitis Karka, a local reed. Tests in 1997 showed a removal rate of 98% for BOD and TSS, 96% COD, 80% ammonia nitrogen and 54% phosphate. In 2003 tests showed 96% removal of BOD and 93% removal of COD and TSS. The hospital has since then expanded the capacity of the plant because they were satisfied with the treatment performance (WaterAid & ENPHO 2008).

Since the introduction of CW in Nepal in 1997, the interest in the technology has grown and many more CWs has been built. The first community based wastewater treatment system was built using CW technology.  Constructed wetlands has been built for treatment of grey water, septage, hospital wastewater, institutional wastewater, landfill leachate and municipal wastewater. The treatment systems have generally performed very well, achieving close to 100% removal of organic pollutants and total coliforms (WaterAid & ENPHO 2008).

Most studies of constructed wetlands in Nepal does not analyze for total phosphorus but a study conducted by Pandey et al. found the reduction in total phosphorus to be between 28.1% and 33.8% in the planted horizontal constructed wetlands depending on loading rate. The influent concentration of phosphorus was between 2.7 and 4.6 mg/L (Pandey et al. 2013).

Another performance evaluation study on two different constructed wetlands at Kathmandu University and Dhulikhel Hospital that had been in operation for one and five years respectively have been conducted by Bista and Khatiwada (2003). Both systems consist of both horizontal and vertical flow wetlands. They tested the influent and effluent wastewater for COD, ammonia-nitrogen (NH3-N), TN (except organic form) and TSS. Findings from Kathmandu university showed a reduction in percent of 93, 86, 58 and 96% respectively. For Dhulikhel Hospital the reduction in percent was 85, 61, 33 and 95% respectively. The CW at Kathmandu University was also tested for orthophosphate-phosphorous and showed a reduction of 75% (Bista & Khatiwada 2003).

Even though constructed wetlands have proven effective for treating different kinds of wastewater there are still some challenges in the promotion of CW. It can be difficult to convince people that it will work due to lack of awareness. Despite CW being a low-cost technology it might be difficult to convince people to pay to treat their wastewater rather than just discharging it into the river. Gravel, sand and reeds might not be locally available for construction. CWs does not require much operation and maintenance, but some is needed for the system to treat efficiently. Legislation and standards in Nepal are week and therefore wastewater treatment is not a priority for city governments, private institutions and industries (WaterAid & ENPHO 2008).

## 2.3 Biofilter

The biofilter at Geta Eye Hospital is essentially a trickling filter only with smaller pebbles as media. Therefore, the trickling filter will be explained in this section.

A trickling filter is a biological treatment process that removes organic material and nitrogen under mostly aerobic conditions from pre-settled wastewater through microbial processes. Wastewater is constantly or intermittently sprayed over the filter which is made up of rocks, gravel, special plastic media or others. This media has a high specific surface area where bacteria can form. The media is usually between 1 and 2.5 meters deep and crushed rock or gravel is the cheapest option when it is available (Tilley et al. 2014). If rocks are used for media the rock size usually varies from 2.5 cm to 10 cm in diameter providing a surface area of approximately 149 $m^2/m^3$. Microorganisms in the wastewater attaches to the large surface area and form a biofilm between 0.1 and 0.2 mm thick. Organic matter in the wastewater is adsorbed by this biofilm and is aerobically degraded by microorganisms in the outer layers of the film. When the film thickens, anaerobic organisms develop because oxygen cannot penetrate to the deeper layers of the film. The film will continue to grow until the organisms close to the surface loses their ability to hold on and sloughs off and new microorganisms will start to grow in their place (USEPA 2000b).

The trickling filters are usually circular with a rotating or a fixed distributing system and can be fed intermittently. If intermittent loading is chosen, the intervals between loadings should be short enough to keep the media humid and avoid drying of the biofilm. The rotating or intermittent loading allows air to enter the empty spaces in the media and supply oxygen to the aerobic bacteria. The ventilation of air is usually natural but can also be increased by adding aeration in the bottom of the filter. Sufficient ventilation is necessary for the aerobic conditions and for maintaining efficient wastewater treatment (Sperling 2007).

Despite the name ñtrickling filterò, filtering is not the primary function as the space between the rocks is too large to work sufficiently as a filter. The medias function is to support formation of biofilm. When the biofilm thickens the empty space in the media decreases which in turn increases the velocity of the trickling wastewater through the media and causes some of the biomass to dislodge and follow the wastewater down. Trickling filters are classified by the organic or surface loading of the filter. A low rate trickling filter has a hydraulic loading of 1 to 4 $m^3/m^2*d$ and is conceptionally simple but efficient in BOD removal. In well designed and operated trickling filter BOD removal of 80-85% can be achieved in addition to intense nitrification. Operational aspects include monitoring ponding on the surface of the filter which indicates excessive biofilm growth or clogging, making sure that the drainage system works and does not accumulate solids and monitoring the treatment efficiency. Because of the simplicity of the system, low construction and operational cost, this wastewater treatment system is suited for developing countries (Sperling 2007).

## 2.4 KAP-studies

A knowledge, attitude and practice (KAP) survey is designed to measure the change in human knowledge, attitude and practice in regards to a certain topic. The use of KAP studies dates all the way back to the 1950s when it was used in the field of family planning and population. Since then it has been used in many other health and social contexts and KAP studies is the most popular and widely used research method for gathering information on socio-cultural and economic aspects in developing countries. Each KAP study is usually designed for a specific location and issue with the intent to uncover how people feel, what they know and how they behave in relation to this issue. Since KAP studies are highly focused on one issue and designed specifically for this purpose, the survey tend to be more cost effective and use less resources than other social research methods (UniteForSight 2010). It has also been an attractive research method because of quick implementation, the quantifiable data you get from the easy design of the survey, easy interpretation of results, and the generalizability and comparability for a larger population. The KAP surveys has been criticized for assuming that the data collected about knowledge, attitude and practice is accurate (Launiala 2009). KAP studies are based on peoplesôopinion and what they say they do, but there might be a gap between what is said and what is done (Gumucio 2011). Among health planners and in the international health community, the KAP survey is seen as a good way to gather information on matters regarding health, and there is little or no discussion anymore about the issue (Launiala 2009). The primary data collection in KAP surveys is conducted through questionnaires and statistical processing of this data. Interviews are conducted with a sample of individuals (or households) that are representative for the study area. By conducting a KAP surveys one can enhance the knowledge, attitude and practice about specific issues and suggest improvement strategies based on cultural factors and local circumstances obtained from the survey (Gumucio 2011).

### 2.4.1 Designing a KAP survey

When preparing a KAP survey, the first step is to define the domain and the objectives of the survey. This will make it easier to define what kind of information we are looking for and gives the survey meaning. After the domain is established, the target group to be studied must be identified. The target group can be individuals sharing some characteristics such as age or drug use, or it can be households in communities and villages. When the target group has been identified, a sample of this target group is chosen at random for the KAP survey. The sample size should be representative for the rest of the target group otherwise the results cannot be used for generalizing for the whole target group. Random selection of the sample increases the chances for representativeness. When the sample have been selected, the questionnaire, which is the most common tool used in a KAP survey, is prepared. Questions in a KAP survey are usually closed ended questions with possible answers prepared beforehand (Gumucio 2011).

Closed ended questions offer the respondent a list of possible answers to choose from. There are different types of closed ended questions such as multiple choice questions, numerical questions (e.g. age), ordinal questions (ranking of responses), categorical questions (e.g. gender) and scaled questions (how the respondents feel on a scale). Closed ended questions may efficiently acquire specific information on an issue. As the responses are made in advance, responses are simple to compare and analyze, but the range of responses will be limited. Closed ended questions can create bias and the data can be invalid. The possible answers that the respondents can choose from are given in a certain sequence either written down or read out loud, thus introducing bias. Uniformity in responses can be deceptive and create bias. However, this method is time efficient and easy to compare over time and between groups (UniteForSight 2010).

Opposed to closed ended questions, open-ended questions allow the respondents to come up with their own answers using their own words. Open-ended questions are useful for acquiring more in-depth information about an issue. The researcher can ask follow-up questions to probe and pursue interesting responses from the participant. This allows a variety of responses and can bring to light new examples and provide new insight. When conducting an open-ended questions interview, the researcher must be very skilled to record all the responses and not lose valuable information. This method is time consuming, and since the data collected is not uniform the data must be coded in some manner to be analyzed statistically (UniteForSight 2010).

The survey can include partially categorized questions. These are like open-ended questions, but to make recording faster and analyzing easier some answers has been pre-categorized. ñOtherò is usually an option in these questions, where the responded fills in the answer if none of the pre-categorized ones are suitable. There are some disadvantages using this method however, among them is that respondents can choose one of the given answers too quickly, thus risking losing valuable information. Another risk is that the researcher might try to force the information from the respondents into the pre-categorized answers. The researcher might also take the lead if the respondents are hesitantly and provide possible answers, which creates bias. It is therefore important that the researcher stays neutral and not provide answers when conducting these kinds of surveys (UniteForSight 2010).

The questionnaire is best developed by using existing questionnaire models as ñformulating a ñneutral questionò, free from bias or subjectivity of any kind is not as easy as it might soundò (Gumucio 2011). It is important to balance the questions between knowledge, attitude and practice. This is not always easy to achieve in practice and depends on the objective of the survey. It is recommended to have the questionnaire tested before it is used for the actual survey. This can be done by using the questionnaire in a village that will not take part in the actual survey. The questionnaire is then revised based on the test. After the questionnaire is completed, mobilization of the survey team is done after a pilot survey has been conducted. When conducting the survey, it is important to meet the respondents with respect and present who you are and why you are there. It is also important to stress that the survey is completely confidential. After the KAP survey has been completed, data is entered into a program and analyzed (Gumucio 2011).

# 3 Methodology and materials

This study was conducted by supervising the end of construction of a new treatment system at Geta Eye Hospital, observation and performance evaluation of a constructed wetland and conducting a knowledge, attitude and practice survey in a community adjacent to Geta Eye Hospital. Mapping of the existing wastewater situation at Geta Eye Hospital was also conducted and suggestions for further improvement for the treatment of wastewater is presented.

## 3.1 Study Area

### 3.1.1 Geta Eye Hospital

An eye survey of Nepal was conducted by the Nepali government and the World Health Organization in 1980/81 where they found out that most cases of blindness were avoidable. After this survey, they established Geta Eye Hospital in Geta Village Development Committee right outside Dhangadhi in 1981 because this area had the highest prevalence of blindness. The hospital was constructed by funds from NORAD and was fully operational in 1982. It has since then been performing preventive and curative eye treatment to people of Far Western Development Region in Nepal and some parts of Northern India. Although the hospital is now self-sustained, the Norwegian organization INFIL has been supporting the hospital since 1985 together with Norwegian Church Aid and independently in some projects since 2005 (NNJS 2015). Among these projects is the newly built constructed wetland with biofilter.

### 3.1.2 Treatment system at Geta Eye Hospital

Before the construction of the new treatment system, Geta Eye Hospital only had septic tanks and a soak pit system with overflow to a nearby canal. Geta Eye Hospital wants to set an example for being an environmentally friendly institution. To avoid contaminating the groundwater and nearby water bodies with untreated septic tank effluent, they decided to build a treatment system in the form of a constructed wetland with biofilter. The existing septic tanks still works as pretreatment. The new treatment system is dimensioned for treating 2000 liters per day, which is only a fraction of the wastewater generated in main hospital building. Further discussions about treatment of the rest of the wastewater generated within the hospital compound will therefore have to be made (Pandey 2015).

The system is designed as a horizontal flow constructed wetland with a biofilter before the CW. Biochemical Oxygen Demand (BOD) removal is used as a design criteria and influent of 200 mg/l BOD is assumed for the design. Values for discharging industrial wastewater to surface water is issued by The Nepal Bureau of Standards and Metrology (NBSM) and are listed in the table below:

*Table 1: Effluent criteria set by NBSM (Pandey 2015).*

| **Parameter** | **Unit** | **Values** |
|---|---|---|
| $BOD_5$ | mg/l | 30-100 |
| COD | mg/l | 250 |
| Ammonia Nitrogen | mg/l | 50 |
| Suspended solids | mg/l | 30-200 |
| Oil and grease | mg/l | 10 |

Since the values for BOD is set between 30-100 mg/l the most conservative of 30 mg/l is chosen for the design of the system (Pandey 2015).

From the septic tank the wastewater goes into a 2000-liter plastic tank from which the biofilter is fed intermittently with wastewater by a pump as seen in Figure 3. The biofilter is a 5000-liter plastic tank with a perforated collection pipe going across the bottom of the tank with a valve for cleaning the filter at one end and the outlet to the constructed wetland on the other. Above the collection pipe is almost 1 meter of filter media divided between 10-15 cm of larger rocks (more than 5 centimeters in diameter) to protect the collection pipe from clogging, and 80 cm of pebbles smaller than one centimeter in diameter. This is smaller than the media usually used in trickling filters. The wastewater is spread out over the pebbles from a perforated pipe going across the top of the tank about 0.5 meter above the filter media as seen in Figure 4. The diameter of the tank is 1.78 meter which gives a surface area of about 2.5 m$^2$. After flowing through the filter media in the biofilter, the wastewater goes into the collection pipe at the bottom and onwards to the constructed wetland.


*Figure 3: Pump tank (nearest) with piping to the biofilter (Photo: Anders Rørå).*

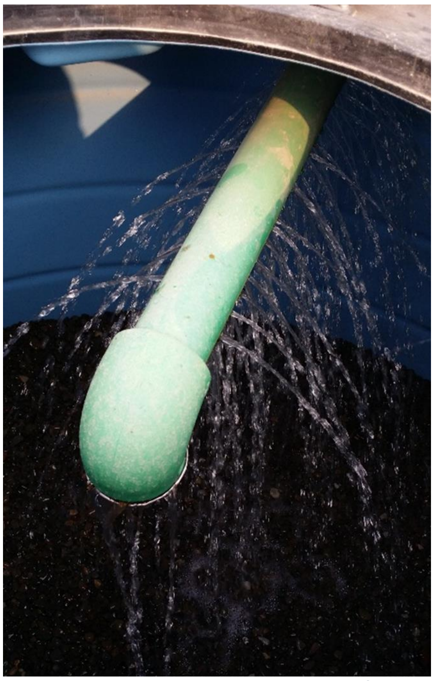
*Figure 4: Fixed distribution in the biofilter from a perforated pipe. The pipe has, since this picture was taken, been extended to go along the total width of the tank (Photo: Anders Rørå).*

The constructed wetland bed measures 13 meters by 5,5 meters which gives it a surface area of 71.5 m$^2$. The depth of the filter media is about 1 meter. The media in the inlet and outlet zones are 2-5 centimeters in diameter and in the middle the media is 1-3 centimeters in diameter. The bed is constructed above the ground with brick, cement and plastic at the bottom and along the sides of the wall to make it water proof. The inlet to the constructed wetland goes across the total width of the bed on top of the filter media as shown in Figure 6. The bed is planted with common reed, which has performed efficiently in other constructed wetlands in Nepal (Pandey 2015). The wastewater exits the wetland in collection pipes and an outlet going to a nearby open drain seen in Figure 5.

*Figure 5: The effluent is discharged into this open drain (Photo Anders Rørå)*

*Figure 6: Inlet to the constructed wetland (Photo: Anders Rørå).*

This drain was originally built to collect surface runoff from smaller drains and rain gutters around the hospital grounds and lead the water outside the premises to a nearby creek. However, the level of the drain inside the hospital grounds is almost 90 cm lower than the drain going along the outside of the wall of the hospital grounds. So for the most part the water stands still in the drain and is even fed with water from the outside. Initially it was used for fish farming, but the fish died because anoxic conditions developed in the stagnant pool of water (Pandey 2015). In addition to being filled with water, even in the dry season, the drain is also filled with rubbish and aquatic plants. The hospital discharges the septic tank effluents from the main hospital building every 15 days to a nearby soak pit which is connected to the open drain. The rest of the septic tanks on the hospital grounds are also being discharges in either soak pits or just on the grass for it to infiltrate into the ground. When making the sanitation improvement plan for Geta Eye Hospital, it was suggested to make this open drain, which is 120 meters long, into a horizontal flow constructed wetland. This option could have treated 4000 liters of wastewater per day, but would have been around 50% more costly. The drain would also most likely be flooded in the rainy season as it was built for surface water runoff. Therefore, the option of a free standing constructed wetland next to the open drain was chosen (Pandey 2015).

Construction of this new treatment system was finished on the 27th of March 2017 and can be seen in Figure 7. When the system was finished, the researcher calculated the pump volume and the intervals in which the biofilter should be fed to meet the 2000 liters per day treatment volume. The pump volume was found by measuring the decrease in water level in the pump tank over one minute. The water level sank by 12 cm in the 51ò tank, which amounts to 158 liters per minute. This is a high loading rate for a biofilter and constructed wetlands. To improve this, a new pump, new piping and /or a smaller nozzle would have to be installed. Due to time limitations, this was not installed while the researcher was there because it would have taken too much time to fix it. But changing this in the future might be advisable depending on the performance evaluation.

*Figure 7: The whole system with biofilter in the plastic tank at the end and effluent from the CW in the pipe nearest in the picture. The water level was kept high the beginning to facilitate plant growth (Photo: Anders Rørå).*

A timer for the pump was brought from Norway and installed. The timer was set to load the system for half a minute every hour, which means the system will be loaded with 79 liters 24 times a day. This amounts to 1896 liters per day. This is less than 2000 liters per day, but it better to load the system a bit less in the start-up phase. During a day when the septic tank had been almost emptied, and no water went into the pump tank, the water level in the bed sank by more than 20 centimeters. This amounts to: 71.5 $m^2$ x 0.3 x 0.20 m = 4.29 $m^3$ of wastewater if the assumed porosity is correct. This is more than the daily dosage into the bed. The reduction in water level is partly due to evapotranspiration but most of the wastewater is probably lost because the plastic liner was ripped during construction and some of the wastewater is leaking into the ground beneath the constructed wetland. To compensate for the lost wastewater, the daily dosage had to be increased to maintain a stable water level and to be able to take wastewater samples of the effluent. The timer was adjusted to work for half a minute every half hour which doubles the daily dosage to 3792 liters per day.

Daily dosage of 3792 liters per day and an assumed porosity of 0.3, gives a hydraulic retention time of:

$$\text{HRT} = \frac{13m\ x\ 5.5m\ x\ 1m\ x\ 0.3}{3.792m^3/day} = 5.66\ days$$

This is theoretical retention time, and the actual retention time might be shorter due to short circuiting.

For the newly planted vegetation to get sufficient amounts of water while their roots were growing deep enough, the outlet of the bed was raised to just below the surface of the bed. This reduces the unsaturated zone in the CW and will most likely give slightly poor performance of the system.

There is currently no treatment or handling of the sludge accumulated in the septic tanks. The sludge is pumped out into the soak pits or just on the grass. In the sanitation improvement plan it was suggested to build two sludge drying reed beds to dewater and dry sludge from the septic tanks. After a resting period of six months the sludge could either be used directly as soil conditioner or co-composted with organic matter (Pandey 2015). This was however not built in the first phase, and will be a part of the next phase of improving the sanitation situation at Geta Eye Hospital.

### 3.1.3 Mapping of existing water and sanitation at Geta Eye Hospital

In addition to supervising construction and checking the performance of the constructed wetland with biofilter, a mapping of the existing water and sanitation on the hospital premises was conducted. This was to get an overview of where the water is coming from and where it finally ends up. With around 1200 patients and dependents inside the hospital grounds at any given moment and 140 staff working in the hospital six days a week, there is a considerable water consumption and production of wastewater. The new treatment facility only treats a small part of this wastewater. By getting an overview of the water and sanitation within the hospital premises it will be possible to try and come up with some recommendations for further improvement in regards to the sanitation situation. The mapping was conducted manually by going over all the sanitation facilities with someone from the hospital staff.

## 3.2 Data collection

### 3.2.1 Samples from the treatment system

Three sets of grab samples were taken at three different places in the treatment system to collect primary data for the performance evaluation of the treatment system. The three different places in the treatment system are:

1. Septic tank effluent/pump tank: the water in the pump tank was stirred with a stick to remove mosquitos and other floating debris then a 500-ml glass bottle attached to a string was lowered into the pump tank to collect wastewater. The sample bottles were then filled from this bottle after having being rinsed.
2. After biofilter/before constructed wetland: water was collected directly from the cleaning valve of the biofilter tank by opening the valve slightly and filling the bottles when the pump had just been running.
3. Effluent from the constructed wetland: samples were collected from the outlet pipe of the constructed wetland by dipping the sample bottles into the pipe.

Samples were taken on the 2nd, 10th and 15th of April. In the third set of samples, only the septic tank effluent and the CW effluent was sampled. This was because the pump tank was almost emptied because the day before had been a public holiday and not many patients in the hospital. Since the pump tank was almost emptied there was no flow into the biofilter at the time of sampling and samples from the biofilter could not be taken. For each sample, pH was measured using a pH-meter (Lutron) and temperature was measured onsite. Samples were collected in two 250 ml bottles, that had been labeled prior to sampling, at each step in the treatment system. Per standard methods, the bottles were rinsed three times in the sampling water before the bottle was filled and capped. Samples from the different places in the treatment system were collected few minutes apart, thus representing a different batch of wastewater.

The analysis of the samples was conducted in Kathmandu, which meant storing of the samples in Geta until they were transported. The samples were stored in a freezer at the hospital. Since it would be more than two weeks from the first samples were taken until they were analyzed, $H_2SO_4$ was added to the samples to bring the pH below two. This was done to stop any biological processes that could alter the results of the analysis. From Geta, the samples were transported in ice boxes to Kathmandu for analyzing. The samples were still frozen when reaching the lab in Kathmandu and was left for defrosting in a fridge in the lab over night before the analyses started the next day.

### Possible errors in sampling

As an inexperienced researcher not having done similar sampling before this study, some errors might have occurred when taking the samples. This might cause the samples to be unrepresentative for the actual wastewater composition.

The samples from the pump tank was taken from the top layer of the pump tank as it was difficult to get the collection bottle deep enough. The pump intake however, is located at the bottom of the tank. I tried to mix the water a bit, but there might be some difference in wastewater composition in the samples taken from the top of the tank and the wastewater that goes into the biofilter. The samples taken from the biofilter was taken from the cleaning valve. The cleaning valve is not used often which means solids and settleables might collect behind the opening of the valve and give increased values for some parameters. This was hopefully avoided by letting the water run for a bit before rinsing the bottles and collecting the samples. The outlet of the constructed wetland is open to the air which allows algae growth and dust and other flying debris to enter the outlet. This can affect some parameters when analyzing the samples.

### 3.2.2 Social studies/KAP studies

The interventions at Geta Eye Hospital, both implemented and proposed, not only benefits the environmental situation at Geta Eye Hospital but will be a showcase for the local communities and patients to observe and learn from. A knowledge, attitude and practice (KAP) survey was therefore carried out in Bijaura, one of the villages near Geta Eye Hospital, to map the baseline water and sanitation situation there. More specifically to get an overview of the knowledge, attitude and practice towards those two topics. With this information, it will be possible to determine how the interventions at Geta Eye Hospital can benefit the local communities. Interviews was carried out using an interpreter from the hospital who lives in this village and knows the area well. The interpreter had no previous experience in translating these kinds of interviews. Households were chosen at random and the aim was to cover at least 10% of the household in the village. None of the people I asked knew exactly how many households there are in Bijaura, so it is difficult to tell if I met the target of 10% of the households. My interpreter said that he thought that there was between 325 and 350 households in the village. By assuming 350 households, I interviewed 14% of the village. This makes the survey somewhat representative for the rest of the village.

A questionnaire was made in preparation for the interviews and is presented in the annex. The questionnaire was based on similar surveys conducted in Nepal and revised to fit Bijaura and the situation there. Due to time limitations, the questionnaire included mostly closed ended questions in the form of multiple choice questions. Having closed ended questions allows for easier coding and comparison of the answers. Some questions were partially categorized, meaning that they had an ñotherò option in the multiple choice if none of the pre-categorized answers were suitable. Some of the questions had a follow up question depending whether the answer ñyesò or ñnoò were given on the previous one. This was to get a better understanding of the situation. After the first round of interviews the questionnaire was revised to remove questions that did not seem important and add some new and follow-up questions to go deeper into topics of interest. The second questionnaire is also presented in the annex.

**Possible errors in KAP survey**

Since the questionnaire mostly consisted of closed ended questions, valuable information may have been lost because the respondents do not answer in their own words. The respondent can also choose one of the given answers instead of elaborating using the ñotherò option. The respondent can have felt more inclined to pick one of the pre-categorized options instead of using this option. Using an interpreter opens for loss of information when the answers are being translated.

### 3.2.3 Field observations

The KAP survey was conducted at the different households participating in the survey. This allowed the researcher to observe the householdsôsanitation facility if they were willing to show it. By seeing the facility first hand you get a better understanding of the technology used and described by the household.

Observations of the final construction of the wetland was done the first week of my stay at Geta Eye Hospital. During the length of my stay, I observed the constructed wetland to make sure that the water level was maintained by adjusting the pump timer accordingly. The pump and pump timer was also checked regularly to see that the constructed wetland was constantly fed water. The vegetation planted in the bed was also observed to see that it was thriving.

## 3.3 Data analysis

### 3.3.1 Wastewater sample analysis

The analysis of the samples was conducted at Institute of Engineering at Tribhuvan University in Kathmandu. Nepali standard methods were used when analyzing for the different parameters. Amit Kumar Maharjan and Kenta Shinoda, two master students, helped me with my analyses.

The performance of the treatment system is measured by analyzing the following parameters: COD, Tot-P, Tot-N, TS, pH and temperature.

As you can see from chapter 2.2.6 the parameters that we tested for differs from the list given by UN-HABITAT (2008). We tested for TS instead of TSS because it was decided that this was easier due to the equipment available at the lab and that they had more experience with this method. I wanted to have the samples tested for BOD since the constructed wetland at Geta Eye Hospital is designed for BOD removal, but it was decided that this would be too time consuming and that values for COD would be sufficient. Instead of testing for ammonia and nitrate we only tested for total nitrogen. This only shows the reduction in nitrogen and does not give an indicator as to what state the nitrogen is in and how the nitrification, denitrification and ammonification works throughout the system. Fecal coliforms were not tested for since the first samples taken from the system were stored at the hospital for almost two weeks before analyses.

### Possible errors in analyzing

There are many possible errors when it comes to analyzing the wastewater samples. I did not have much experience with lab work before this study but decided together with my supervisors that this would be a nice way for me to learn how wastewater samples are analyzed. Even though I received much help from the lab assistants, my inexperience in the lab might have affected the results of the analysis. Human errors in the form of incorrect measurements of chemicals or samples, too much use of standardized FAS in titration, wrong readings from the machines and so on might have occurred. Diverting from the standard method may also have affected the results. The machine used for TN and TP had been giving some weird values earlier but apparently was much better when my samples were analyzed. The samples for TS and TN had to be retested because the values were a bit off. For TS, the results gave slightly increasing values throughout the system and the first analysis of TN gave higher values than for the standard solution. In the first analysis, the samples were diluted 10 times, which was not enough and in the second time around the samples were diluted 25 times. This still gave higher values than for the standard samples but were decided to be good enough for this thesis.

# 4 Results and discussion

The following chapter presents observations and performance evaluation of the treatment system at Geta Eye Hospital, findings from the KAP survey and a plan for further improvement of the wastewater treatment at Geta Eye Hospital.

## 4.1 Treatment system at Geta Eye Hospital

### 4.1.1 Performance evaluation

The results from the analysis of the wastewater samples taken on 2nd, 10th and 15th of April are presented in this chapter in different tables and graphs to show the overall treatment efficiency of the wastewater treatment system. As you can see from Table 2-Table 5 the influent and effluent values vary quite a lot only a couple of days apart, and subsequently the treatment efficiency varies as well.

*Table 2: Treatment efficiency for the different parameters on 02.04.17*

| Parameter | Sample site 1 (mg/l) | Sample site 2 (mg/l) | Sample site 3 (mg/l) | Treatment efficiency (%) |
|---|---:|---:|---:|---:|
| **COD** | 172.8 | 137.5 | 129.6 | 24.9 |
| **TP** | 12.9 | 11.8 | 8.9 | 31.0 |
| **TN** | 79.0 | 76.7 | 69.2 | 12.4 |
| **TS** | 1700 | 1860 | 2000 | -17.6 |

*Table 3: Treatment efficiency for the different parameters on 10.04.17*

| Parameter | Sample site 1 (mg/l) | Sample site 2 (mg/l) | Sample site 3 (mg/l) | Treatment efficiency (%) |
|---|---:|---:|---:|---:|
| **COD** | 247.5 | 204.3 | 129.6 | 47.6 |
| **TP** | 17.8 | 16.9 | 10.8 | 39.6 |
| **TN** | 118.4 | 130.8 | 80.1 | 32.3 |
| **TS** | 3760 | 3380 | 3580 | 4.8 |

*Table 4: Treatment efficiency for the different parameters on 15.04.17*

| **Parameter** | **Sample site 1 (mg/l)** | **Sample site 3 (mg/l)** | **Treatment efficiency (%)** |
|---|---|---|---|
| **COD** | 223.9 | 168.9 | 24.6 |
| **TP** | 22.9 | 13.4 | 41.6 |
| **TN** | 155.0 | 116.0 | 25.2 |
| **TS** | 4380 | 4400 | -0.5 |

*Table 5: Mean values for treatment efficiency for the different parameters*

| **Parameter** | **Sample site 1 (mg/l)** | **Sample site 2 (mg/l)** | **Sample site 3 (mg/l)** | **Treatment efficiency (%)** |
|---|---|---|---|---|
| **COD** | 214.7 | 170.9 | 142.7 | 33.5 |
| **TP** | 17.9 | 14.4 | 11.0 | 38.3 |
| **TN** | 117.5 | 103.7 | 88.4 | 24.7 |
| **TS** | 3280 | 2620 | 3327 | -1.4 |

### 4.1.2 COD

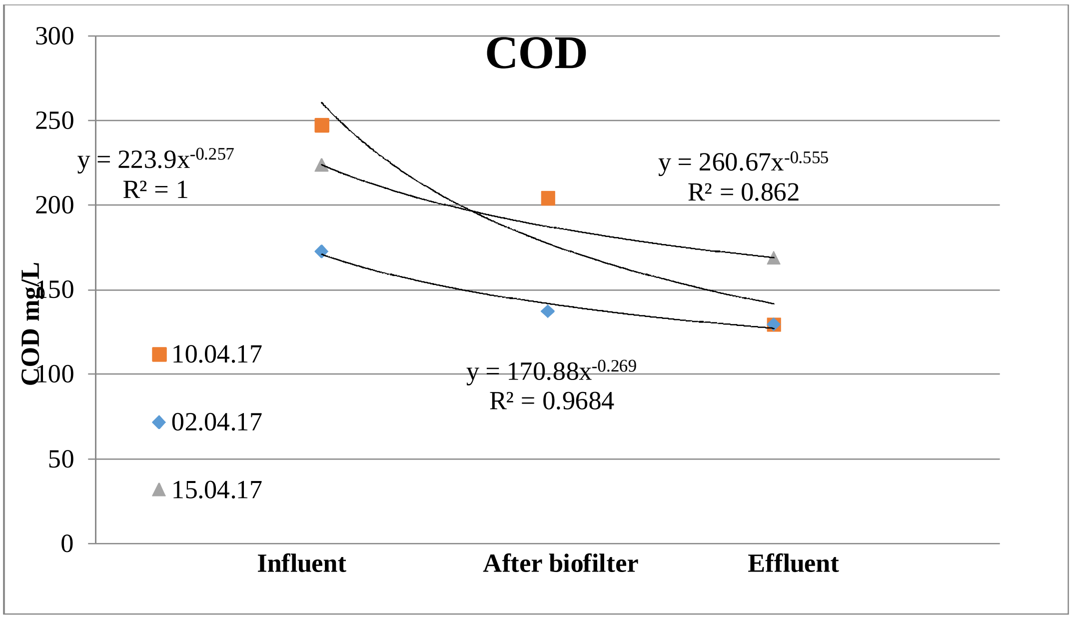

*Figure 8: COD concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

In Figure 8 and Figure 9 values for COD in the system is shown graphically. In all three sample sets the COD reduces throughout the treatment process. Highest reduction was achieved on the 10th of April with a 47.6% reduction. In the two other sets of samples the reduction is 24.6% and 24.9%. The effluent values in COD are the same on 02.04.17 and 10.04.17 but with very different values in influent COD. This could substantiate constructed wetlands ability to handle different loadings well. All the values for COD concentration are below the effluent criteria of 250 mg/l set by the NBSM (Pandey 2015). As described in chapter 2.2.2 the main removal processes of organic matter are filtration and deposition of settleable organics. Soluble organics are degraded anaerobically and aerobically by suspended microbial growth. According USEPA (2000) it takes three to six months for the microbial biomass to fully develop in subsurface CWs. The CW system at Geta Eye Hospital had only been in operation for one week before the first samples were taken and can explain the poor treatment efficiency for COD. The high loading rate in the biofilter might also explain the poor treatment efficiency as the wastewater do not have enough contact time with the media and microbial growth through the filter.

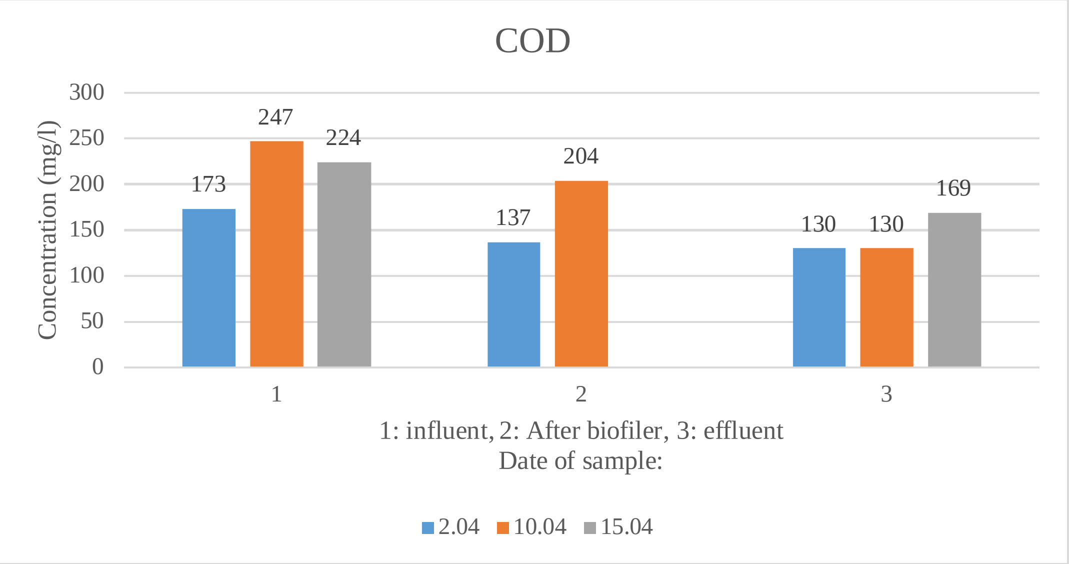

*Figure 9: COD concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

### 4.1.3 Total Phosphorus

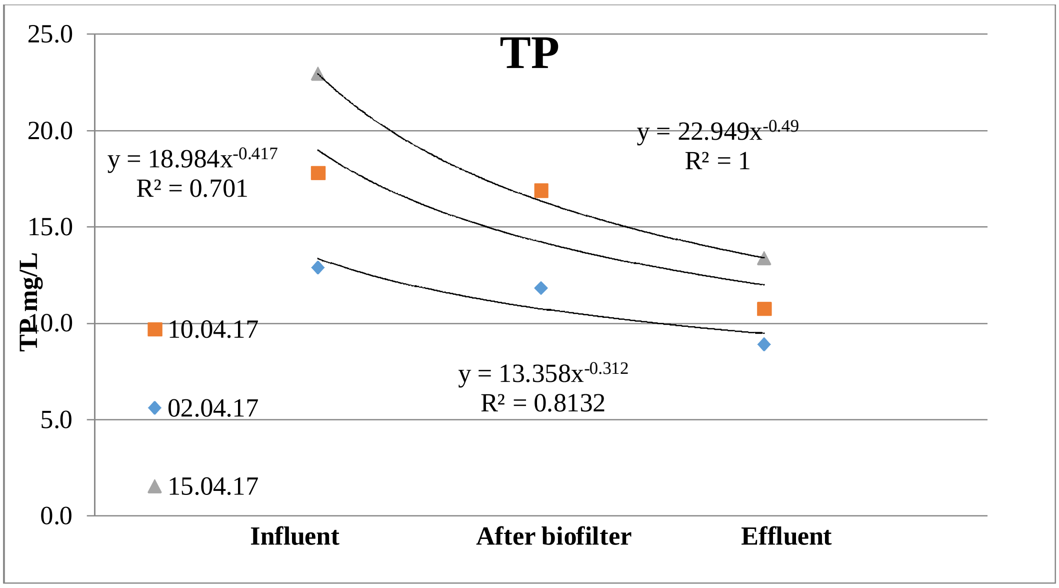

*Figure 10: TP concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

The concentration of total phosphorus is showed in Figure 10 and Figure 11. There is a constant reduction of TP throughout the system. The highest reduction was achieved on the 15th of April with a reduction of 41.6% and a mean reduction of 38.3% for all the samples. The removal mechanism for phosphorus is explained in chapter 2.2.2 and include straining, settling, adsorption, precipitation, microbial degradation and plant uptake. Gravel, which is the media in this CW, is not suited for phosphorus removal as it has low adsorption capacity. The removal of phosphorus is rather poor in constructed wetlands in general, and might even get worse as the system matures and the already limited adsorption sites on the media are saturated (Garcia et al. 2010). Some of the phosphorus is removed by plant uptake and microbial activity but is negligible according Garcia et al. (2010). However, in tropical climates plant uptake might be of greater significance. Since the plants are in the growing phase they might account for more of the phosphorus removal. For the phosphorus to be removed permanently the plants will have to be harvested.

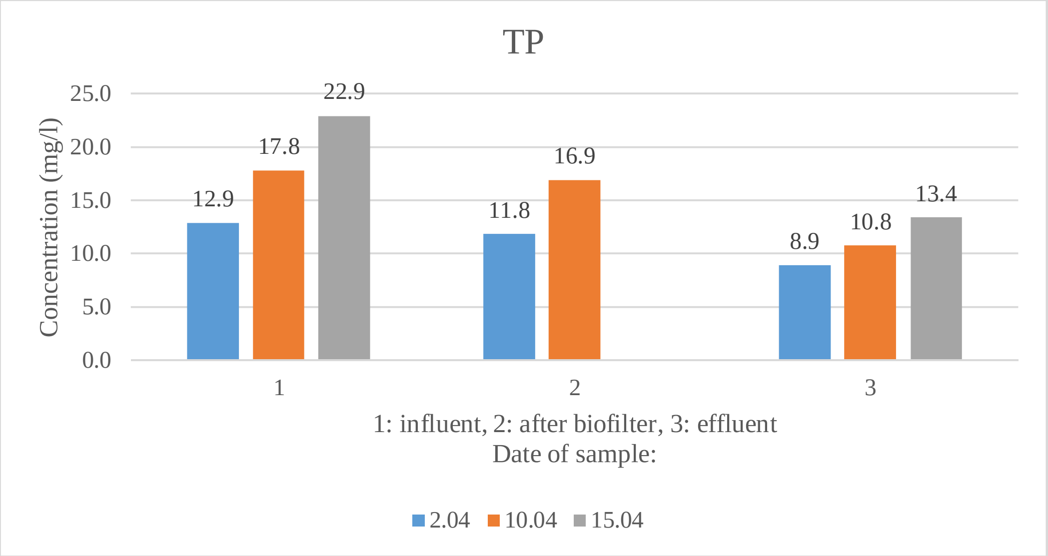

*Figure 11: TP concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

### 4.1.4 Total Nitrogen

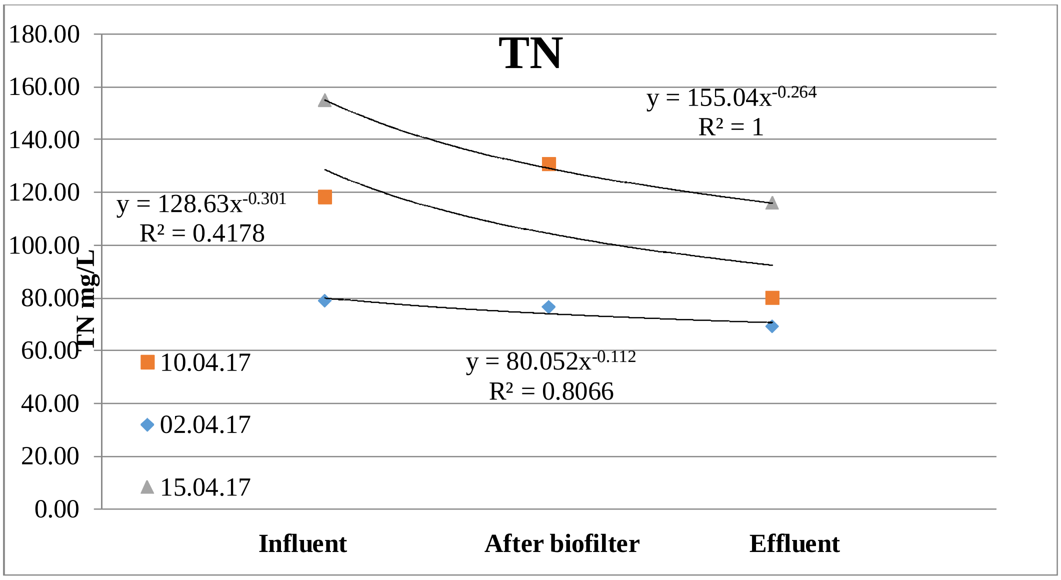

*Figure 12: TN concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

The values for total nitrogen in the system is shown in Figure 12 and Figure 13. The reduction of TN varies greatly between 12.4% on the 2nd and 32.3% on the 10th. Even though there is a reduction in TN from the influent to the effluent of the system in all the samples taken there is an increase in TN values in the second set of samples taken on the

10th from the inlet in the system to the sample taken after the biofilter. This is most likely due to sampling error or error in the analysis. The removal processed for nitrogen is explained in chapter 2.2.2 and include microbial degradation, plant uptake, sedimentation and chemical adsorption. Since the microbial biomass has not fully developed, microbial degradation is probably not significant in the removal of TN in this CW and can explain the poor treatment efficiency for TN. Plant uptake and sedimentation are most likely the major removal processes for now before the system has matured. If the system continues to show low reduction in nitrogen, aeration of the biofilter should be considered to increase the nitrification process in this step of the treatment system.

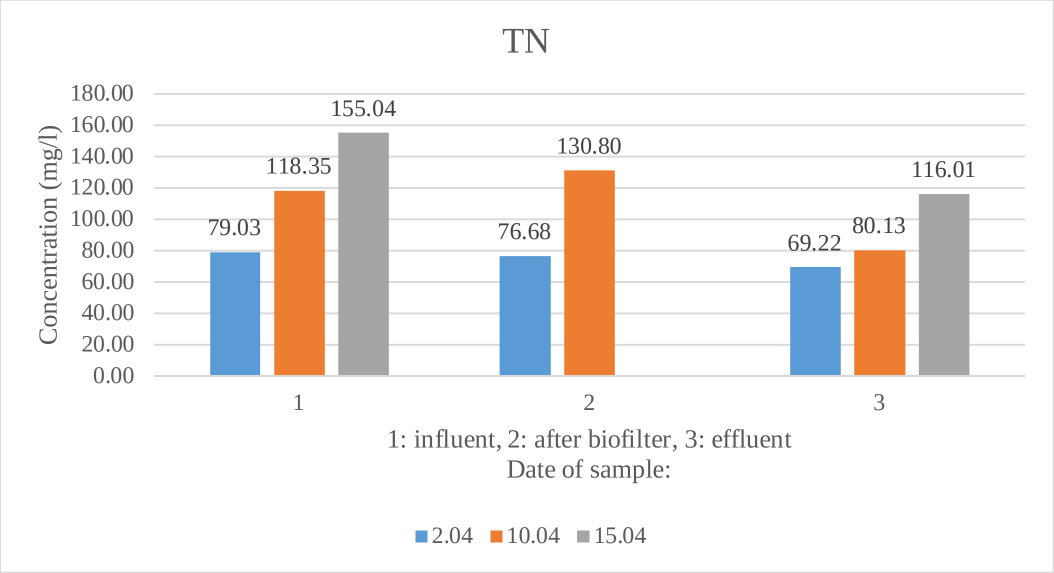

*Figure 13: TN concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

### 4.1.5 Total Solids

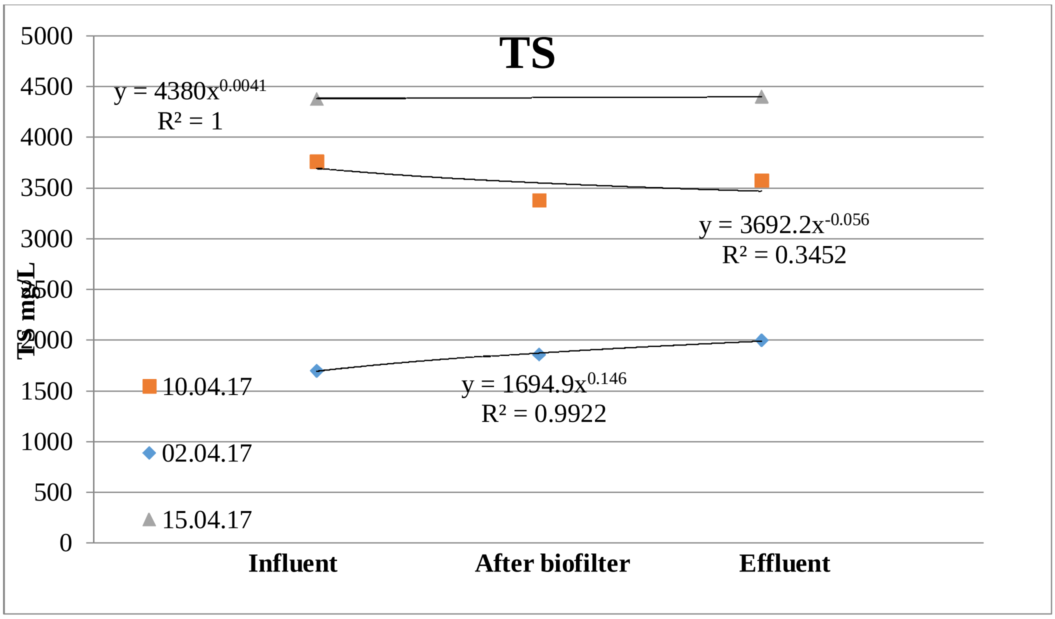

*Figure 14: TS concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

The values for total solids is presented in Figure 14 and Figure 15. Analysis of the samples showed an increase in TS in samples taken on the 2nd and the 15th and a slight decrease in the samples taken on the 10th. Total solids consist of both suspended solids and dissolved solids. As explained in chapter 2.2.2 constructed wetlands are very efficient for removing TSS through straining, settling and adsorption. These mechanisms should not be very dependent on a maturing process of the treatment system and the values for TS should be decreasing in this CW. However, the constructed wetland was filled directly with wastewater from the septic tank in the first days of operation and the solids accumulated in the bed might be washed out from the bed giving increasing values for TS.

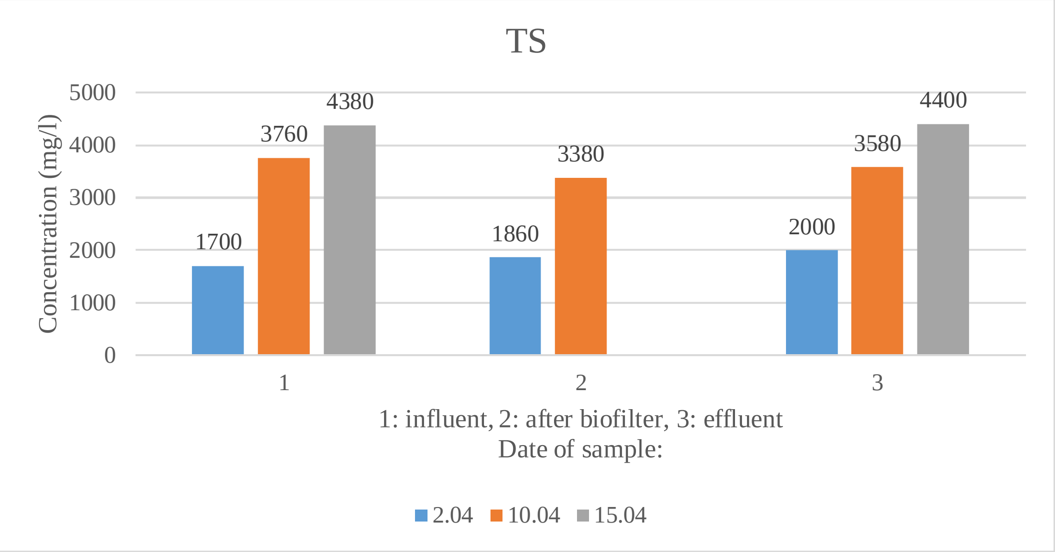

*Figure 15: TS concentration in the system for the different sets of samples taken on the 2nd, 10th and 15th of April.*

### 4.1.6 Other parameters (pH, temperature)

*Table 6: pH in the system*

| Sample Location | 02.04.17 | 10.04.17 | 15.04.17 |
|---|---|---|---|
| 1 | 7.52 | 7.71 | 7.61 |
| 2 | 7.44 | 7.58 | |
| 3 | 7.65 | 7.91 | 7.8 |

The pH values in the system is shown in Table 6. The wastewater samples are taken at the different points in the system at the same time, thus representing different batches of wastewater. This can explain some of the difference in pH. In all the samples taken, the pH decreases slightly from in the inlet of the system right after the biofilter before it increases slightly in the effluent. The pH should decrease in the biofilter because of the nitrification process (USEPA 2002). However, the pH increases slightly through the biofilter, hence indicating that the wastewater is currently not undergoing a nitrification process in the biofilter. As the system matures and the nitrifying bacteria is fully developed, the nitrification process should increase and the pH should decrease in the biofilter. Nitrogen removal is most efficient when the pH is between 6.5 and 8.5 (Lee et al. 2009). All the measured pH values are within this range so the system should be suited for nitrogen removal.

*Table 7: Temperature in ºC in the system*

| Sample Location | 02.04.17 | 10.04.17 | 15.04.17 |
|---|---|---|---|
| 1 | 27 | 21 | 23 |
| 2 | 25 | 21 | |
| 3 | 24 | 20 | 23 |

Temperature in the system in shown in Table 7. The samples on 2nd of April were taken in the afternoon while the two other sets were taken in the morning. This explains the higher temperature in the first set as the sun has heated the water in the pump tank, the biofilter and CW. Lee et al. (2009) states that nitrogen removal is most efficient in temperatures between 20-25 ºC which in theory makes this system suited for nitrogen removal, although the temperatures might increase even further in mid-summer.

## 4.2 Comparative performance evaluation of a new CW with matured CWs

The mean reduction in percent in the treatment system at Geta Eye Hospital can be seen in Table 5. There is a mean reduction of 33.5% for COD, 38.3% for TP, 24.7% for TN and an increase of 1.4% for TS. None of the performance evaluation studies presented in this thesis have tested for TS so it is difficult to compare TS reduction in a new system with a matured one. COD reduction in existing constructed wetlands have been very high with 96, 93 and 85% reduction measured in Dhulikhel Hospital by two different research teams at three different times (Bista and Khatiwada 2003; WaterAid & ENPHO 2008). The reduction in COD at Geta Eye Hospital is low in comparison at 33.5%. TP has not been measured in most of the studies presented in this paper, but Pandey et al. (2013)

achieved a 33.8% reduction in TP in their planted horizontal constructed wetland. It is not stated how long this constructed wetland had been in operation before samples were taken. This is a sliglthy lower reduction than in the CW in Geta which has a reduction of 38.4%. This difference in reduction might be due to the fact that the CW at Geta Eye Hospital is newer and has more adsprtion sites left. The reduction rate is also affected by difference in the media used and the retention time in the bed as adsorption, settling and straining are the major removal mechanisms for phosphorus. Performance evaluations of the constructed wetlands at Dhulikhel Hospital and Kathmandu University was conducted by Bista and Khatiwada (2003) and showed a reduction of TN (except organic form) of 33 and 58% respectively. Both these values of reduction are higher than the mean reduction at Geta Eye Hospital at 24.7%.

Many of the constructed wetland systems in Nepal can be considered as secondary treatment systems. That means that they are constructed to remove BOD and to reduce ammonia, but not to remove nutrients at nitrogen and phosphorus. A reduction of around 30% is observed for nitrogen and phosphorus in secondary treatment dependent on biological processes. If the biofilter works as in Norwegian systems a higher nitrogen removal (40-60%) can be obtained (Jenssen et al. 2010). This is due to nitrification in the biofilter and denitrification in the subsequent horizontal subsurface flow wetland.

The low reduction values for COD and TN in the constructed wetland at Geta Eye Hospital is most likely due to the microbial biomass has not yet fully developed since the operation of the system just started. The high loading rate of the system and the increased water level in the bed might also affect the performance of the system. As the system matures, a higher reduction of COD and TN should be expected when compared with existing matured systems in Nepal. Reducing the loading rate and lowering the water level to the designed operating level will most likely improve the treatment efficiency of the bed.

## 4.3 Observations of the treatment system

Observed problems with construction:

- The pump is powerful, pumping 158 liter/minute, resulting in a high loading rate of the system and less contact time between the wastewater and the media in the biofilter.
- The pipe diameter from the pump to the biofilter is too big at 63mm.
- The wastewater pump is connected to the same circuit as a water pump the hospital use regularly to pump water to storage tanks on the roof. When the water pump is running, the flow rate going from the wastewater pump is significantly reduced which makes is difficult to calculate the exact daily amount of wastewater going into the constructed wetland and subsequently treated.
- There is no screen between the septic tank and the pump tank, this results in garbage (i.e. eye droppers), duckweed, as shown in Figure 16, and other debris to enter the pump tank. This can clog the nozzles in the pipe or in worst case spoil the pump.

*Figure 16: Duckweed in the pump tank (Photo: Anders Rørå).*

- Some clogging of the nozzles was already noticed before the pipe into the biofilter was extended to cover the entire width of the tank.
- There is only one biofilter, which means if the biofilter is clogged and should be cleaned, or at worst emptied, the whole system would have to be shut down while this is done.

- The septic tank cover of two of the four septic tanks are always slightly open. This leads to breeding of insects and other aquatic life and plants such as frogs and duckweed. The duckweed can clog the nozzles in the inlet pipe to the biofilter.
- The holes in the inlet pipe to the constructed wetland does not have a fixed length between them and are not perfectly level. The distribution pipes are not perfectly level either. This causes some uneven distribution of the wastewater to the bed.
- The plastic lining in the bottom have most likely been ripped when placing the media because reduction of water level in the bed suggested that around 4000 liters per day disappeared from the bed without leaving the outlet pipe. Some of this is from evapotranspiration, but leaking through the bottom of the bed is believed to be the main reason. Some wet soil around the walls of the bed and wet spots on the wall itself, as seen in Figure 17, also suggest leaking from the bed.
- The current outlet is difficult to adjust as it is just a hard plastic pipe heated to make it fit around the operating outlet. We had to saw off the top a couple of times to get the water level down to just below the surface of the media. The added pipe will be taken off when the plants have set long enough roots and the constructed wetland can operate at the designed water level.

*Figure 17: Wet spots on the wall and moist ground indicates leaking from the bed (Photo: Anders Rørå).*

*Figure 18: Outlet basin filled with water. The outlet is currently raised to allow the plants to form deeper roots (Photo: Anders Rørå).*

- The outlet basin is constantly filled with water, as shown in Figure 18, because the drainage pipe is located some 15-20 cm above the bottom of the basin. This causes major algae growth in the basin and the pipe and walls of the basin are already green. The walls and pipe above the stagnant water are covered with mosquitos in the morning and is a potential breeding ground for mosquitos and aquatic insects.
- Monkeys kept eating the newly growing plants in the bed which would have kept the plants from growing to the desired size.
- The biofilter tank is made from a 5000-liter black plastic tank which are the same as people use for storing drinking water. This has led to some confusion for some patients at night as they have opened the cleaning valve thinking it is drinking water. On my last day in Geta, the valve had been opened and not closed again so a lot of the wastewater was directly discharged on the ground instead of going into the CW.
- The four septic tanks that are feeding the pump tank are connected to each other. One of these tanks are filled with garbage and aquatic insects, as seen in Figure 19, and the water level did not decline when we emptied one of the other septic tanks. This indicates that the connection between this and the other septic tanks are clogged and reduces the retention time in the septic tanks accordingly.

*Figure 19: One of the septic tanks were filled with garbage and aquatic insects (Photo: Anders Rørå)*

Possible solutions to the problems:

- A smaller pump and/or new piping restricting the flow to the biofilter should be installed to reduce the flow rate into the biofilter and increase the contact time between the wastewater and the media. New nozzles should also be installed to get a more even distribution of wastewater over the surface of the media.

- The wastewater pump should have its own circuit so it will not be affected by the water pump.
- A screen should be installed before the wastewater enters the septic tank and the septic tank cover should always be closed when not inspecting the tank. This would minimize the prevalence of foreign and unwanted objects in the septic tanks and pump tank, thus minimizing the risk of the nozzles clogging and the pump spoiling.
- A second biofilter can be constructed to avoid shutting down the whole system if one of the biofilters needs cleaning or maintenance.
- The septic tanks should be covered to avoid people falling in, garbage to enter and duckweed to form in the tanks.
- A new inlet pipe to the wetland might have to be considered to get an even distribution of wastewater to the bed.
- There is not so much to be done with the leaking bottom of the bed. The soil under the constructed wetland will clog with time and seal itself. How long time this will take is unknown. This can potentially cause groundwater contamination, but unsaturated soil between the bottom of the bed and the groundwater is probably more than two meters and the soil is fine grained (silt and possibly with some clay). This soil has very high filtering capability unless there are macropores occurring. However, the study of potential groundwater pollution is beyond the scope of this study. The caretaker of the constructed wetland must pay close attention to the water level in the bed and the amount of water coming out of the outlet and adjust the pump timer accordingly.

*Figure 20: The constructed wetland had to be covered to protecct the plants from being eaten by monkeys (Photo: Anders Rørå).*

- An adjustable outlet would be more convenient for future operation and maintenance but is not crucial for now. When the plants have grown deep enough roots, the added pipe can be taken off and the operating level will be achieved. To install an adjustable pipe, the outlet basin should be made longer so that the pipe can be raised or lowered to maintain the desired water level.
- Covering the outlet basin or lower the drainage pipe would avoid algae growth and mosquito breeding.
- The bed was covered with chicken wire, as seen in Figure 20, to keep the monkeys away from the bed in the beginning. When the plants have grown bigger the protection can be removed.
- The cleaning valve has now been forced shut with wire to prevent people opening it.
- The septic tank filled with garbage should be emptied and the connection to the other tanks should be unclogged.

## 4.4 KAP-studies

A total of 51 households participated in the KAP survey. The questionnaire was changed a bit midway in the survey where some questions were taken out and some new ones were added. 26 households were surveyed using the first questionnaire and 25 household surveyed using the revised version. Below are the results from this KAP survey conducted in Bijaura village.

### 4.4.1 Characteristics from the KAP survey

*General*

Between 2 and 17 people lived in the households surveyed with an average of 6-7 people. All the household that participated in the survey did farming to some extent, either for personal use, commercially or both. Only one household stated that they do not use fertilizer and one households said that they only use animal manure. The rest of the households buy urea, DAP and/or potassium to use on their fields. Some of the households also had other jobs such as teachers, laborers and Geta Eye Hospital staff. 43 households used firewood as a source for cooking, and 13 had firewood as their only energy source for cooking. 13 households used gas for cooking, only 2 had gas as their only source. 29 households used biogas produced by themselves and 4 of the households had biogas as their only source for cooking. Three households said that biogas was their only source in the summer, but that production reduced in the winter and that they had to use other sources as well.

*Water*

All the households got their water from a private pump well and this was their only source of water for all their water needs. Most households used water for drinking and cooking directly from the well, but nine households stored water in buckets with lid, one household stored it in bottles and one household stored it in buckets without lid. Only one of the households treated their drinking water, and this was done by boiling it. Of the 26 asked in the first questionnaire all but one said that their water source never goes dry, the last one was not sure. 20 households said that they were not satisfied with their water. 2 households said that they had problems with color in the water and 16 households expressed concern about both color and smell. Ten of the households said this problem could be solved by government supply of water to the whole village and four said that a deeper well would be better.

*Sanitation*

All but one households had standard squatting pan toilets with pour flush. The last toilet belonged to my interpreter who was also interviewed since he lived in Bijaura village. They had a standard sitting, button flush toilet going to a septic tank emptied by a government truck when full. 46 of the toilets observed were only used by one household, 4 of the toilets were shared by two households and the last toilet was shared by three households. 19 of the households used pits for their toilet waste, 23 used biogas reactors and 9 used septic tanks. The effluent from the septic tanks are most likely discharged into soak pits. The percentage for the different facilities is shown in Figure 21. One household had three toilets, two with pits and one with septic tank, but only the toilet connected to the septic tank was being used. Of the 19 households using pits, 17 said that they dug out the pits by hand and put it on the fields. The last two households had connected a pipe to their pits and discharged the sludge into a nearby river formed in the rainy season. Out of the nine households using septic tanks, two said that government trucks came and emptied it when it was full, six said that they emptied it by hand and used it on the fields and the last one said that they emptied it by hand and threw the sludge away.

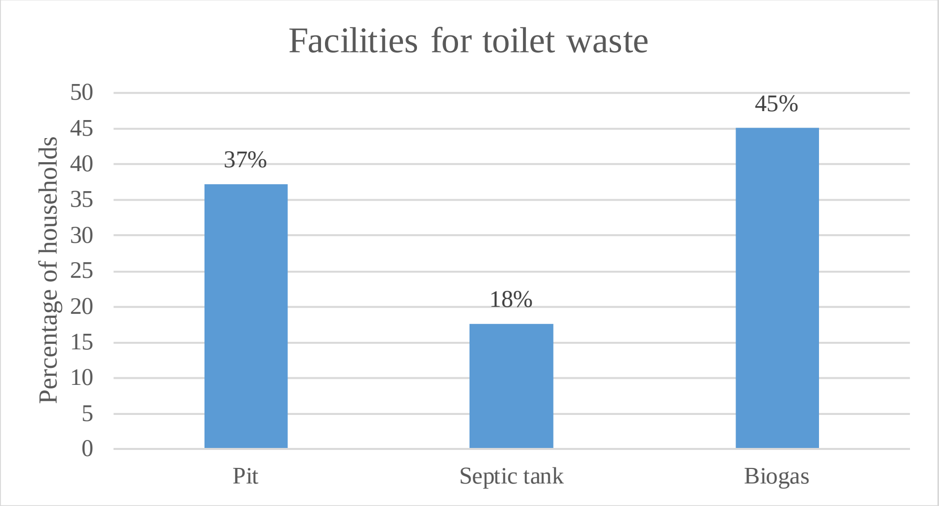

*Figure 21: Percentage of households using different facilities for toilet waste.*

Out of the 46 households asked how long they store and dry the sludge before they use it on the fields, 10 said that they used it directly without any storage. 3 households said they stored it for 1-2 months, 7 said they stored it for 3-4 months, 12 households stored it for 5-6 months, 1 household stated they stored it for 7-8 months and 8 households stored the sludge for 9-12 months before application to the field. This is shown in Figure 22 below. 5 households did not use the sludge on their fields as it was either taken away by government trucks, thrown away or discharged into the river.

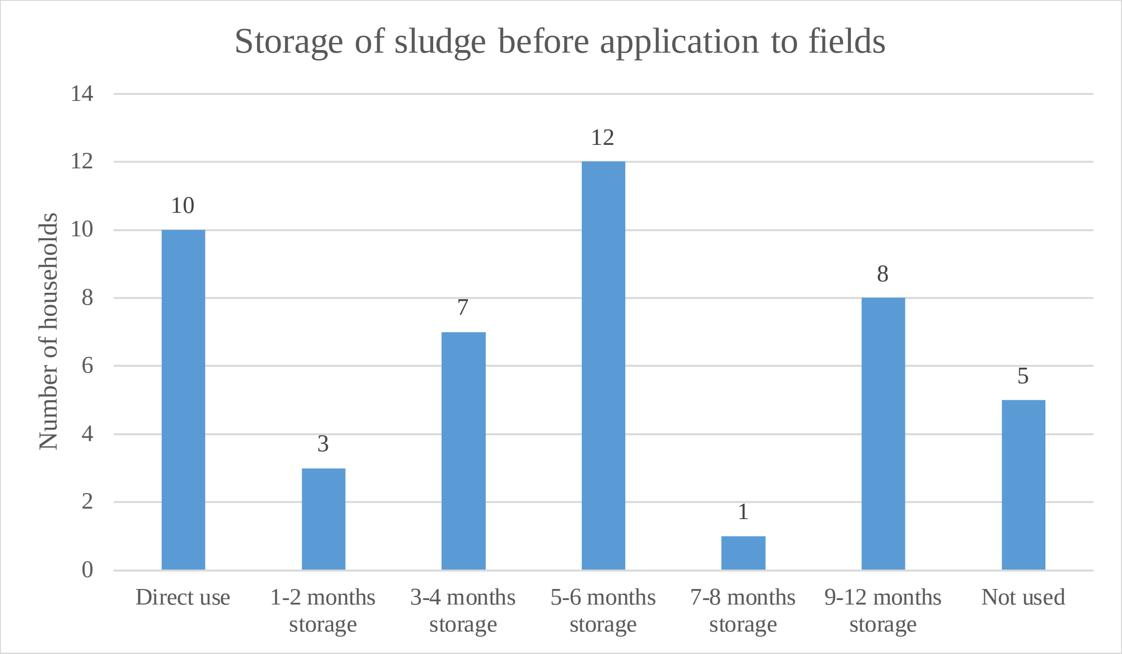

*Figure 22: Duration of storage before application to the fields among 46 households asked.*

All but three households using a biogas reactor had their toilets connected to it in addition to using cattle dung. The three households using a biogas not connected to a toilet were only using cattle dung. Two of them had been connected to the toilet before, but had disconnected it due to smell, clogging and insects. None of the households with biogas reactors added food waste to the reactor. None of the households knew any members of the community that practiced open defecation.

Out of the 51 households, 14 stated that they had some kinds of problems with their toilet. The major problem with the toilets connected to a biogas reactor was that they could not use chemicals for cleaning the toilet as this would reduce the biogas production. This leads to a dirty and smelly toilet. This problem was stated by 6 of the 26 households with toilets connected to a biogas reactor. Other problems with the toilets are listed in the next chapter. Only 8 out of the 27 households not satisfied with either their water, sanitation or both are willing to pay for an improved system.

### *Health and hygiene*

All 51 households said they used soap when washing their hands, and all 26 asked in the first survey said they washed their hands after defecation, after being in the field, before preparing food, before eating food and after meal.

In the revised questionnaire, the households were asked if any of the members had suffered from diarrhea or dysentery in the last two years. 8 out of 25 households said that there had been multiple episodes of diarrhea or dysentery for one or two of the members in the household. This may indicate that the water source is contaminated or that unhygienic practices while cooking occurs.

### *Knowledge*

In the revised questionnaire, questions about urine diverting toilets, urine as fertilizer and biogas production from excreta were asked to see what knowledge they had about those topics. When asked about urine diverting toilets, 14 households (out of 25) said that they had heard about it. Many of these had received project training for farmers and had learned about it there. Others had heard about it on the radio or seen it on the TV. Two of the participants had read about it in a book and heard about it from a neighbor. All but three of the asked had heard that urine can be collected, stored and used as fertilizer. The percentage of the knowledge among the 25 households can be seen in Figure 23. All the 25 households had heard about biogas reactors and that gas for cooking can be produced from excreta. This is not surprising given the fact that there is a high prevalence of biogas reactors already installed in the village.

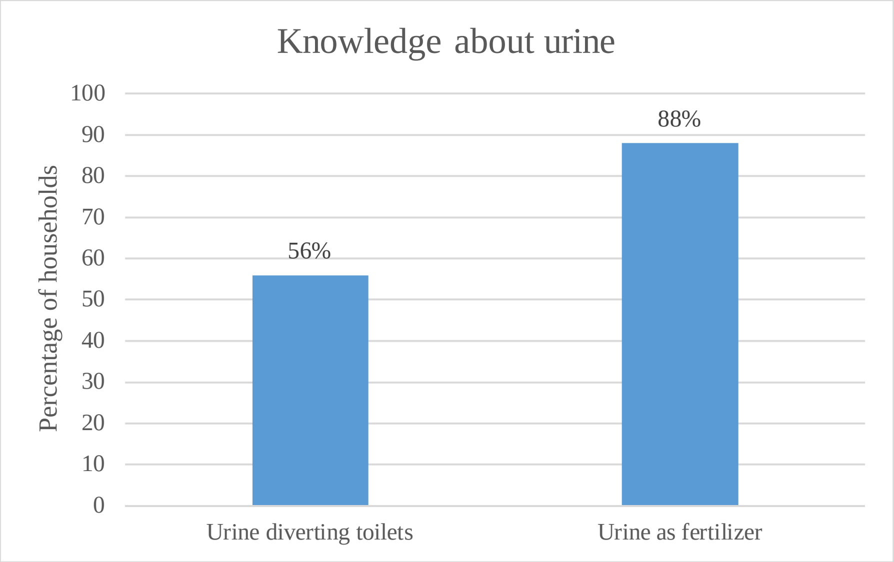

*Figure 23: Percentage of householdsôknowledge about urine diverting toilets and urine as fertilizer among 25 households.*

### *Attitude*

Peoples attitude towards using fertilizer from excreta, using urine as fertilizer, using sludge from biogas reactors connected to a toilet in agriculture and cooking with biogas made from the same reactor was surveyed in all 51 households. None of the households had any problems with using urine as fertilizer and using sludge from a biogas reactor connected to a toilet if they had these systems. All but one said they would use toilet waste that had been stored for a long time and turned into fertile soil as a fertilizer on their fields. The last one said that he would maybe do it. This might be because he did not understand the question because the same household use a pit latrine today and said that they dig out the contents when it is full and put it on the fields. All but one household said that they would cook with the gas made from a biogas reactor connected to a toilet. The last one said that he would not cook with the gas because he was concerned about the smell from the gas. This shows that there is generally a positive attitude towards using biogas connected to a toilet and using the gas for cooking.

### 4.4.2 Observations and special situations in some of the households

*Figure 24: Pump well right next to toilet using pit (Photo: Anders Rørå)*

One of the households used their neighborsô toilet because wind had blown down the superstructure for their own toilet. They have plans of rebuilding the toilet when they have money for it.

It was observed that some of the toilets were built very close to the pump well. If the toilet utilizes a pit or a biogas reactor that leaves the sludge on the ground this could cause groundwater contamination and water borne diseases. One example of this is shown in Figure 24.

One household stated that they did not have a water tank for cleansing water in the toilet.

One of the households that had a biogas reactor had disconnected the toilet from the reactor claiming that the sludge coming out of the reactor was too smelly. The sludge was left on the ground to dry right behind the toilet, as seen in Figure 25. He would consider reconnecting the toilet if there was some way to reduce the smell. Another household that also had disconnected their toilet from the biogas reactor said that it was because of smell, insects and that the toilet clogged too often. They built a new toilet connected to a septic tank which is emptied by government trucks.

One household complained that they only had a blanket to cover the toilet and no proper door. The same household also said that the pit filled up very quickly and had to be emptied every year.

The superstructures for the toilets were usually bricked and sometimes plastered with cement. Only two of the toilets observed had a straw fence around it, an example is shown in Figure 26. Two of the toilets were missing a proper door.

One household told me that the government had paid for his toilet because the family could not afford one themselves. This was a standard squatting pan toilet with discharge to a ventilated pit. The pit however is very small and must be emptied every 4-5 months. The same household stated that they would not cook with gas from a biogas reactor if the toilet was connected to the system because they were worried about the smell.


*Figure 25: Sludge from biogas reactor left in the open to dry (Photo: Anders Rørå).*

One of the households with a toilet connected to a biogas reactor stated that the toilet was often clogging and have plans of building a new toilet when he has the money.


*Figure 26: Toilet with superstructure built of straw (Photo: Anders Rørå).*

One household stated that their pit was too small and filled up too quickly. They must empty it every two years. However, the household is not willing to pay for an improved sanitation service.

One of the household was in the middle of constructing their own toilet with septic tank and used their neighborsôtoilet in the meantime. They stated that sharing a toilet was inconvenient because of queuing and was looking forward to having their own. This made them willing to pay for an improved system.

One household complained that the toilet was too small. They want to build a bigger toilet, but do not have the funds for it right now.

One of the householdsôtoilets was missing the roof. They said this was not a problem as it provided light and fresh air into the toilet. Another household said that they wanted to replace their tin roof with a bricked one.

Two of the households had installed a pipe into their pits and emptied the pits in the rainy season for the excreta to be taken away by the river that formed behind the toilet. One of these households also complained that their toilet was a bit far away from the house as the toilet was built on the edge of a slope on the far end of their property.

All but two household let me see their toilets and document it by taking photographs. One of the households that did not want me to see their toilet said that it was because the toilet was missing the door and that it was not clean. They have plans for buying a new door for the toilet. The other household did not want me to see their toilets because it had not been cleaned and the pits were full.

One of the households had urine collection and storage tank for buffalo urine as seen in Figure 27. He had attended project training for farmers and they had come to his house and helped him construction. This is the only household that has constructed a urine collection facility for buffalos in the area according himself. Another household also collected urine from cattle but from my understanding this was done manually by holding a bowl under the animal when it was peering and collecting it in a big tank. This shows that they are aware of the value of urine as fertilizer and strive to collect it.

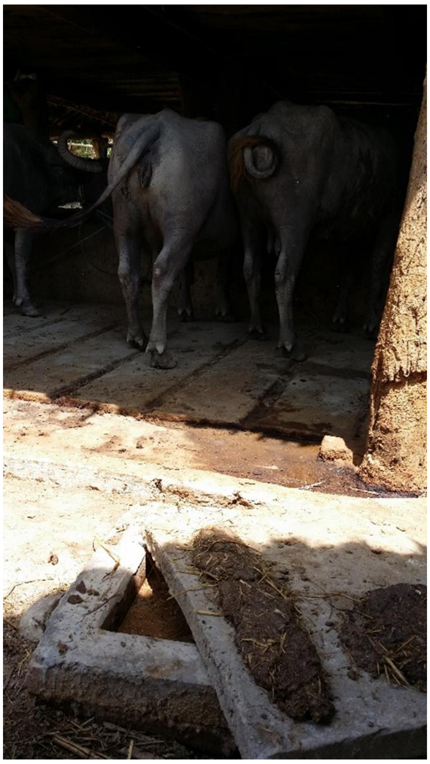

*Figure 27: Collection of urine from buffalos (Photo: Anders Rørå).*

One of the households had three toilets where only one of them were being used. One was clogged and the other one had just a leaf superstructure around it with no roof. They used both septic tank and pit systems for the excreta. This is the only household that stated that they throw away the sludge instead of using it on the fields claiming they do not have time to use it.

### 4.4.3 Knowledge of value and reuse of excreta

People in the village has good knowledge about the value of reuse of excreta as 46 out of 51 households use the excreta on their fields. This has been practice among farmers in this area for a very long time. All but one household said they would use fertile soil made from excreta if they had a toilet designed for this, the last household answered maybe. However, there is some lack of knowledge about the pathogens in the excreta and the possible harmfulness of using the excreta without necessary storage for the sludge to be safe to use. Sludge should be stored for at least six months for the sludge to be safe to use in agriculture (Bahri et al. 2009). Ten households used the sludge directly. Ten more households store it for less than five months. 21 households store it for 5 months or more. This means that at least 20 households do not store the sludge long enough to ensure its safe use in agriculture. Depending on what these farmers grow and how long before harvesting the excreta is applied, it could be harmful not to store the sludge before it is used, especially if it is applied on fields where they grow vegetables that are consumed raw.

All the households knew about biogas reactors and that gas for cooking can be made from excreta as these systems are common in the village. People in the village also have good knowledge about urine as 22 out of the 25 asked said that they knew urine can be collected, stored and used as a fertilizer. 14 out of the 25 said they had heard about the urine diverting toilets. None of the households in the village had these toilets, but two households collected urine from animals to use on their fields. All the households said they would use urine as a safe and free source of fertilizer if they had a urine diverting toilet. All the households said they would use sludge from a biogas reactor connected to the toilet if they had the system, and all but one household would cook with the gas from the same system. All in all, there is good knowledge about the value of reuse of excreta in this village.

### 4.4.4 Suggestions for improvement based on KAP-studies

Longer storage of the sludge is needed for many of the households in the village for it to be safe to use in agriculture. For easier handling of excreta and for use of urine as fertilizer, urine diverting toilets could be installed in this village. This would mean construction of new toilets if UDDT were to be used as they must be elevated to get free access to the chamber below the toilet. As anal cleansing is common practice is common in Nepal a transition to UDWT might be easier because there is no need for a separate hole for cleansing water. Construction is also easier with the UDWT since the existing pits, septic tanks or biogas reactors can still be used for the faeces and cleansing water. The squatting pan must be changed into a urine diverting squatting pan for both systems and a collection tank for the urine installed. All but one households buy chemical fertilizers in the form of urea, DAP or potassium. If urine toilets are installed, urine can be used as inexpensive and easily available fertilizer and reduce the need for chemical fertilizers.

As only 8 out of 27 households that were not satisfied with their water and/or sanitation situation were willing to pay for an improved system it might be difficult to convince the households to invest in a new toilet. It is most likely not about the willingness to pay, but the lack of funds to do it, as some of the households expressed. As the households are far apart and are used to having their own toilet, a communal system would also be difficult to implement.

All the households were positive to the use of sludge from biogas reactors and all but one would use the gas for cooking. However, biogas reactors are too expensive to install for many of the households. Out of the asked households only four said that biogas alone was sufficient to cover their cooking needs. Three more households said that biogas production was sufficient in the summer time but had to use firewood as well in the winter because the production of biogas reduced. By adding food waste to the biogas reactor, production will increase, but none of the households asked said they were practicing this.

Government supply of water would be very expensive to install and operation and maintenance costs for a water treatment plant would be high. I do not see this as a good solution for this village as the houses are spread out over a large area, and all the households have their own private pump well already installed. 20 of the 51 households are not satisfied with their water supply and mention color and smell from the water as the major issues. This problem can be reduced by installing filters or boring deeper wells and is a better option for this village than government supply. Some of the pump wells in the households were installed very close to the toilet facility. The toilet facility or the pump well should be relocated so that there is a minimum of 30 meters between them when a pit is used for toilet waste discharge.

With the newly implemented treatment system and possible further upgrading of the sanitation situation at Geta Eye Hospital, the hospital can work as a showcase for the local communities. Patients, their dependents and locals can observe and learn about importance of proper treatment of wastewater, different sanitation technologies, nutrient recovery and more. Fact sheets can be put up by the new treatment system explaining how it works, and information about nutrient recovery and different technologies can be put up in or around the toilets. People travel to Geta Eye Hospital from all over the western parts of Nepal and some parts of northern India and can help spread the information they have obtained from the hospital.

## 4.5 Suggestions for further improvement for Geta Hospital

The hospital compound is a large are with many buildings. There are 300 beds and 102 staff working in the hospital buildings that are connected to the new constructed wetland. This means that the new treatment system only treats a fraction of the wastewater generated in the hospital. There are also apartment buildings and houses inside the hospital compound for hospital staff. Rooms and toilets are also provided for the patientsô caretakers on hospital premises and many spend at least two nights inside the hospital. During working hours, an average of 1200 are inside the hospital premises and 550 stay overnight. At present, wastewater from toilets and some of the greywater are mostly collected in septic tanks. These tanks probably work as holding tanks because I witnessed some of the tanks being emptied by pumping all the contents out onto the ground behind the solid waste disposal site. Some of the tanks are emptied in a free water surface soak pit which is connected to the same canal that the discharge from the CW goes into. Some of the greywater from the main hospital building and from the caretakers staying inside the hospital premises goes directly into the same canal. Some of the water from washing dishes, clothes and people is infiltrated directly into the ground on site. Wastewater pumped onto the ground or into the soak pit might cause groundwater contamination and should be avoided. Some of the toilets are connected to pits and one of those pits were overflowing with excreta when I was there. This shows that there is a lack of proper handling and disposal of wastewater within the hospital and improvements are necessary for safe treatment.

With so many toilets and buildings spread out over the hospital premises it is difficult to come up with one solution for treatment of all the wastewater generated. One significant improvement of the wastewater handling for the main hospital building and for the apartment buildings would be to separate blackwater and greywater. Blackwater is the fraction of the wastewater that contains faeces, urine and flush water and contains most of the organics, nutrients and pathogens. Greywater is the largest fraction of wastewater and comes from showers, kitchen, taps etc. and is easier to treat. By separating greywater and blackwater, the amount of wastewater contaminated by pathogens and pollutants is reduced because the two fractions are not mixed. The greywater can be treated in constructed wetlands, one by the three apartment buildings and one by the main hospital building. The blackwater could go into biogas reactors and gas for cooking could be used by the hospital canteen or by the staff living on the premises.

By installing urine diverting toilets, urine can be separated from the blackwater, leaving only faeces and flush water to be treated. UDWTs are easier to install in existing multiple story buildings. It is also easier for the people to adapt to compared to the UDDT as anal cleansing is common practice and there is no need for a separate hole for this. Urine is practically sterile and only needs to be stored for a period to be safe to use as a fertilizer (Tilley et al. 2014). Assuming all the urine from all the people that are inside the hospital during a day is collected, a total of: 1200 people x 1.5 liters of urine = 1800 liters of urine per day could be collected. This would be enough to fertilize 1200 $m^2$ of farmland every day (Tilley et al. 2014).

Urine and brownwater (faeces and flush water) can be collected in separated tanks. The urine can be pumped out of the tanks by trucks and sold to nearby farmers as fertilizer. The brownwater sludge can be treated in sludge drying beds and the drainage from these beds can be treated in constructed wetlands. When the sludge has been stored and dried for six month it can be taken out and used by nearby farmers on their fields. Some of the smaller houses inside the hospital compound can use UDDT and use the fertile soil and urine directly on their own crops that they grow inside the hospital. It is easier to install UDDTs for these stand-alone houses than for the big buildings because there is space outside for a new toilet to be built. Otherwise UDWT can also be installed by changing the squatting pan to a urine diverting one and installing a collection tank for the urine and the faeces and flushing water can go into the existing pit or septic tank. The sludge from the septic tanks can be pumped into the sludge drying bed and the sludge from the pits can be stored and dried before application to the fields.

The separation of greywater, urine, and brownwater within existing buildings can be difficult and expensive to execute. Taking out existing squatting pans and sitting toilets and replacing them with urine separating versions is also expensive and a major construction operation but is something that should be considered for the future. Urine separation is most likely the cheapest option for nutrient recovery and is also feasible to install in existing buildings. Sludge drying beds should be constructed to treat the sludge accumulated in the existing septic tanks. There is also enough space within the hospital premises to construct two new constructed wetlands to treat more of the wastewater generated in the hospital. These new constructed wetlands could go over to only treating greywater and/or sludge drying bed drainage if the greywater separation is installed.

By implementing new technology, Geta Eye Hospital can work as a showcase for the local communities in and around Geta VDC and for the patients and dependents traveling to the hospital. Information about the different technologies should be put up next to the system and in the toilets. Information about the importance of proper wastewater treatment, urine as fertilizer, nutrient recovery and more should also be presented. The patients and their dependents will take this information with them back home and can help spread the knowledge and improve sanitation in their own villages.

There is clearly need for further improvement of the treatment and handling of wastewater within the hospital. The construction of the new treatment facility shows that the hospital is concerned with proper treatment of wastewater and are willing to do something about it. Land is available within the hospital compound but funds for construction might not be there. Further improvements of the wastewater treatment within the hospital can be done gradually when funding is available.

# 5 Conclusion and recommendations

The overall performance of the new wastewater treatment system at Geta Eye Hospital is not satisfactory when it comes to TN, COD and TS. This is most likely because the facility had only been in operation for one week before the first samples were taken. As the system matures and the microbial biomass is fully developed the treatment efficiency should increase. The increased loading in the beginning, and the high loading rate are probably reducing the treatment efficiency. A smaller pump and/or smaller diameter pipes should be installed to reduce the flow into the biofilter to increase the contact time between the wastewater and the media. A smaller nozzle should also be installed to improve the distribution of wastewater over the bed. To avoid the smaller nozzle to get clogged, a screen between the septic tank and pump tank should be installed. It would have been interesting to check treatment efficiency in a year or so to compare the results. Given the fact that this treatment facility is not designed for phosphorus removal the removal rates are above the expected, but might reduce as the system matures and adsorption sites are saturated. The numbers for TP in the effluents are quite high with a mean value of 11 mg/l.

From the social survey, it can be concluded that there is good knowledge about the value of reuse of excreta. There is however, a lack of knowledge when it comes to the potential harmfulness of use of excreta in agriculture by some of the households. Even though there is knowledge about collection, storage and use of urine none of the households practice this for human urine. Biogas reactors connected to a toilet are also well know and would be used by all the households if they had such a system. There has already been project training for some of the farmers in the area and further training programs should be implemented for more of the households.

The new treatment facility at Geta Eye Hospital shows their willingness to do something about the wastewater situation. And even though the performance is not optimal now, it is still better than the wastewater being discharged directly into the soak pit. There is still need for further improvement of the wastewater treatment, and can include urine diverting toilets, sludge drying beds and biogas reactors. The new treatment system at Geta Eye Hospital and possible new installations will not only benefit the environment in Geta Eye Hospital, but can work as a showcase and benefit the local communities. Patients, their dependents and locals can observe and learn from the hospital when it comes to the importance of proper treatment of wastewater and nutrient recovery.

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# Appendix

## Questionnaire 1

**Directions: Please, specify the most appropriate answer. Some questions may have more than one answer that applies.**

### General

1. How many people live in your household?

☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ 7
☐ 8
☐ More than 8

2. What is your occupation?

☐ Farmer
☐ Laborer
☐ Carpenter
☐ Technician
☐ Teacher
☐ Other

3. What kind of energy source do you use for cooking?

☐ Firewood
☐ Electricity
☐ Gas (LPG)
☐ Biogas
☐ Other

### Water

4. Where do you get your water from?

☐ Private/household deep well
☐ Private/household shallow well

☐ Public tap stand

☐ Public well

☐ Springs

☐ River/stream/lake

☐ Rainwater

☐ Bottled water

☐ Other (please specify)

5. Which of the following activities do you use this water source for?

☐ Drinking

☐ Cooking

☐ Bathing

☐ Washing

☐ Livestock

☐ Garden

☐ Irrigation

☐ Other (please specify)

6. How is water for drinking and cooking purposes stored?

☐ Jerry cans

☐ Bucket without lid

☐ Bucket with lid

☐ Bottles

☐ No storage

☐ Other (please specify)

7. How do you treat/purify your drinking water?

☐ Boil

☐ Add bleach/chlorine

☐ Strain through a cloth

☐ Water filter

☐ Solar disinfection

☐ Let stand and settle

☐ Do not treat/purify my drinking water

☐ Other (please specify)

8. Each day, how many liters of water do you use?

☐ 1-5

☐ 6-10

☐ 11-15

☐ 16-20

☐ 21-25

☐ >25 (please specify)

9. How often does your water source go dry?

☐ Daily

☐ Weekly

☐ Monthly

☐ Every six months

☐ Yearly

☐ Never

☐ Do not know

10. When do you wash your hands?

☐ After defecation

☐ Before preparing food

☐ Before meal

☐ After meal

☐ After being in the field

☐ Never

☐ Other (Please specify)

11. What do you use to wash your hands?

☐ Soap

☐ Mud

☐ Sand

☐ Washing powder

☐ Only water

☐ Other (Please specify)

12. Do you have to pay for your water service? Yes/no

    a. If yes: How much? ________

**Sanitation**

13. If you have access to toilet facilities in your community, what features do the toilets have?
    a. What is the flushing method?
       ☐ Pour-flush

       ☐ Button-flush

       ☐ No flush (separate hole for cleansing water)

    b. What is the toilet pan like?
       ☐ Standard squat pan

       ☐ Urine-diverting squat pan

       ☐ Hole (no squat pan)

       ☐ Bucket (no squat pan)

    c. What other features does the toilet have?
       ☐ Windows/holes in the building

       ☐ Ventilation chimney

       ☐ Bin for disposal of menstrual rags

       ☐ Other (please specify

14. How many households share these toilets?

☐ 1

☐ 2

☐ 3

☐ 4

☐ More than 4

☐ Sometimes shared

15. Where does the sewage from these toilets go?

☐ Community wastewater treatment plant

☐ Pit

☐ Septic tank

☐ Biogas reactor

☐ River

☐ Left out in the open

☐ Other (please specify)

☐ Do not know

16. What happens when the septic tanks or pits are full?

☐ Dug out by hand and sludge put on fields *(ask for more details if yes)*

☐ Dug out by hand and sludge buried

☐ Sludge pumped out and taken away

☐ Pit covered and new pit dug

☐ Toilet is not used any more

☐ Do not know

☐ Other (please specify)

17. Do you ever have any problems with your toilet facility?
    a. If yes: what kind of problems?

18. Are you satisfied with your water and sanitation situation today? Yes/no
    a. If no: what can be done to improve it?

    b. Would you be willing to pay for an improved system? Yes/no

19. If any members of the community defecate in the open, why do you think they do this?

☐ They do not have access to a toilet

☐ Their toilet is too expensive to operate and maintain

☐ Their toilet smells

☐ Their toilet is dirty

☐ Their toilet is difficult to use

☐ They have not learnt why it is important to use a toilet

☐ Do not know

☐ Other (please specify)

## Agriculture

17. How many *katta* does your household use for farming?

| a. Irrigated | b. Non-irrigated |
|---|---|
| | |

21. How many animals does your household own?

| a. Cows | b. Buffalo | c. Goats | d. Other |
|---|---|---|---|
| | | | |

22. What fertilizer do you use on your agricultural land?

☐ Animal manure

☐ Urea

☐ DAP

☐ Potassium

☐ Other (please specify)

☐ Do not use fertilizer

## Opinionated Responses

23. Toilets *can be designed so that the contents in the hole under the toilet become a fertile soil after storage for a long time and can be used as a fertilizer on fields.*

If you had one of these toilets, would you use the soil to fertilize your fields?

☐ Yes

☐ Maybe

☐ No

☐ Unsure

24. *At the Institute of Engineering at Tribhuvan University, they have researched using human urine as a fertilizer on vegetables. Their research has shown that its use increases the size of vegetables and if used correctly, they are safe to eat. Toilets can be easily designed to collect urine in a removable container. Using urine as a free source of fertilizer for your crops would mean that you could spend less money purchasing chemical fertilizer.*

If you had one of these systems, would you use this urine to fertilize your fields?

☐ Yes
☐ No
☐ Maybe
☐ Unsure

25. *Biogas means using waste from animal manure, crop waste, garden waste and kitchen waste to produce energy used for cooking. Toilets can be connected to a biogas reactor to increase biogas production to produce energy used for cooking. During biogas production, pathogens are reduced and a sludge is produced that can be used as a fertilizer.*

If you had one of these systems, would you use the sludge to fertilize your fields?

☐ Yes
☐ No
☐ Maybe
☐ Unsure

If your toilet was connected to the system to increase the gas production, would you cook with the gas?

☐ Yes
☐ No
☐ Maybe
☐ Unsure

## Questionnaire 2

**Directions: Please, specify the most appropriate answer. Some questions may have more than one answer that applies.**

### General

20. How many people live in your household?

☐ 2
☐ 3
☐ 4
☐ 5
☐ 6
☐ 7
☐ 8
☐ More than 8

21. What is your occupation?

☐ Farmer
☐ Laborer
☐ Carpenter
☐ Technician
☐ Teacher
☐ Other

22. What kind of energy source do you use for cooking?

☐ Firewood
☐ Electricity
☐ Gas (LPG)
☐ Biogas
☐ Other

### Water

23. Where do you get your water from?

☐ Private/household hand pump well
☐ Private/household well
☐ Public tap stand
☐ Public well

☐ Springs

☐ River/stream/lake

☐ Rainwater

☐ Bottled water

☐ Other (please specify)

24. How is water for drinking and cooking purposes stored?

☐ Jerry cans

☐ Bucket without lid

☐ Bucket with lid

☐ Bottles

☐ No storage

☐ Other (please specify)

25. Do you treat/purify your drinking water? Yes/no

26. When do you wash your hands?

☐ After defecation

☐ Before preparing food

☐ Before meal

☐ After meal

☐ After being in the field

☐ Never

☐ Other (Please specify)

27. Do you always use soap when washing your hands? Yes/No

**Sanitation**

28. If you have access to toilet facilities in your community, what features do the toilets have?
    a. What is the flushing method?

    ☐ Pour-flush

    ☐ Button-flush

☐ No flush (separate hole for cleansing water)

b. What is the toilet pan like?

☐ Standard squat pan

☐ Hole (no squat pan)

c. What other features does the toilet have?

☐ Windows/holes in the building

☐ Ventilation chimney

☐ Other (please specify)

29. How many households share these toilets?

☐ 1

☐ 2

☐ 3

☐ 4

☐ More than 4

☐ Sometimes shared

30. Where does the sewage from these toilets go?

☐ Community wastewater treatment plant

☐ Pit

☐ Septic tank

☐ Biogas reactor

☐ River

☐ Left out in the open

☐ Other (please specify)

☐ Do not know

a. If biogas: Do you add animal waste and/or food waste to the reactor? Is the biogas sufficient for your cooking needs? Yes/no

31. What happens when the septic tanks or pits are full?

☐ Dug out by hand and sludge put on fields *(ask for more details if yes)*

☐ Dug out by hand and sludge buried

☐ Sludge pumped out and taken away

☐ Pit covered and new pit dug

☐ Toilet is not used any more

☐ Do not know

☐ Other (please specify)

32. If sludge is put on fields how long is it stored and dried before application?

☐ 1-2 months

☐ 3-4 months

☐ 5-6 months

☐ 7-8 months

☐ 9-12 months

☐ More than a year

☐ Direct use (No storage

33. Do you ever have any problems with your toilet facility?
    a. If yes: what kind of problems?

34. Are you satisfied with your water and sanitation situation today? Yes/no
    a. If no: what can be done to improve it?

    b. Would you be willing to pay for an improved system? Yes/no

35. Do you know of any people in your community that practices open defecation? Yes/no

36. Has anyone in your household suffered from diarrhea or dysentery in the last two years? Yes/no

**Agriculture**

18. How many *katta* does your household use for farming?

| a. Irrigated | b. Non-irrigated |
|---|---|
|  |  |

18. How many animals does your household own?

| a. Cows | b. Buffalo | c. Goats | d. Other |
|---|---|---|---|
|  |  |  |  |

19. What fertilizer do you use on your agricultural land?

☐ Animal manure

☐ Urea

☐ DAP

☐ Potassium

☐ Other (please specify)

☐ Do not use fertilizer

20. What do you grow?

☐ Wheat

☐ Rice

☐ Oil

☐ Vegetables

☐ Other (please specify)

**Knowledge**

21. Have you heard about urine diverting toilets? Yes/No

22. Did you know urine can be collected, stored and used as fertilizer? Yes/no

23. Have you heard about biogas reactors? Yes/no

24. Did you know that gas for cooking can be made from excreta? Yes/no

**Opinionated Responses**

26. Toilets *can be designed so that the contents in the hole under the toilet become a fertile soil after storage for a long time and can be used as a fertilizer on fields.*

If you had one of these toilets, would you use the soil to fertilize your fields?

| | |
|---|---|
| ☐ Yes | ☐ No |
| ☐ Maybe | ☐ Unsure |

27. *At the Institute of Engineering at Tribhuvan University, they have researched using human urine as a fertilizer on vegetables. Their research has shown that its use increases the size of vegetables and if used correctly, they are safe to eat. Toilets can be easily designed to collect urine in a removable container. Using urine as a free source of fertilizer for your crops would mean that you could spend less money purchasing chemical fertilizer.*

If you had one of these systems, would you use this urine to fertilize your fields?

| | |
|---|---|
| ☐ Yes | ☐ No |
| ☐ Maybe | ☐ Unsure |

*28. Biogas means using waste from animal manure, crop waste, garden waste and kitchen waste to produce energy used for cooking. Toilets can be connected to a biogas reactor to increase biogas production to produce energy used for cooking.*

*During biogas production, pathogens are reduced and a sludge is produced that can be used as a fertilizer.*

If you had one of these systems, would you use the sludge to fertilize your fields?

☐ Yes ☐ No

☐ Maybe ☐ Unsure

If your toilet was connected to the system to increase the gas production, would you cook with the gas?

☐ Yes

☐ Maybe

☐ No

☐ Unsure

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