Fakulteten för hälsa, natur- och teknikvetenskap
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Linn Andersson

Evaluation of biosand filter as a water treatment method in Ghana

An experimental study under local conditions in Ghana

Utvärdering av biosandfilter som vattenreningsmetod i Ghana

En experimentell studie under lokala förhållanden i Ghana

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Handledare: Maria Sandberg
Examinator: Lena Brunzell

Karlstads universitet 651 88 Karlstad
Tfn 054-700 10 00 Fax 054-700 14 60
Information@kau.se www.kau.se

Abstract

The availability to clean drinking water is something a lot of people take for granted today. Daily, there are about 1.8 billion people around the world that drinks water from a contaminated water source. Unfortunately, the deficiency is a fact, and about 361 000 children under the age of five die each year because of diarrheal disease (WHO, 2016a).

Earlier studies show that a biosand filter is an easy and efficient water purification method that cleans the water both physically, biologically and chemically. A biosand filter is often built using local material and is filled with sand, which makes the construction cheap and easy to repair is needed. Earlier studies have shown that this purification method can reduce waterborne disease by 99,9% with the help of a biofilm layer which develop in the top layer of the sand if the conditions are meet (CAWST, 2009).

The purpose with this study was to build and evaluate a biosand filter as a water treatment method in Ghana. In total, three biosand filters was built with local material, each with different sand heights. The evaluation was done by studying the waters physical, biological and chemical properties before and after the filtration, which then was compared to the water quality standards from the World Health Organization (WHO) and Sweden. The results show that none of the three filters could produce water which met the standards for drinking water, which might be caused by the high flow of water through the filter which prevented the biofilm to grow. With the help from the results in Ghana, a new design of a water filter has been made to reduce the flow of water through the filter. Which gave a new biosand filter design with a diameter of 42 cm that, sand height of 80 cm and gravel height of 15 cm.

Sammanfattning

Tillgången till rent dricksvatten är idag något som många tar som en självklarhet. I dagsläget är det omkring 1.8 miljarder människor i världen som dagligen dricker vatten från en kontaminerad vattenkälla. Dessvärre är bristen på rent dricksvatten ett faktum, vilket gör att det årligen dör cirka 361 000 barn under fem års ålder på grund av diarrésjukdomar världen över (WHO, 2016a).

Tidigare studier har visat på att biosandfilter är en enkel och effektiv vattenreningsmetod för att rena vatten både fysiskt, biologiskt och kemiskt. Ett biosandfilter är ofta byggt med lokala material och fylld med sand, vilket gör konstruktionen billig och enkel att reparera vid behov. Tidigare studier har visat på att vattenreningsmetoden kan reducera vattenburna sjukdomar med upp till 99.9% med hjälp av ett biofilmslager som utvecklas i sandlagrets övre skikt om förhållandena är gynnsamma (CAWST, 2009).

Syftet med denna studie var att bygga och utvärdera biosandfilter som vattenreningsmetod i Ghana. Totalt byggdes tre biosandfilter av lokala material med olika sandhöjder. Utvärderingen gjordes utifrån att studera vattnets fysiska, kemiska och biologiska egenskaper före och efter filtrationen, som sedan jämfördes med vattenkvalitetsstandarder från World Health Organization (WHO) och Sverige. Resultaten visade på att ingen av de tre sandfiltret kunde producera vatten med en drickvattenstandard, detta tros bero på det höga flödet genom filtret som hindrat biofilmstillväxten. Med hjälp av resultat från Ghana har en ny design av ett biosandfilter tagits fram för att minska flödet genom filtret. Vilket gav en filterdiameter som är ungefär 42 cm som sedan är fylld med 80 cm sand och 15 cm grus.

Preface

This is the final thesis that qualifies the author to her Bachelor of Science in Energy and Environmental technology at Karlstad University, Sweden. The thesis comprehends 30 credit points and was executed in Ghana during the spring of 2017. It was partly financed by the Minor Filed Study (MFS) Scholarship, founded by the Swedish International Development Cooperation (SIDA), and The ÅForst Foundation.

The thesis was presented to an audience with knowledge within the subject and has later been discussed at a seminar. Another seminar was held where the author of this work was acting as an opponent to a study colleague's thesis.

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1 Introduction

Access to clean drinking water is a thing some people take for granted. In 2010, the UN General Assembly voted that access to clean drinking water and sanitation is a basic human right (Sveriges radio, 2010). In total, there are about 1.8 billion people worldwide who drinks water from an unsafe water source. Unfortunately, the lack of clean drinking-water, sanitation and hand hygiene results in 842 000 losing their lives yearly, caused by diarrhea. It is also estimated that about 361 000 children under the age of five dies due to diarrhea each year. Yet, diarrhea is largely preventable. By having access to clean drinking water and proper sanitary equipment, as well as knowledge of hand hygiene, the mortality can be decreased (WHO, 2016a).

In 2015, the United Nation's members together set 17 Sustainable Development Goals till 2030 to end poverty, protect the planet and ensure prosperity for all (UNDP, 2017). The basis to achieve the SDGs and to build up a prosperous society is to ensure that the people have access to approved water and sanitation (SDG number 6), as well as good health (SGD number 3) and a society with gender equality (SGD number 12) (UN, 2017). By managing the water sustainably, many of the SDGs will be achieved easier. For example, to better manage the production of energy, food and to also contribute to more decent work and economic growth and act on climate change and preserve the water ecosystems.
SDG number 12 is to ensure suitable consumption and production patterns (UNDP, 2017).

Besides the SDGs, it is important to have interaction between economic growth, social development and environmental sustainability (UNDP, 2012). When all these parts interact, and are balanced with each other, the 'Triple win' outcomes which is the optimum situation for sustainable development to be achieved.

There are currently various methods of purifying drinking water in the home. One step forward to achieve SDG number 6, that all people have access to proper water, may be by installing a biosand filter (also called slow sand filter in bigger scale) in a house or a village. Slow sand filtration as a purification method would be a simple solution for small scale purification where access to clean drinking water is not possible. The sand filter could easily be built in place which would facilitate for those living further away from the big cities.

According to a study from the University of North Carolina (Sobsey et al. 2008), slow sand filtration has a great potential to improve the drinking water quality and reduce diseases supplied by the water. The study indicate that a sand filter effectively reduces bacteria, viruses and protozoa, and that diarrhea disease can be reduced by about 47%. Sand filtration as a purifying method has been tested and is now being used in Cambodia (Water for Cambodia, 2017). Water for Cambodia is an organization that builds and installs sand filter for household use in villages in Cambodia. According to the organization their sand filter can reduce the bacteria up to 95,5%, up to 99,9% of protozoa, up to 95% of turbidity and 90-95% of iron.

The purpose of the study is to examine biosand filtration as a water treatment method in Ghana based on the water's physical and chemical properties. The goal of the study is to design a filter based on Ghanaian water ratio and quality, as well as design the sand filter based on Ghanaian materials (local materials).

In this thesis, CAWST's biosand filter manual (2009) have had a great influence in this work.

1.1 The situation in Ghana

Ghana is located in West Africa and is being considered as one of the most stable democracies in the region. The 6th of March 1957, Ghana became the first independent country in West Africa after the British colonization in 1901.

Ghana's climate is tropical and relatively constant thought the year. Compared to Europe and North America, Ghana do not have any big seasonal changes. The two main seasons are the wet and the dry seasons. The rainfall is the highest in the southwestern part of Ghana where it can rain up to 2,000mm each year, and lowest in the northern part where 800mm of rain can fall. Apart from the raining seasons, the climate is stable throughout the year. Temperature is relatively constant in both northern and southern Ghana. Along the coast, the annual average temperature is 30°C and humidity 80% (Briggs, 2014).

Ghana's economy has long been dependent on the country's exports of gold and cocoa, but in 2010 oil companies started to extract oil which gave Ghana a big economic growth. Therefore, Ghana was upgraded from a low-income country to a middle-income country, even though more than half of the population is dependent on agriculture (Globalis, 2016).

Ghana has a population of about 27 million. Most of the population is unemployed or living in poverty. This results in 23 million people lack access to improved sanitation and over 3 million people are forced to drink unclean water from dirty sources (Water, 2017). According to Water (2017), diarrhea diseases is the third largest cause of illness and 25% of all deaths of children under five years of age are caused by diarrhea diseases.

Plastic is a major problem in Ghana. Drinking water is normally bought on the streets or markets in small 500 ml water sachets. After use, they are usually thrown onto the ground or in the environment. The plastics thrown on the streets end up clogging drains, which can cause seasonal flooding. Other plastics makes it to the sea which later is being washed up on the beaches (CNN, 2010).

2 Theory

According to Huisman et. al (1974) biological filtration is the best water treating method to improve surface water's physical, chemical and bacterial quality.
Slow filtration is one of the oldest water treatment methods. In beginning of the nineteenth century was designed and built in Paisley, Scotland, by John Gibb for experimental use.

The most common material used for filtrations is sand. Sand filters are normally divided in two groups, pressure filters and gravity filters (Huisman et al. 1974). In pressure filters the water is forced through the bed of granular material or sand in an enclosed space. Pressure filters are suitable for industries that requires automation of the technology. The gravity filters are constructed as an open container and the water is added at the top of the sand bed. The gravity is the momentum for the water to flow through the bed of sand.

The gravity filters can also be divided into two groups, rapid filters and slow filters. According to Huisman et al. (1974) the rapid sand filters operates at a rate of 20-50 times faster than the slow filters.

There are principally three basic types of granular/sand filters; rapid sand filter (RSF), pressure sand filter (PSF) and slow sand filter (SSF). Sand is the most common material for filtration (Huisman et al. 1974). Rapid and pressure filter improves the waters physical quality, while slow sand filter improves both the biological and physical quality (Binnie et al. 2002).

2.1 Rapid sand filters

Rapid sand filters and pressure sand filter is almost the same, the difference is that the pressure filter is operating under pressure in a closed vessel. Rapid and pressure sand filters are both operating under high velocities through the filter, while slow sand filters are operating at low-loading rates (Binnie et al. 2002).

Rapid sand filter is basically constructed as an open pool with a bed of sand that is being supported by bigger grains at the bottom (Binnie et al. 2002). The filtration rate through the filter is higher than for slow sand filters due greater sand sizes. The effective sand size in rapid sand filter is normally between 0.6-2.0 mm which contributes to flow rates between 5-15 $m^3/m^2/h$ (Huisman et al. 1974). According to Binnie et al. (2002), the depth of sand in rapid sand filter is between 0.5-0.75 m with a flow rate of 6-8 $m^3/m^2/h$. Normal head loss within a cleaned rapid sand filter should be around 0.3 m. When the head loss reaches 1.5-2 m within the filter due to clogging it will be cleaned by backwashing. Rapid sand filters operate best when the turbidity in the influent water is 5 NTU or less, the filtrated water should have a turbidity of 0.1 NTU (Binnie et al. 2002). Compared to the slow sand filters, the rapid sand filter operates 20-50 faster and uses only 2-5% of the area of a slow sand filter (Huisman et al. 1974).

2.2 Pressure sand filters

Pressure filters are closed filters in which filtration speed in increased by overpressure. Maximum head loss is higher. Pressure filters are often used to remove off iron and manganese in groundwater by decreasing the turbidity (Binnie et al. 2002).

2.3 Slow sand filters

Slow sand filter is usually constructed in an open concrete box where the water flows from the top to the bottom of the filter. From the bottom, water is passed further by the under-drainage system to the consumers or for further treatment. To prevent fine sand from being transported in the effluent water is the sand resting on top of a layer of gravel (Huisman et al. 1974).

Typical slow sand filters have a depth of fine sand from 0.8 to 1.2 meter with a grain size of 0.2-0.4 mm. The sand bed should be supported by a 0.3 m layer of gravel of different depths and sizes. Under the fine sand there should be a layer of fine gravel, followed by medium gravel and coarse gravel, see table 1 for specific depths and sizes. The water head over the sand surface is normally between 1.2 and 1.8 meter (Binnie et al. 2002). According to Huisman et al. (1974) should a slow sand filter have a depth of sand between of 0.6-1.2 meter and a raw water depth of 1-1.5 meter over the sand surface. Flow rates within slow sand filters should be between 0.1-0.4 $m^3/m^2/h$. The best way to start up a slow sand filter is by filling it with water backwards after the filter media has been put to place. By filling it backwards it reduces the chance for air being trapped between the grain of sand (Binnie et al. 2002).

Table 1. Construction recommendations of a sand filter according to Binnie et al. (2002).

	Depth (m)	Grading (mm)
Water	1.2-1.8	-
Sand	0.8-1.2	0.2-0.4
Fine gravel	0.05	5-10
Medium gravel	0.05	10-25
Coarse gravel	0.15	10-80
Underdrains	-	-

2.3.1 Biosand filter

There is a smaller version of a slow sand filter, biosand filter (BSF), that is used as a point-of-use (POU) method in households to improve water's quality. The POU water treatment method allows people without access to safe water sources to improve water's quality by treating it at home. The biosand filter is a small-scale version of the traditional slow sand filter (CAWST, 2009) and as many as 500 000 people are using the water treatment method to produce safe drinking water (Elliot et al. 2008). The difference between a slow sand filter and a biosand filter is that water is continuously added to the slow sand filter while it is added once a day in the biosand filter. It is also common that a slow sand filter has a pre-treatment and being cleaned by backwashing.

Characterization of a biosand filter is that it is a simple water treatment process for households and are normally made of local materials. The filter body is usually constructed by a plastic container or a concrete mold. Sand and gravel is used as the filtration media inside the filter. Water is added at the top and is then being pushed through the filter bed by gravity. The filtration procedure uses both physical and biological mechanisms to improve water's quality (CAWST, 2009).

The biosand filter have showed great potential to reduce physical and microbial contamination in water. Previous studies, presented in CAWST (2009), have had successful bacteria, virus, protozoa and turbidity reduction by a biosand filter. Up to 96.5 % of bacteria could be reduced in laboratory tests and 87.9 – 98. 5% in field. Virus reduction, based on laboratory test, was from 70 to over 99%. The influent water's turbidity level could be reduced by 95 % to a level lower than 1 NTU. Protozoa could be reduced by 99.9%.

The filtration sand is recommended to be made of crushed rocks because it reduces the risk of being contaminated by pathogens and organic matter. River and beach sand should be avoided due to high risk of contamination from human and animal excreta and organic matter. The water quality may be worse after filtration if the sand is contaminated. If there is a lot of organic matter in the sand, like leaves and sticks, they can be sieved or washed away. The pathogens can be removed by disinfection in the sun or by using chlorine. If chlorine is being used, make sure all is washed away before it is put in the biosand filter so the biofilm can develop (CAWST, 2009).

CAWST's biosand filter manual (2009) gives one example on how to build a biosand filter. The filter body is constructed by concrete, the height of the filter is 94 cm, inner width and depth is 22.2 cm. The filtration sand should be smaller than 0.7 mm in diameter and a height of about 54 cm (30 liter). The filtration sand is being supported by 5 cm of 1-6 mm separating gravel, followed by 5 cm 6 – 12 mm drainage gravel, to prevent the sand from follow the effluent water. On CAWST's website, they recommend a flow rate of 0.4 $m^3/m^2/h$ (CAWST, 2017). When water is quickly added to the filter, it may create holes in the sand and disturb the microbiological activity at the top layer. Therefore, a diffuser is used to slow down and spread out the water being poured over the sand bed. It is usually constructed by a plastic plate or stainless steel and a 3-mm nail to do the holes (CAWST, 2009).

2.3.2 Maintenance

During operation, the flow rate through the filter decreases as suspended matter gets stuck between the sand grains and growth of the biolayer. Water with high concentration of suspended matter tend to clog the filter faster, which requires maintenance more often (Huisman et al. 1974). According to CAWST (2009), maintenance is required when the flow rate is less than 0.1 liter/minute. If the flow rate is too slow, the consumer may not have the patience to wait and eventually stop using the filter. On the other hand, is a slow flow rate good for improved water quality.

"Swirl and dump" is an easy maintenance method to improve the flow rate through the filter. The method is done manually by swirling the top layer of the sand by hand. By doing so, the suspended particles that have been stuck between the sand grains is being released and suspended into the water. The dirty water is then being removed and the sand levelled out carefully. The "swirl and dump" method may be applied a few times before the flow rate is restored to its normal (CAWST, 2009).

2.3.3 Important parameters to a good water quality

To ensure a high-water quality after filtration in the biosand filter, there are a few important parameters that should be considered. Recent research by Elliot et al. (2008) showed that the filter performance depended on the ripening time and development of the biolayer. Elliot et al. also concluded that the batch volume (volume of water being added in the filter) is an important parameter. CAWST

(2009) considerers the water source, development of the biolayer, flow rate, pause period, standing water layer and maintenance as important parameters to get a good water quality.

Development of the biolayer can take up to 30 days and the efficiency of pathogenic removal will vary during this time. When fully developed, the biolayer can consume up to 99 % of the pathogens in the influent water. During the ripening process, the biosand filter can reduce up to 30 – 70 % of pathogens by only physical treatment (CAWST, 2009). The biolayer is being adapted to the water source that is being used, which means that the filter is being subjected to a certain amount of dirtiness, like nutrients and bacteria, by the influent water (Huisman et al. 1974). If the levels of contamination would change, or a new water source would be used, it would take several days for the filter to be adapted to the new conditions. Therefore, the recommendation is to use the same water source with a stabilized contamination level.

The pause period is presented as the time between two batches of water being added. During the pause period, the microorganisms within the filter are consuming pathogens. The recommended pause period time is a minimum of 1 hour up to a maximum of 48 hours. If the pause period is too short the microorganisms will not have the time to consume all the pathogens, which will not be suitable for drinking. If the pause period, on the other hand, are too long, the microorganisms will die off due to low oxygen and nutrient levels, which later will affect the purification process negatively (CAWST 2009).

Characterization of the sand is important to have in mind to increase the removal of physic and organic matter (Huisman et al. 1974). Finer sand decreases the pore volume within the filter, which can reduce the flow rate and improves the straining mechanisms. Due to reduced pore volume with finer sand, the surface area increases. Then, the water will be exposed to a larger sand area. Mechanisms like sedimentation and adsorption are dependent on the total sand surface area.

The filtration rate has shown to have an impact on the filter's efficiency. High filtration rate through the filter will decrease the time where water is exposed to the sand area. It will also reduce the contact time between the water and the biological layer in the upper zone, which means that pathogens and nutrients will follow the water deeper down in the filter and be adapted further down if the environment is favorable. Then, if the flow rate is too high, the microorganisms will follow the effluent water because they cannot hold stay intact to the sand (Huisman et al. 1974).

The flow rate can be controlled by the batch volume (water added to the filter). When new water is added, the hydraulic head increases which is the driving force to push out the old treated water within the filter. A high hydraulic head gives a fast flow rate, which means that the flow rate is highest in the beginning. The flow rate will decrease by decreased hydraulic head (CAWST, 2009).

The volume of water added to the filter should be equal or less than the pore volume of the filtration media to get a good water quality (Elliot et al. 2008). If more water than the pore volume is being added, the treated water will be mixed with the newly added that may not be treated enough and contaminated the already cleaned water.

A biosand filter can be used to purify both surface- and groundwater, but the choice of water source should be the cleanest available since the biosand filter cannot remove all the pathogens in the influent water. If the water source is too contaminated for the biosand filter, it may not be drinkable after the filtration due water still being contaminated (CAWST, 2009).

2.4 Function

According to Huisman et. al (1974), biological filtration is the best water treating method to improve surface water's physical, chemical and bacterial quality. As the water is flowing within the filter, it is being exposed to mechanisms that can improve the water quality of the influent water. Mechanisms acting within the filter to improve the water's quality is; *transport mechanisms, attachment mechanisms and purification mechanisms*. The mechanisms are interdependent to each other to improve the best water quality in the effluent water (Huisman et al. 1974).

Some of the mechanisms are dependent of the flow rate through the filter. The flow rate through the filter is proportional to the cross-sectional area of the sand, the water loading head (hydraulic head) above the outlet of the sand filter, length of the sand filter, properties of the flowing fluid and properties of the sand. By using coarser sand particles, or decreasing the sand height, will result in high flow rates through the filter bed (Biosand filter, 2004). Smaller sand particles provide higher surface area per unit volume than coarser once, which increases the flow resistance. The pressure drop will increase further if the flow is turbulent inside the filter. The sand particles within the filter will reduce the area where the water can flow through. With reduced area, the fluid will have to squeeze through the grains of sand which will increase the velocity within the sand bed (Holdich, 2002).

2.4.1 Transport mechanisms

Transportation is a mechanism which brings impurities, e.g. particles and microorganisms, within the water into contact with the sand grains. Transport mechanisms depends primarily on the physical properties (i.e. size, shape and density) of the particles (Thames Water and University of Surrey, 2005). According to Huisman et al. (1974), some of the transport mechanisms are; straining, sedimentation, inertial and centrifugal forces, diffusion and electrometric attraction. According to Binnie et al. (2002), the transport mechanisms are; sedimentation, diffusion and hydrodynamic action.

Straining, occur when the particle size is larger compared to the pore opening between the sand grains and is independent of the filtration rate. It takes place almost entirely at the surface of the filter (Huisman et al. 1974). Particles in the influent water decreases the pore volume within the filter as it settles between the sand grains, which increases the straining and headloss across the upper sand layer. Therefore, straining should be avoided in the sand filter by a pre-treatment method so the bigger particles is being removed (Thames Water and University of Surrey, 2005). Also, the straining mechanism increases due to the development of the schmutzdecke which is a purification mechanism within the filter that will be described later (Huisman et al. 1974).

Sedimentation uses the gravitational forces to remove particles from the influent water. It is dependent of the settling velocity of the suspended matter and the velocity of the fluid through the filter, which make large and dense particles to be removed more effectively (Binnie et al. 2002). Compared to a conventional settling tank, the sedimentation within the filter utilize the total upward-facing surface of the grain media and not only the bottom (Huisman et al. 1974).

Inertial and centrifugal forces. A mechanism when suspended particles leave the stream lines, due to higher density than the water, and come into contact with the sand grains (Huisman et al. 1974). Greater surface load increases the inertial mechanism (Thames Water and University of Surrey, 2005) since the mechanism does not occur when the velocity and Reynolds numbers are low (Binnie et al. 2002).

Diffusion, also called Brownian movement in fluids, occur in the whole depth of the filter (Huisman et al. 1974). It mainly brings very small suspended matter (Binnie et al. 2002) into contact with the filtration media and is independent of the filtration rate, even when the water is not flowing in the filter (Huisman et al. 1974). The particles in the influent water will move randomly between streamlines till it collides with a media grain (Thames Water and University of Surrey, 2005). Diffusion depends on the water’s temperature and size of the suspended matter and media grain size, higher temperature and small suspended matter and media grain size increases the diffusion (Binnie et al. 2002).

Electrostatic and electrometric attraction keeps the particles stuck to the grain of media after it have been brought in contact.

Hydrodynamic action is dependent on the velocity gradient of the suspended matter near the media grains. Due to the velocity gradient, the particles within the influent water tend to rotate which causes a pressure difference across the particles that later brings into contact with the grains of media. This is not a main mechanism within the filter (Binnie et al. 2002).

2.4.2 Attachment mechanisms

Helps the particles to be attached to the grain of media once they have been brought to contact. The attachment mechanisms are; electrostatic attraction, Van der Waals force and adherence.

Electrostatic attraction. The particles in the influent water may be either attracted to or repelled by the grain of media depending on the electrostatic charge of the particular matter (Huisman et al. 1974). Particles will follow the stream through the filter till it is being attracted to a grain of media with an opposite charge.

Van der Waals force helps the particles to stay at the grain surface once they have been brought into contact. In some cases, the particles can be drawn to the grain of media even though the force is small (Huisman et al. 1974).

Adherence. As water is flowing through the filter, organic matter is being arrested on the grain of sand at the sand surface. Later, it develops a slimy layer, called zoogloea, of organisms and bacteria over the schmutzdecke which adhere particles of organic and inert matter in the influent water. The organic matter is later being a part of the zoogloea while the inert matter will be removed once sand is being removed (Huisman et al. 1974).

2.4.3 Purification mechanisms

Compared to the rapid sand filter, slow sand filter has the ability to develop a biological layer, called schmutzdecke, which improves waters biological and chemical quality (Huisman et al. 1974). The word schmutzdecke comes from Germany and means ‘dirty layer’ in English (Binnie et al. 2002). It appears as a reddish-brown sticky film, consisting of algae, protozoa, bacteria and other form of decomposing organic matter. The schmutzdecke is removing and breaking down organic matter and microorganisms in the influent water which improves the quality of the water. The schmutzdecke uses organic matter and microorganisms as food in the influent water as energy for their metabolism (dissimilation) and to form cell material (assimilation). The bacterial activity goes down to a depth of 30-40 cm and is dependent of the organic material in the influent water. There is bacterial below 30-40 cm, but since much of the food is being consumed in earlier stages the activity is low compared to the top (Huisman et al. 1974). To obtain a good biochemical oxidation of organic matter, the time, concentration of oxygen and temperature is important.

It is also important for microorganisms to have aerobic conditions within the filter. An anaerobic condition will encourage production of odor- and taste-producing substances, like hydrogen sulfide and ammonia. Also, low concentration of dissolved oxygen will produce dissolved metals, like iron and manganese, which make it inappropriate to use be used as a water source for drinking and washing. To avoid anaerobic conditions should the average dissolved oxygen concentration be at least 3 mg/l (Huisman et al. 1979).

3 Water contamination

Microorganisms are natural in our environment and many of them are harmless to humans. But some has the potential to cause diseases to humans, these microorganisms are called pathogen microorganisms (Svenskt Vatten, 2016a). Microbiological contamination caused by human and animal excreta, and more, is a great health risk for human and is a worldwide problem (WHO, 2011). The most common pathogens will be described below.

3.1 Coliform bacteria

Total coliform bacteria are microorganisms that can grow and survive in water and soil environment. Some of the total coliform bacteria are also found in the faeces of humans and animals. The total coliform bacteria have been proposed to be used as a disinfection indicator. This could be used as an indicator to evaluate the cleanliness and integrity of distribution systems and the potential presence of biofilms (WHO, 2011).

Escherichia coli, or E. coli, are species of the total coliform bacteria group. The presence of E. coli shows contamination of faecal matter (WHO, 2011), but most E. coli are harmless (WHO, 2016b). Shiga toxin-producing E. coli (STEC) is a strain that can cause severe foodborne diseases. Humans can be infected by consumption of contaminated food and water. Infection of STEC gives serious symptoms like stomach cramps, bloody diarrhea, fever and vomiting. Infected patients are commonly recovered after 10 days, but some patients (most common young children and elderly) may get a life-threatening disease such as haemolytic uraemic syndrome (HUS). HUS can cause acute renal failure, haemolytic anaemia and thrombocytopenia. If young children get infected by HUS, it is common that they get acute renal failure. About 25% of HUS patients can get neurological complications (such as seizure, stroke and coma) and about 50% of the survivors can get mild chronic renal sequelae (WHO, 2016b).

3.2 Bacillus

Most of the Bacillus spp. bacteria do not have a human health effect, but a few of them can be pathogenic for humans and animals. Illness can be caused by consumption of infected food. *Bacillus cereus* is a pathogenic bacteria that can cause food poisoning, vomiting and diarrhea. Bacillus are also often detected in drinking-water supplies and can survive disinfection of the water (WHO, 2011).

3.3 Staphylococcus

Staphylococcus is a genus for at least 15 different species. S. aureus, S. epidermidis and S. saprophyticus are three types of species from the genus *Staphylococcus* that may cause diseases in humans Staphylococcus aureus exists naturally in the normal microbial flora of the human skin, but it can produce extracellular enzymes and toxins that may cause skin infections. It has not been proved that consuming water, contaminated by staphylococcus aureus, can transmit the disease (WHO, 2011).

3.4 Viruses

Viruses are hard to remove by physical processes, like filtration, because they are the smallest pathogen type. Viruses survive for a long period in water and can cause infection in low dosage (WHO, 2011). Humans can be infected by direct contact by the viruses, or consumption of water and food. Viruses cannot be removed by chlorine due to resistivity. (Svenskt Vatten, 2016b).

3.4.1 Rotaviruses

Rotaviruses is the main cause of children diarrhea in developing and low-income countries (WHO, 2011). The symptoms are fever, diarrhea and vomiting. Severe rotavirus infection may require hospital care because it can cause dehydration, cramps and brain inflammation (Folkhälsomyndigheten, 2017). The virus is spread by infected patients and by water contaminated by human waste (WHO, 2011).

3.4.2 Protozoa and parasites

Cyclospora cayetanensis and Giardia intestinalis are two examples of protozoan parasites. The parasite causes stomach illness like diarrhea, illness and abdominal cramps. Giardia intestinalis has been known as the human parasite for 200 years and occurs in the faeces from infected humans and animals. Humans can be infected by consumption of parasite contaminated food and water. Cyclospora cayetanensis can cause watery diarrhea, vomiting, ever and anorexia. Giardia intestinalis can cause diarrhea and abdominal cramps. Protozoa can be removed by physical processes because of the size. It is not sensitive to disinfection and can easily survive in water for a long time (WHO, 2011).

4 Parameters and drinking water standards

4.1 Suspended solids

Total suspended solids (TSS) consists of inorganic and organic materials in water, like sediment, silt, sand, animal decay and algae. The particulate matter is considered as suspended solid when the particle size is larger than 2 microns, otherwise is it considered as dissolved solids. The concentration of suspended solids in water can be a parameter of water's clarity. High concentration of suspended solids results in less clear water. There are two different types of suspended solids, settleable and nonsettleable solids. Settleable solids can settle at the bottom of a water reservoir over a period of time. While nonsettleable solids will be remained in the water because they are too light to settle to the bottom (Fondriest Environmental, 2014).

4.2 Total coliform bacteria

According to The Swedish National Food Agency (2015), the water is considered drinkable (but with a remark) if coliform bacteria are detected in 100 ml of water in user's tap, or 250 ml of packed water. The water is considered undrinkable if 10 bacteria are detected in 100 ml of water at user's tap or if 10 bacteria are detected in 250 ml packed water. WHO (2011) guidelines for drinking-water quality is presented in table 2.

Table 2. The health risk due to concentration of coliform bacteria in drinking water according to the WHO (1997).

Concentration of coliform bacteria [number/100 ml]	**Remark**
0	In conformity with WHO guidelines
1-10	Low risk
10-100	Intermediate risk
100-1000	High risk
>1000	Very high risk

4.3 pH

The pH for drinking water should be between 6.5-8.5. Natural water sources may have a lower pH due to acid rain and higher pH due to contamination from limestone areas. The pH does not have any direct impact on the consumers, but it is an important parameter in distribution systems since water with a pH lower than 7 is more likely to be corrosive. Failure to minimize corrosion can result in the contamination of drinking-water and in adverse effects on its taste and appearance

(WHO, 2007). If corrosion would occur it will have an unfavorable impact on taste and appearance (WHO 2011).

4.4 Dissolved oxygen

Dissolved oxygen is the amount of oxygen dissolved in water and is expressed as a concentration of oxygen in a volume of water. The dissolved oxygen content is dependent on the source, temperature and chemical and biological processes taking place (WHO, 2011). It is one of the most important water quality parameters for the organisms, fishes, invertebrates, bacteria and plants living within a body of water since they use oxygen in respiration. The living creatures has their own desired oxygen content, see figure 1, which means that a too high or too low dissolved oxygen content may harm aquatic life and effect water quality. (Fondriest Environmental, 2013). According to Huisman et al. (1974) should the average oxygen content in the water not fall under 3 mg/liter.

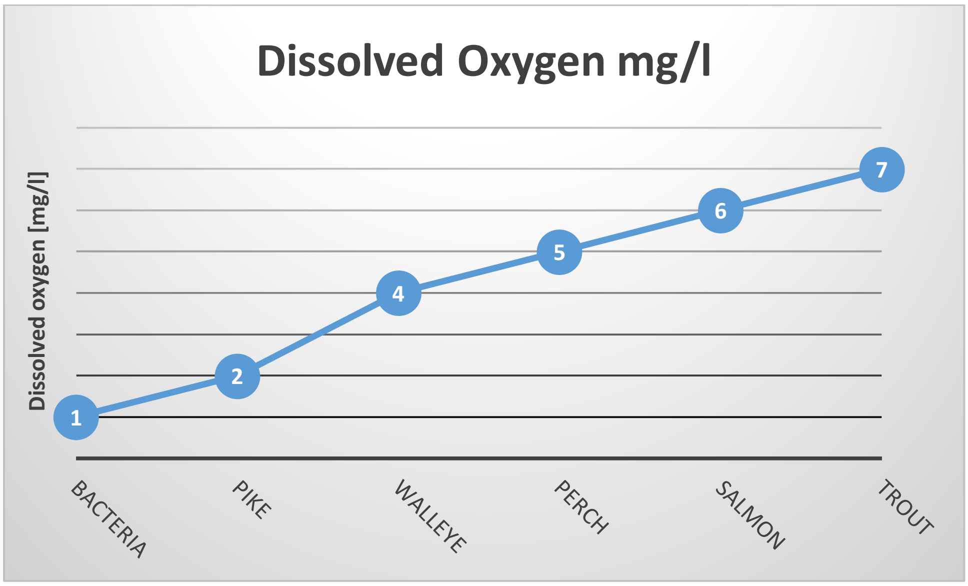


Figure 1. Examples of the minimum dissolved oxygen requirements of freshwater fish and organisms (Data available: Fondriest Environmental, 2013. Accessed: http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/).

Oxygen diffuses naturally from the atmosphere into the water, but the dissolved oxygen level can be increased further by aeration, whether natural or man-made. Examples of natural and man-made aeration is wind, rapids or waterfalls respective hand-turned waterwheel and air pump. Water's ability to hold air depends on the temperature, cold water holds more oxygen than warm water (Fondriest Environmental, 2013). Low concentration of dissolved oxygen in water may transform nitrate to nitrite and sulfate to sulfide. A hydrogen sulfide concentration of 0,05-0,1 mg/l gives the water a rotten egg odor. A too high concentration of hydrogen sulfide may affect the health of a human (WHO, 2011).

4.5 Turbidity

The turbidity is presented by nephelometric turbidity units (NTU) and can be seen by the naked eye by 4 NTU. Turbidity describes the amount of suspended particles or colloidal matter in water that prevent the light from transmission through the water. The cloudiness in the water may be caused by inorganic or organic matter. Turbidity itself is not a threat to the human health, but it is an important indicator since microorganisms, like bacteria, viruses and protozoa, has the characteristics of being attached to particulates which may contaminate the water. Methods of reducing the turbidity are by coagulation, sedimentation and filtration. Filtration will also reduce the contaminations of microorganisms (WHO, 2011). To ensure effectiveness of disinfection the turbidity level should not be more than 1 NTU.

According to WHO (2011), large scale water supplies should be able to achieve water with a turbidity of 0.5 NTU or less. Small scale water supplies, on the other hand, may not be able to produce low turbidity water due to economic aspects and limited resources. Where the treatment is limited, the aim should be to achieve a turbidity of 5 NTU or less (WHO, 2011). Guidelines from The Swedish National Food Agency shows that water treatment plants should be able to produce water with a turbidity of 0.5 NTU. Water in costumers tap or bottled water should not be more than 1.5 NTU (Swedish Food Agency, 2015).

5 Previous work

5.1.1 Biosand filter in Tanzania

In 2016, a biosand filter in Tanzania (Lindgren et al, 2016) was built, studied and evaluated for seven weeks. The biosand filter was constructed with a pre-manufactured plastic tank with a volume of 100 liters and a diameter of 46 cm and a discharge pipe made of PVC plastic. The total height of the filter was 65 cm; 5 cm drainage gravel, 5 cm separating gravel, 31 cm sand, 18 cm standing water level and 6 cm air which worked as a hydraulic head during operation. The effluent water was collected in a 20-litre storage tank with a lid and tap. Materials to the biosand filter were found locally; sand were taken from construction site and gravel from gravel pit in the area. The water added to the filter was approximately 20 liters which was the same as the pore volume of the sand and gravel (30% pore volume of the total volume 68 liters of sand and gravel). The pore volume of the sand filter was 30%, which is 20.4 liters of the total volume of gravel and sand. Water was added with an interval of 19-72 hours. The first three weeks, water was added four days a week with a pause period of 24 hours during weekdays and up to 72 hours during weekends. Week four to six water was added six days a week.

Water was collected from a rainwater tank and poured into the biosand filters by hand.

Results showed that the total coliform in the rain water tank varied during the test period. The coliform bacteria varied from 0 to 500 CFU/100 ml in the rainwater tank. Temperature in the rainwater tank did not vary much throughout the test period. Mean temperature value in the rainwater tank was 22,4 °C. The mean pH was 10.1.

Over time, the filtered water improved its microbiological quality to a satisfactory level according to the Tanzanian, Swedish and WHO standards. The content of total coliforms and E. coli decreased as the biolayer developed during the test period. The first two measurements of the filtrated water showed the highest concentration of organisms, higher than the rainwater tank.

The total coliform bacteria content in the filtrated water decreased over time, by end of week five the content was less than 10 CFU/100 ml. E. coli was found in the first water sample and in one sample during week three. In addition to these two occasions, the concentration of E. coli was kept at a stable level of 0 CFU/100 ml during the test period.

The pH level increased linearly during the study, from 8.4 to 9.5. The filtrated water had always a lower pH than the water in the rainwater tank. The mean temperature was 24.1 °C of the filtrated water. Flow rate through the biosand filter were 1.5 l/min (0.54 m3/m2/h) in the beginning and 0.5 l/min (0.18 m3/m2/h) in the end.

5.2 Study visits at water plants

Two water plants were visited, one in Sweden and one in Ghana, that uses some form of sand filtration in the cleaning process. The visits were done in order to receive a wider understanding of sand filtration as a treatment method and the differences between the countries water treatment methods. The water treatment plant in Sweden was visited on the 17th of February 2017 at Trollhättan Energi in Trollhättan. Johanna Hilding, a process engineer, gave a guided tour through the treatment steps.

The raw water, taken from Göta Älv, was treated by chemical precipitation, rapid- and slow sand filtration before it is distributed to about 50 000 people. Before the water enters the sedimentation step, lime water and carbon dioxide is being added to raise the water's alkalinity and hardness. The dosage of lime water is pH controlled and the carbon dioxide are dosed with a fixed flow. When the raw water with increased alkalinity and hardness enters the sedimentation step a precipitation chemical and coagulant aid are added. There are four double-bottomed sedimentation tanks and two lamella sedimentation tanks. Residence time for the sedimentation process is about 4 hours before the water enters the rapid sand filtration. In total there is six rapid sand filters, four after the double-bottomed sedimentation tanks, with a rapidity of 3,2 m/h and a residence time of about 47 minutes, and two after the lamella sedimentation tanks with a rapidity of 3,05 m/h and a residence time of about 49 minutes. Thereafter the flows from the rapid sand filters comes together and sodium hydroxide is being mixed in to adjust the pH before the flow enters the slow sand filtration step. The purpose of the slow sand filtration is to remove the bacteria by the biological activity. The residence time are about 12 hours and a rapidity of about 0,16 m/h. After the slow sand filtration step the water passes through UV treatment with radiation minimum rate of 400 J/m^2. The last step in the water treating process is to disinfect the water with sodium hypochloride before it is distributed to the costumers. The total time for the water treatment is about 24 hours from the intake to the distributing system.

The water treatment plant was visited on the 10^{th} of March at Ghana Water Company in Kumasi. The first filtration step was to aerate the water by water falling from a height, see figure 2. This step is done in order to reduce odors by increase the dissolved oxygen content in the water and to mix in the polymer. Second step was sedimentation wherein the particles formed flocks after the polymers were mixed into the water, see figure 3. After the sedimentation, the water enters a rapid sand filtration step, see figure 4 and 5. The water passes through 4 feet (approximately 120 cm) of fine sand with a particle size of 0,25-0,35 mm and a drainage of 2 feet (approximately 60 cm). The hydraulic head is controlled by a floater to provide a constant hydraulic head of 2 feet (approximately 60 cm) over the bed of sand. After the sand filters, chlorine gas is added to the water to disinfect it further before it is stored and distributed to the costumers. The total time for the water treatment is about 6 hours from the intake to the distributing system.

Figure 2. The first step where the water gets an increased oxygen percentage.

Figure 3. One of the five sedimentation basins.

Figure 4 and 5. Left: One of the sand filters is being washed (backwashing). Right: The filter gets started up again after being backwashed.

6 Method

The following methods will be divided into three parts; *Preparations in Sweden, Minor field study in Ghana* and *The ideal biosand filter*. The project was started in Sweden were filtration tests were made with different ratios, like sand heights connection of a hose, to achieve a recommended flow rate of 0.4 $m^3/m^2/h$ (CAWST, 2009). Results from Sweden was taken into account in the design of the constructed biosand filters in Ghana. When the field study in Ghana was finished and data was collected, calculations of an optimized biosand filter was made, which was based on the filtration tests in Ghana.

6.1 Preparations in Sweden

6.1.1 Literature study

The projects were introduced by a literature study about the construction and function of a biosand filter and the technique and the mechanisms within the filter. The literature was mainly based on articles and journals, but also facts from basic internet sources.

6.1.2 Filtration tests without a hose

Water filtration tests, with and without a hose, were made to study the relationship between sand height and filtration rate. Two, already constructed, tubes with an outlet at the bottom were used to evaluate the filtration rates, see figure 6. The tubes were transparent and had an inner diameter of 6.0 cm. The different sand heights that was evaluated were; 20 -, 30 -, 40 -, 50 -, 60 -, 70 -, 80 -, 90 - and 100 cm. The different sand heights were supported by 15 cm of gravel. Lines at every 5-cm were marked outside the tubes to easily see the sand- and water height, see figure 7.

Figure 6 and 7. The small pipes in Sweden that was used for flow rate tests

Original (not washed or dried) sand was poured into the tubes to the desired height. Water was poured in to saturate the sand before the filtration test started. When the water level was stabilized over the bed of sand it was saturated and water was gently poured in to avoid unevenness in the sand. When filtration tests were made without a hose, the hydraulic head (i.e. water level from the outlet of the tube to the highest water point) were 151 cm for all filtration tests, irrespective of the sand height. A valve at the outlet started and stopped the water flow. When the valve was opened, a stopwatch was started and the water was let flow free. At every 5-cm marked line, the time was documented to determine the flow rate. The test was stopped when the water head was in the same height as the sand. The flow rate (m3/m2/h) were determine the volume of water between two marked lines, divided by the inner area (m2) of the tube and the time in hour, see equation (1).

$$Flow\ rate\ \left[\frac{m^3}{m^2,h}\right] = \frac{Volume\ of\ water\ [m^3]}{Area\ of filter\ [m^2] * Time\ [h]} \qquad (1)$$

6.1.3 Filtration tests with a hose

Tests with the hose was done in order to make it look like the final biosand filter design where the outlet will be placed 5-cm over the sand bed to ensure that the sand bed is kept wet. The same small tubes were used. Filtration tests were made with sand heights of 30-, 50-, 80- and 100-cm when a hose was connected. Outlet of the hose were placed approximately 5-cm over the sand. The hydraulic head varied for the different sand height, because the tests took a long time. Hydraulic heads for the different sand heights is presented in table 3. When water started pouring out, the stopwatch was started and time was documented every 5 cm. The test was stopped when the water head was in the same height as the sand. The flow rate was calculated by equation (1).

Table 3. Height of hydraulic head for the different sand heights.

Height of sand [cm]	Tests made	Hydraulic head [cm]
30	3	20
50	1	70
80	1	35
100	1	20

6.1.4 Flow rate test of the constructed biosand filter at Karlstad University

A biosand filter was built at Karlstad University by a PVC pipe (inner diameter of 19 cm and a height of approximately 150 cm) and a wooden plate as the bottom. The PVC pipe were siliconized to the wooden plate and let dry. Two small angle irons were also screwed on to the PVC pipe to make the wooden plate stay in place. Approximately 15 cm of gravel and 80 cm of sand was placed in the filter. The outlet was placed 100 cm over the bottom of the filter to get a standing water level of 5 cm over the sand bed. Water was poured into the filter to fill it with water and to flush it. Water was added to the filter till the water looked relatively clean. When the water stopped flowing, the water level was stabilized about 5-cm over the sand bed.

A volume of about 11.3 liter was added to get a hydraulic head of 40 cm. The stopwatch started when water was pouring out from the hose. A 1-litre measuring glass was placed under the hose and the time was documented every 100 ml that poured out. The flow rate was calculated by equation (1).

6.2 Field work in Ghana

The main purpose of this minor field study in Ghana was to evaluate the biosand filter purification method in the Ghanaian environment. Three biosand filters with different sand heights were constructed to study the difference in efficiency of purification. The three biosand filter had different sand heights of; 30-, 50- and 80-cm of sand. The biosand filters were operating from the 11th of March to the 5th of

April (25 days). Water analysis were made every day where new water was added on the influent and effluent water from the biosand filters.

The three biosand filter were constructed by local materials which facilitate the construction and reparation. The influent water in the biosand filters were collected from a river through Kwame Nkrumah University of Science and Technology (KNUST). The river water and the effluent water from the biosand filters were analyzed by equipment from Sweden and laboratory equipment from KNUST. Physical, chemical and microbial properties of the influent and effluent water of the filter was analyzed in order to evaluate the three biosand filters. The three filters were placed outside the biotechnology laboratories at KNUST's campus area. According to Elliot et al (2008) should the volume of water added to the filter be equal to the filter's pore volume. Therefore, was the operation of the biosand filters chosen to be dimensioned by the pore volume of the 80-cm filter.

6.2.1 Construction of sand filter

The three biosand filters were constructed as follows:

A PVC pipe with an inner diameter of 16,2 cm (6") were used as the body for the three sand filters. The PVC pipes were cut in the right length for the three sand filters with different heights, see table C. Each pipe was heated up over a fire in one end to make the plastic more tractable so the PVC lid could fit. When one end was heated up, glue was applied on the PVC lid before it was placed into the heated PVC pipe. The PVC lid had a part that can be unscrewed which were sealed with teflon tape which was spun around the threads before it was screwed back on. This was done in order to seal the bottom and prevent water leakage. When the filter bodies were constructed and the outlet with the hose were placed, it was filled with water to track leakage. None of the filters were leaking.

To ensure that the sand bed was kept soaked at all times, the outlet was placed 5 cm above the sand bed, see the placement for each pipe in table 6. The holes were made with an electric screwdriver and a drill the size of 25 mm. The PVC nipples with a diameter of 25 mm was then set in the holes with silicone and let dry. The hoses were put through the holes and down to the bottom of the filters so the end of the hose was laying on the bottom in a circle and about 10 cm were outside filters. See the different lengths of the hoses in table C. A smooth 90°-bend/PVC fitting, with an inner diameter of 2.5-mm, was then attached with silicone on the PVC nipple. Later, duct tape was used to fix the 90°-bend/PVC fitting better. This was a quick and temporary solution that worked for a period. But it was not a sustainable solution in the long run. It was easy to move the 90°-bend/PVC fitting since it was hold in place with tape, so the outlet might not always be 5 cm above the outlet.

When the filter bodies were constructed and the outlet with the hose were placed, it was filled with water to track leakage. None of the filters were leaking.

Table 6.

Type of filter	Length of PVC pipe [cm]	Placement of the outlet from the bottom [cm]	Length of hose [cm]
30 cm sand filter	95	50	106
50 cm sand filter	115	65	126
80 cm sand filter	145	95	156

6.2.2 Diffuser

A 4 inch PVC pipe and a 4 inch PVC lid were used to construct the diffuser. The PVC pipes were cut to a length of 52 cm. The PVC lid were glued onto one end of the PVC pipe. A pattern of 2,5x2,5 cm was marked on the PVC lid, see figure 8. A hole at each intersection on the grid were made with a heated 3-mm nail. The nail was heated up in a furnace at 600 °C to make it easier to penetrate the plastic. A pair of pliers was used to hold and push the heated nail through the PVC lid. The diffusers were designed to hang on the edges of the sand filters, see figure 10. Therefore, four 5 cm lines was marked, with a distance of 4-cm between, on top of the PVC pipe. A saw was used to cut in the lines. The created tabs were the headed up and bent, see figure 9. One diffusor was made to each filter.

Figure 8. The 2.5x2.5 marked pattern on the PVC lid to the diffusor.

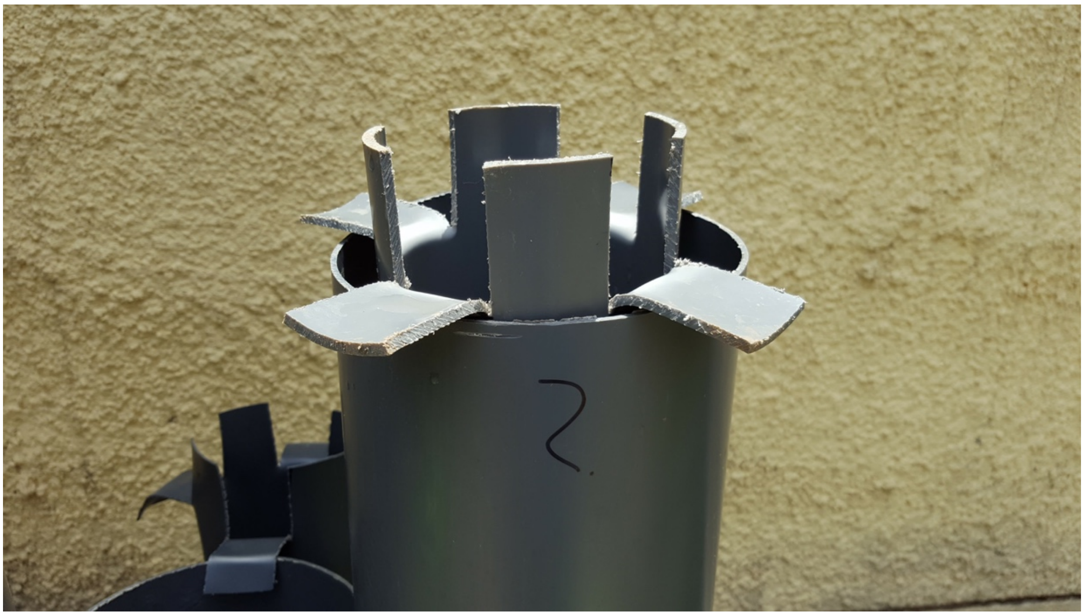


Figure 9. The diffuser.

6.2.3 Preparation of the filtration sand and gravel

The sand and gravel was prepared the same way as described in CAWST's (2009) *Biosandfilter Manual*. Steps to prepare the sand according to CAWST (2009) is:

1. **Collect the sand/gravel.**
2. **Dry the sand in the sun.**
3. **Sieve the sand.**
4. **Wash the sand.**
5. **Disinfect the sand in the sun.**

Sand was collected from the river at KNUST's campus area. Two places were located near two bridges. In total, six buckets, with a volume of 22 liters, of wet sand were collected from two different places but by the same river. Two buckets were collected at the first bridge and the remaining four buckets were collected at the second bridge because the sand sizes at the second bridge looked smaller, see figure 10. Sand were taken by small containers and then poured into the 22 liter buckets. The wet sand was then evenly spread over a big plastic sheet to dry (see figure 11) in the sun for 4 days, approximately 5 h each day. Total dry time were 20 hours. The sand was dried to facilitate the sieving step.

When the sand had dried, it was sieved by a fabric with a hole diameter of approximately 1 mm x 1 mm to get the small particle size that eventually was going to be used as the filtration sand in the slow sand filters. The sand that were sieved through the fabric were used as filtration sand. The particles that did not get through the fabric were used as the separating gravel between the filtration sand and the bigger gravel.

The forth step was to wash the filtration sand. A jar test was first done in order to see how many times the filtration sand should be washed to get the right “dirtiness”. The sand was poured in a plastic bottle to a depth of about 4 cm, then the same amount of water as sand was poured into the bottle, see figure 12. Result showed that the sand should be washed about 5-6 times to be cleaned just right. When the river sand was washed the two 22 liter containers was used. Approximately 4 liters of sand were poured into one container with 4 liters of water. 4 liters of water was poured in 5-7 times, depending if the water was considered as too dirty or not. The washed sand was then evenly spread over the plastic sheet to get disinfected. The disinfected time in the sand was in total about 13 hours, about 4,5 hours each day in three days. After disinfection, the river sand was ready to go in the slow sand filters.

Figure 10. The second place were river sand was collected.

Figure 11. Shows when the river sand was dried in the sun. The bright colored sand was dried while the dark colored was wet.

Figure 12. Jar test to see how many times the sand should be washed to not be to dirty or clean.

Preparing the separating gravel were done in the same way as the filtration sand. The difference between washing the filtration sand and the separating gravel is that the separating gravel should be washed until the water in the container is clean. It was washed for about 4-7 times before it was placed at the same plastic sheet as the sand to disinfect in the sun for about 6 hours.

Preparing the gravel were done by step 1, 4 and 5. Since the gravel did not need a drying and sieving step. The gravel was collected at a building construction area in Kumasi and washed. About 3 liters of gravel were put in the 22-litre container with twice as much water. The hand was used to swirl in the container to make the water dirty. The dirty water was then poured out and new clean water was poured into the container. It was hard to say how many times the gravel needed to be washed because it differed from time to time, but approximately 5-9 times, depending on the dirtiness of the gravel. When the gravel was washed it was placed on the same plastic sheet as the sand but in a separate part to disinfect in the sun for 3 days in about 4,5 hours every day. In total, the gravel had a disinfection time of 13 hours.

6.2.4 Maintenance

During operation, the three sand filters were in need of maintenance. After about one week of operation, algae were growing on the outlet hose and particles was stuck inside the diffusor. Water was boiled and poured on the outlet to remove the algae and kill bacteria. Boiled water was also poured inside the diffuser and outside at the bottom to kill bacteria and remove stuck particles. Maintenance was done when needed, which was once a week during the operation time.

6.2.5 Preparations of the sand filters

When the biosand filter's constructed filter bodies were finished, they were placed outside, see figure 13. The three filters were dug about 10-15 cm in through the ground and were supported by bricks to prevent them from falling during heavy rainfalls.

Figure 13. The constructed biosand filter in Ghana.

When they were set in place, the filters were filled halfway with water before gravel and sand were added to the filters. This was done in order to prevent pockets of air being trapped within the sand. The total height of the sand filters was measured with measuring stick from the bottom to the top. Approximately 10 cm of gravel were added in each filter and levelled out. Then 5 cm of separating gravel were added and levelled out. The filtration sand was quickly poured into the filters to get a good mix of the particle sand size. See table 7 for the precise volume that was poured in the filter and heights.

The volume of the filter medias was measured with a 2.0 liter measuring cup.

Table 7. Shows the total volume of the filter media which was poured into the different sand filters.

	Volume of gravel [l]	Height of gravel [cm]	Volume of separating gravel [l]	Height of separating gravel [cm]	Volume of sand [l]	Height of sand [cm]
30 cm sand filter	2,0	12,0	1,0	5,0	7,9	32,0
50 cm sand filter	2,0	12,0	1,0	4,0	11,0	49,0
80 cm sand filter	2,0	10,0	1,0	6,0	18,3	81,0

After all filter media was poured in the filters, water was poured in and let run until the water level was equalized. The height of water was measured with a measure stick from the sand surface. If the water level was more than 5 cm, more sand was added. If less than 5 cm, sand was removed. The top layer of the sand was swirled to free small particles from the sand to the water which prevent the sand from clogging. The muddy water was dumped out with siphon mechanism and the sand surface was smoothed out.

Next step was to flush the filtration bed with tap water till the effluent water was clear (CAWST, 2009). This was done in order to remove small particles between the sand grains. The tap water was poured in the diffuser. A total volume of 45 liters was flushed through all three sand filters. The effluent water was collected in containers and then poured out. After the filters were flushed they were ready to be used. A plastic bag was used as lid to prevent rain water to come into the filters.

6.3 Cost to build a sand filter and cost of bottled water

The sand filters were built of local materials. Materials were collected from Tech Junction and the main market in Kumasi. Usually, there are no fixed prices in Ghana which means bargaining is common. Therefore, the cost may differ from person to person, depending on who is shopping. The currency in Ghana is Ghanaian New Cedi (GHs) and during the visit 1 GHC was 2.0 Swedish Krona (SEK) and 0.23 United States Dollars (USD).

During the visit, the cost of water sachets was studied which is commonly used in Ghana. By studying the different prices of water sachets, an average cost could be determined. The price of one water sachet bought on the street was around 0.25 GHC.

6.4 Take water sample from the river at KNUST

Water that was poured into the sand filter was taken from the river that flows through KNUST. Before the water samples was taken, water tests were done with HANNA Instruments® Multimeter (Code: HI9829-00042, S/N: E0069419) which logged several parameters, like pH and temperature.

The water samples were taken with a 1.5-litre water bottle and poured into two 15-liter water containers till they were full. The water bottle was held horizontally with the water and was gently brought into the water. The entire opening of the water bottle was never brought under the water surface to make sure that no air bubbles was formed that would have oxygenated the water. River water from the water bottle was gently poured into the water container to make sure that no air bubbles was formed that would have oxygenated the water. After water was collected, the water bottle was cleaned with soap and tap water, the 15 liter containers were flushed with tap water.

6.5 Pour water from the river into the filters

Elliot et al. (2008) concluded that the batch volume should be equal or less than the pore volume of the filter media to attain an improved water quality. As earlier described, three filters with different sand heights was built. Each filter had its own pore volume, where the 80-cm filter had the greatest and the 30-cm filter has the smallest pore volume. The batch volume was chosen to be the same for all three biosand filters and were based on the pore volume of the 80-cm filter. This means that the amount of water poured into the 80-cm filter were the same as the pore volume, while it was greater than the pore volume of the 30- and 50 cm filters. This was done in order to study the difference in improved water quality between the filters. The pore volume analysis of the 80-cm filter was calculated to approximately 7.0 liters.

Another important parameter to get a good water quality was the pause period, according to CAWST (2009). The recommended pause period was between a minimum of 1 hour to a maximum of 48 hours. A pause period of 24 hours was chosen for all three sand filters.

The pore volume of the sand, separating gravel and gravel was calculated for the 80-cm filter which resulted in a pore volume of 7.3 liters. Since the water that will be poured into the filter should be equal or less than the pore volume, a volume of 7.0 liter was chosen to be poured into all three filters. A plastic measuring cylinder was used to measure the desired volume of 7.0 liter and was then poured into a bigger cleaned water container. When 7.0 liters were measured it was poured into the filter. The same procedure was repeated for the other two filters.

6.6 Description of the river through KNUST's campus area

Water were taken from a river through KNUST's campus area and was poured into the filters. Water were taken by a bridge near the chemical department. Wash water was connected to the river where water samples were taken. The wash water had a white and blue color, see figure 14. The water level in the river varied throughout the test period due to rain, which increased the turbidity level in the river, see figure 15. When it did not rain for a while, the water level decreased and the water became clearer, see figure 14. There were more odors when the water level was low. Generally, there was a lot of fish in the water, the sizes were both big and small, and not much floating organic matter in the water. The bottom of the river was made of sand where water was taken.

Figure 14. Low water level in the river.

Figure 15. High water level in the river.

6.7 Water analysis

Physical and microbial analysis were performed on the influent and effluent water of the filters. The physical properties were analyzed by temperature, pH, suspended solids, turbidity, and dissolved oxygen. Total coliform bacteria were used as an indicator of the microbial analysis of the water.

Water samples from the biosand filter were taken on the influent and effluent water at the same nonce as water was added to the filters. The pause period for the filters were 24 hours, which means that water samples were taken every day. The filters were up and running for four weeks, from the11th of March to the 5th of April (25 days). The last week, water samples were taken of the first 600 ml effluent water, the mix and the last 600 ml of effluent water. On some occasions, water analysis could not be made because it was a lack of equipment or due to sickness.

Total coliform bacteria tests were made every day, except from day 8 to day 16 where test was made every other day. The pH and temperature was measured with a multiparameter from Hanna Instruments®.

6.7.1 Dissolved oxygen

Dissolved oxygen was measured from day 1, but it was discovered that the values from the equipment was incorrect. On day 9, the equipment was swapped. Dissolved oxygen was measured on the influent and effluent water from day 9 to day 25. At day 5, aeration of the influent water started because the effluent water had bad odors. Aeration was continued to the end of the project. The dissolved oxygen was measured by the Thermo Scientific™ Orion™ Star A216 pH, DO and RDO Benchtop Meter and shows the dissolved oxygen in parts per million (ppm).

6.7.2 Suspended solids

A micro-glass fiber filter, a measuring cylinder, an aspirator, a funnel and a balancer were used to measure the suspended solids. First, the micro-glass fiber filters were incubating at 105 °C for four hours and let to cool before it was weighed. The weight was written down. A micro-glass fiber filters were put in the funnel, see figure 16. The micro-glass fiber filter was soaked before the test water was poured in to prevent the dirty water passing between the micro-glass fiber filter and the funnel. A certain volume of water was measured by a measuring cylinder and poured over the micro-glass fiber filters. The amount is dependent if you can see a color difference on the micro-glass fiber filter. Afterwards, the micro-glass fiber filter was incubating at 105 °C for four hours more before the last weigh was weighed. The amount of suspended solids in the water sample is calculated by equation (2). Negative values due to error measurement of suspended solids was not presented in the results.

$$Suspended\ solids\ \left[\frac{mg}{ml}\right] = \frac{Weight\ before\ [mg] - Weight\ after\ [mg]}{Volume\ of\ water\ sampling\ [ml]} \quad (2)$$

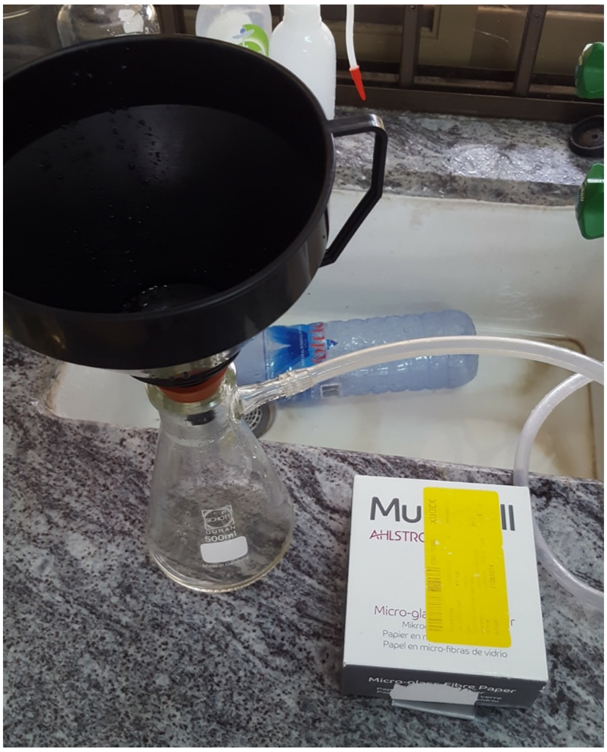


Figure 16. Equipment to measure the suspended solids.

6.7.3 Microbial analysis of total coliform bacteria

Bacterial tests were executed by using paddle testers before the untreated water was poured over the sand beds and after filtration in the three filters. The paddle testers were bought from HACH® and measured total aerobic bacteria/total coliforms. The paddle tester was removed from the vial and then dipped into the water for 8-10 seconds before it was put back in the vial. After that, the test was incubated for about 48 hours in a temperature locker at a temperature of 37 °C. Thereafter, the paddle tests were compared and interpret with references from HACH (2016).

6.8 Particle size tests in Sweden and Ghana

Particle size tests were made in Sweden and Ghana to see the sand particle size. To do the test, a small cylinder, balancer and sieves with different sizes were used. The small cylinder was put on the balancer, filter material was poured in and weighed before it was put on top of the sieves. The sieves were placed in order, the biggest screen size on top and the smallest at the bottom. In Sweden, the sieves were placed in order as follows; 4.0-, 2.0-, 0.5- and 0.25 mm. In Ghana, the sieves were placed in order as follows; 4.0-, 2.0-, 1.0-, 0.5-, 0.25-, 0.125-, 0.063- and 0.045

mm. When the sand was placed on top of the sieve, it was shaken for a couple of minutes to get the different particle size at the right level.

In Sweden, 100 grams of dry filtration sand was measured and poured over the sieves. The sand size test in Sweden showed that it contained the biggest amount of sand with particle size 0.5-2.0mm, see table 7.

Table 7. The distribution of sand sizes from the test in Sweden.

	< 0.25mm	**0.25-0.5mm**	**0.5 -2.0mm**	**2.0 4.0mm**	**> 4.0mm**
Sand	16.6%	29%	39%	10.8%	4%

In Ghana, particle size of original river- and filtration sand and finer gravel were made. 100 grams of river sand, 50 grams of filtration sand and 100 grams of finer gravel were separately weighed by the small cylinder and balancer. The test concluded that the river sand mostly contained sizes between 0.5-1.0mm, filtration sand sizes between 0.25-0.5 mm and finer gravel sizes between 1.0-2.0mm, see table 8.

Table 8. The results of particle sizes of river- and filtration sand and finer gravel in Ghana.

	River sand	**Filtration sand**	**Separating gravel**
> 4.0 mm	3.2%	-	17.9%
2.0-4.0mm	4.5%	-	38.2%
1.0-2.0mm	20.9%	24.9%	**41.4%**
0.5-1.0mm	**37.9%**	33.0%	2.1%
0.25-0.5mm	25.4%	**35.6%**	0.38%
0.125-0.25mm	7.4%	6.4%	-
0.063-0.125mm	0.8%	-	-
0.045-0.063mm	-	-	-
< 0.045mm	-	-	-

6.9 Pore volume analysis

The pore volume in the sand was calculated by dividing the water volume added with the volume of sand. It was evaluated with a small container, measuring cylinder and sand. Water were added to the sand till the water table was shown over the bed of sand. The pore volume of the separating gravel and gravel were assumed to be the same as the sand since it was difficult to get reliable results.

The pore volume analysis of the sand in Sweden were made on the original (not washed) sand. A sand volume of 100 ml was measured and poured into the small container. A water volume of 40 ml could be poured in before the water table was shown, which gives a pore volume of 40.0%.

In Ghana, the pore volume test was made after the sand was sieved, washed and dried. A sand volume of 450 ml was measured and poured into the small container. A water volume of 165 ml could be poured in before the water table was shown, which gave a pore volume of about 36.6%. The total amount of the three biosand filters were calculated by equation (3) and is presented in table 9.

$$Pore\ volume\ [liter] = Total\ filtration\ media\ volume\ [liter] \cdot Pore\ volume\ [\%] \quad (3)$$

Table 9. Approximate pore volumes for the three biosand filters.

	30 cm BSF	50 cm BSF	80 cm BSF
Pore volume (liter)	~ 3.4	~ 4.9	~7.2

6.10 Flow rate test in Ghana

Flow rate test were performed every day during the filter's operation. The flow rate test was done in order to see if the biosand filters were operating under unaccepted low filtration rate and would need maintenance. The flow rate also tells if the filtration media is in the right size or if the sand have been washed to much or too little. Throughout the test period, except the last two days, was 7 liters of water was poured directly into each biosand filter. When water started to pour out, the stopwatch was started. Measurements were taken every 1 liter of water that was poured out. The flow rate was determined by equation (1).

The last two days, day 24 and day 25, were water not poured into the filter directly. First, 3 liters of water was poured into the diffusor. When 1 liter of water had come out, 1 more liter of water was poured in. This method continued till a total volume of 7 liter of water had been poured in the biosand filter.

6.11 The ideal biosand filter

This part was based on results from Ghana. An optimization of the filter design was based on filtration parameters from the 80-cm filter in Ghana. The recommended flow rate of 0.4 m3/m2/h was pursued and could be achieved by changing the design of the filter or by changing the "pouring in water technique".

Mean filtration values, at different hydraulic heights, was calculated over the test period. If the flow rate of 0.4 m3/m2/h was achieved at a different hydraulic head that the current one, the right hydraulic head was used to calculate the ideal diameter of the biosand filter by using equation (4), or to determine the maximum volume of water that could be inside the filter by equation (5). The poured in water volume was 7.0 liters.

$$Volume\ [liter] = \frac{Right\ hydraulic\ height\ [m] \cdot Filter\ area\ [m2]}{1000} \quad (5)$$

6.12 Microbial analysis with agar plate

Microbial analysis tests were done in the biotechnological laboratory at KNUST. Water samples were collected at three times on the effluent water of the three biosand filters and the collected river water. A small volume was sampled from the first and last batch of the effluent water, and when about 3.5 liter of water had been poured out, see figure 17. Water was sampled the 4th of April 2017.

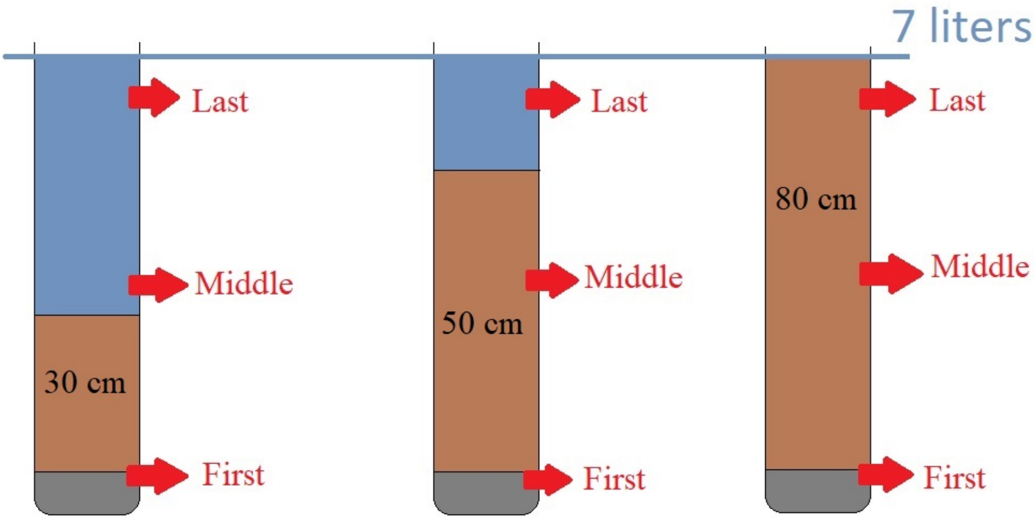
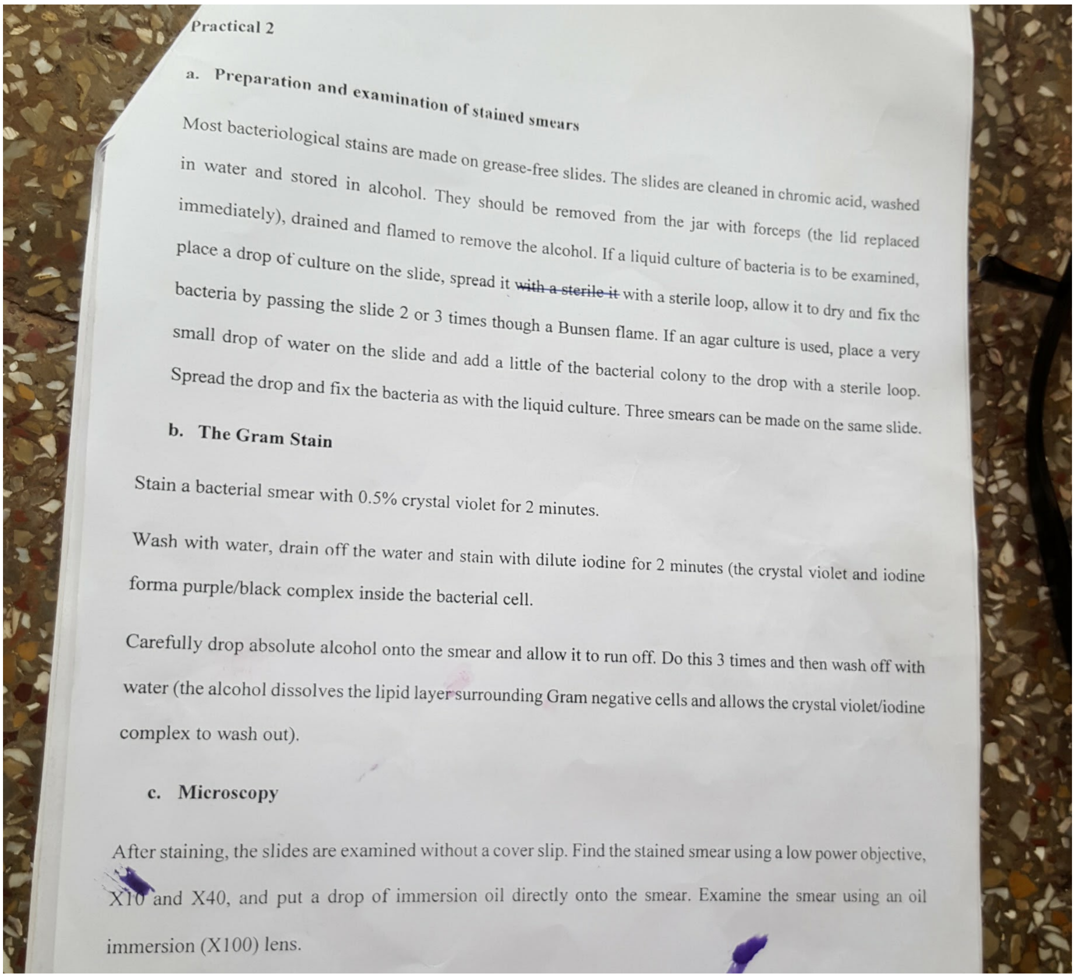


Figure 17. An illustration of from what part water from the effluent water was collected from each sand filter.

To do the microbial tests, a laboratory technician was taken to help. First, a small amount of the sampled water was placed on agar plates for growth. After some days when bacteria had grown on the agar plate, subcultures were picked out by a tool and placed on a new agar plate. When the subcultures had grown, gram straining were done in order to study the type of bacteria in a microscope. The gram straining process is presented in figure 18.

When the gram straining process were done, the bacteria were looked at through the microscope. The bacteria seen in the microscope were compared with the bacteria seen in figure 19.



Practical 2

a. Preparation and examination of stained smears

Most bacteriological stains are made on grease-free slides. The slides are cleaned in chromic acid, washed in water and stored in alcohol. They should be removed from the jar with forceps (the lid replaced immediately), drained and flamed to remove the alcohol. If a liquid culture of bacteria is to be examined, place a drop of culture on the slide, spread it ~~with a sterile it~~ with a sterile loop, allow it to dry and fix the bacteria by passing the slide 2 or 3 times though a Bunsen flame. If an agar culture is used, place a very small drop of water on the slide and add a little of the bacterial colony to the drop with a sterile loop. Spread the drop and fix the bacteria as with the liquid culture. Three smears can be made on the same slide.

b. The Gram Stain

Stain a bacterial smear with 0.5% crystal violet for 2 minutes.

Wash with water, drain off the water and stain with dilute iodine for 2 minutes (the crystal violet and iodine forma purple/black complex inside the bacterial cell.

Carefully drop absolute alcohol onto the smear and allow it to run off. Do this 3 times and then wash off with water (the alcohol dissolves the lipid layer surrounding Gram negative cells and allows the crystal violet/iodine complex to wash out).

c. Microscopy

After staining, the slides are examined without a cover slip. Find the stained smear using a low power objective, X10 and X40, and put a drop of immersion oil directly onto the smear. Examine the smear using an oil immersion (X100) lens.

Figure 18. A photo of the gram straining method from KNUST

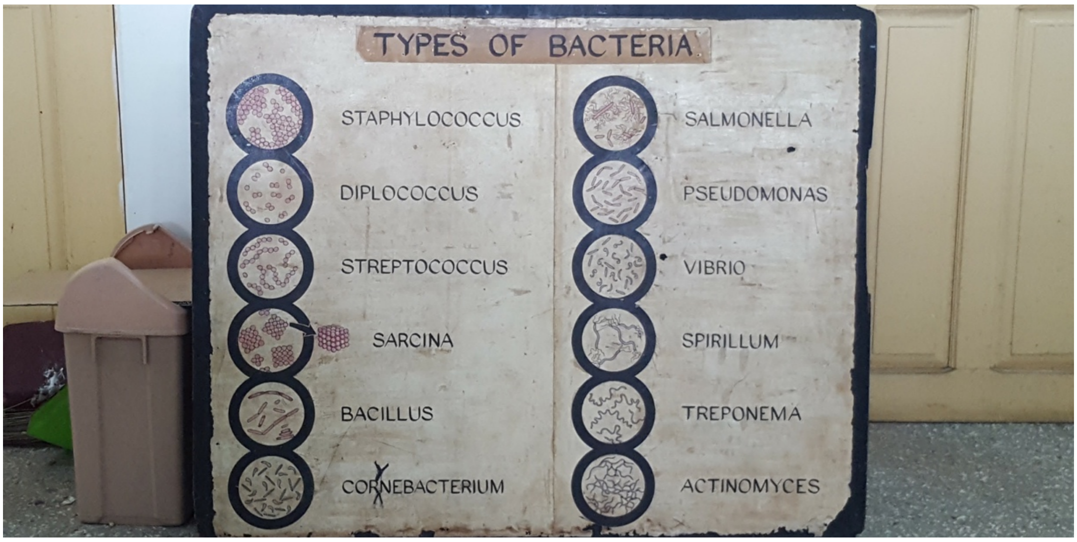


Figure 19. Shows different types of bacteria that could be discovered in the microscope. Picture taken at the biotechnological laboratory at KNUST.

7 Results

In this section, results from Sweden and Ghana will be presented. The result in Ghana will present the efficiency difference between the biosand filter by physical and microbial analysis. In the end of this section, a new biosand filter design will be presented. The new design has been based on results from Ghana.

The flow rate tests in Sweden and Ghana showed that the flow rate was greater in Ghana than in Sweden. The recommended flow rate of 0.4 $m^3/m^2/h$ was achieved when the hydraulic head was about 65 cm over the outlet in Sweden, while just 5 cm over the outlet in Ghana. Results from the total coliform bacteria tests and the physical properties tests of the effluent water showed that none of the three filters could produce water that would be approved by the WHO's drinking water standards or the National Swedish Food Agency's standards.

7.1 Results in Sweden

Flow rate tests were made in Sweden in order to study under what conditions a recommended flow rate could be achieved. Recommended flow rate is between 0.1-0.4 m3/m2/h according to Binnie et al. (2002), while CAWST (2009) recommends a maximum flow rate of 0.4 m3/m2/h. The flow rate tests were done in tubes with and without a hose. A biosand filter were also built to study the flow rate.

The flow rate test in Sweden without a hose showed that the flows did not differ so much from each other, see figure 20. A sand height of 20 cm showed a clearly higher flow rate than the others. The flow rate for the 30-cm sand were high in the beginning, but was evened out with the other flows in the end. Between 40- and 100-cm the flow rate remained in the same region and did not differ clearly from each other. The results also showed that the flow rate decreased with decreased hydraulic head. But no sand height gave the recommended flow rate of 0.4 m3/m2/h.

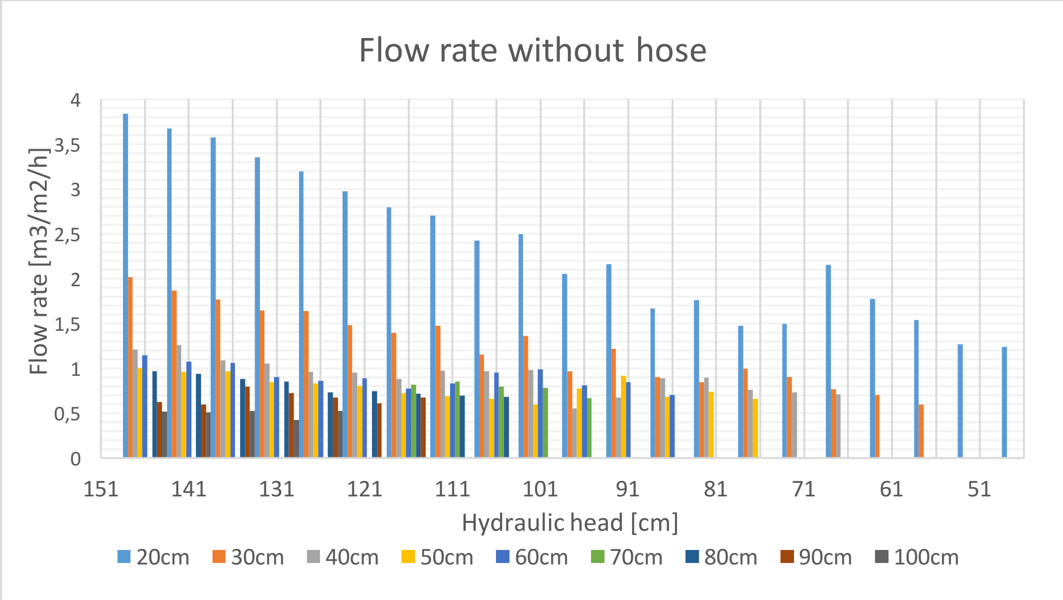


Figure 20. Results from the flow rate test with different sand heights.

When a hose was connected to the pipes, the volume flow was reduced for all four sand heights. This is because the hydraulic head, which is the driving force for water to come out, become smaller when a hose was used. The recommended volume flow of 0.4 m3/m2/h (CAWST, 2009) was obtained when the sand height was 50 cm and hydraulic head started at 70 cm, see figure 21. The first flow rate for the 80 cm was 0.2 $m^3/m^2/h$ when the hydraulic head was 30 cm above the outlet, half as low as recommended, see figure 21. When the sand height was 30 cm, hydraulic head 30 cm, the flow rate was slightly lower at 0.3 m3/m2/h which is lower than recommended. A flow rate of 0.3 m3/m2/h was reached when the hydraulic head was 50 cm and sand height 50 cm, see figure, 21. When 100 cm of sand was used and hydraulic head was 20 cm, the flow rate reached an unacceptable low flow rate of 0.1 m3/m2/h in the beginning. According to CAWST (2009), this filter is in need of maintenance. For all four sand heights, flow rates decreased with decreased hydraulic head. Water stopped flowing, for all four sand heights, when the hydraulic head was about 5-10 cm over the hose outlet.
From this test, it was concluded that the perfect flow rate was reached when the hydraulic head was 70 cm with a sand height of 50 cm. Hydraulic head could be higher for the 30- and 80 cm sand tests. Also, that it was unsustainable to use 100 cm of sand with a hydraulic head of 20 cm.

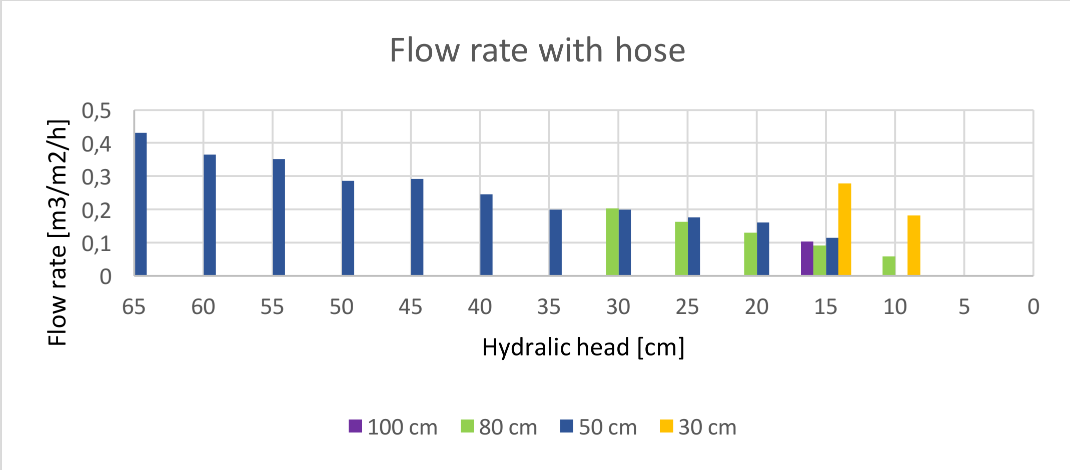


Figure 21. Flow rates when a hose was connected. Height of sand is 30-, 50-, 80- and 100 cm.

7.1.1 Constructed biosand filter in Sweden

The constructed biosand filter at Karlstad University had an inner diameter of 19 cm and was filled with 80 cm of sand and 15 cm of gravel. When the hydraulic head was 40 cm over the 5-cm standing water, the flow rate was higher than the recommended value in the beginning. The flow rate reached CAWST's (2009) recommended 0.4 m3/m2/h when the hydraulic head was slightly lower than 26 cm, see figure 22.

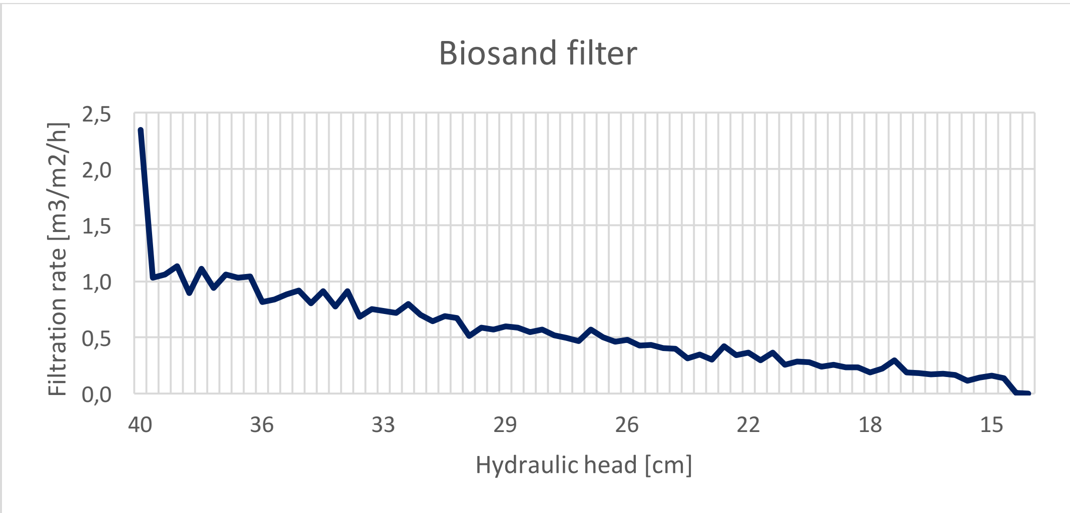


Figure 22. Results from the filtration rate test on the constructed biosand filter in Sweden.

7.2 Results in Ghana

Water temperature in the river were higher during the day than in the morning, but it was not a great change. The average temperature in the river during the test period was 27.8 °C. The average temperature in the 80-cm filter was 28,9°C and 29,3°C for the 50- and 30-cm filters.

The pH level in the river and filters were stable throughout the test period. The mean pH value for the river, 50- and 30 cm filters was pH 7.2 and 7.3 for the 80-cm filter.

7.2.1 Optical visions and smell

The color of the effluent water from the three filters were never colorless. The trend was that the 80-cm filter had a more yellow color than the other two. The 30-cm filter had a less yellow water color throughout the test period, see figure 18. On the other hand, the 80-cm filter did have the less cloudy water than the 30- and 50 cm filter, see figure 23. This results in the higher sand height, the more yellow water, but less cloudy. On some occasions, the first 600 ml of effluent water was black/dark brown from the 50-cm filter, see figure 24, which also is a sign of anaerobic conditions.

The effluent water in all three filters had a bad odor throughout the test period. At the beginning, the odor was like in the river. But after some time, it started to smell like rotten egg, hydrogen sulfide, which is a sign of a lack of oxygen and an anaerobic environment within the filters.

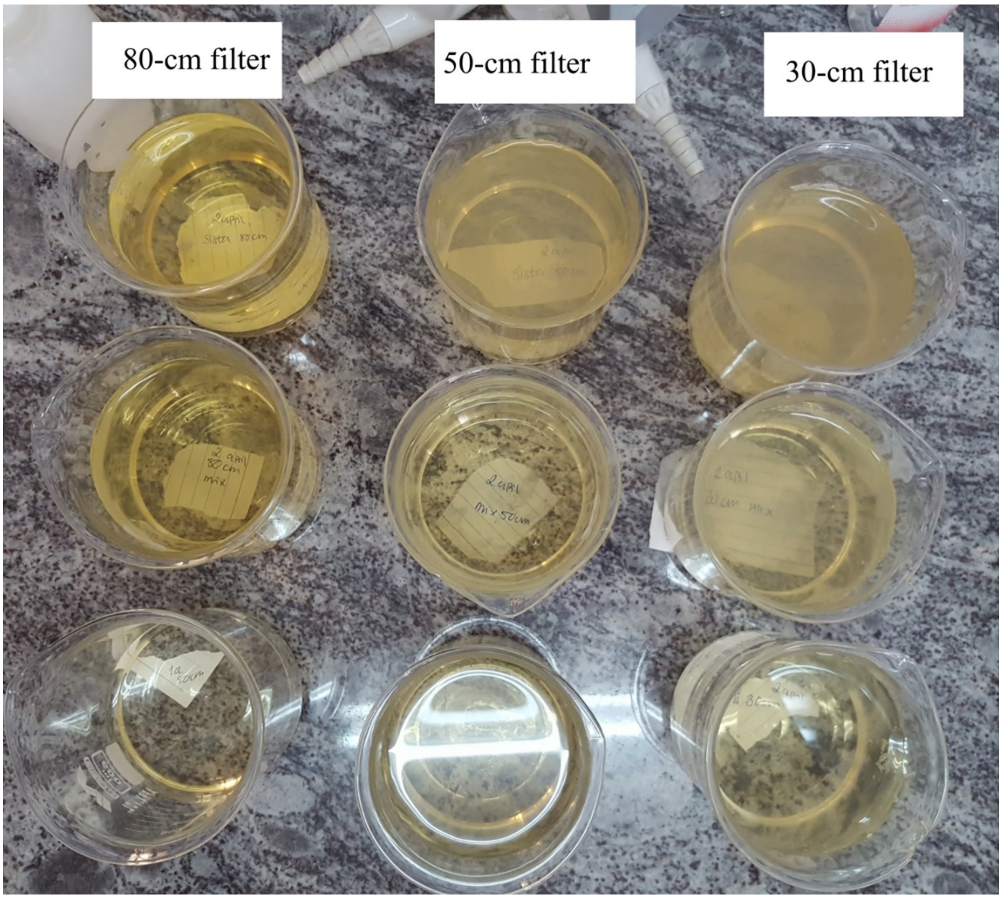


Figure 23. Pictures of the water samples. Picture is taken the April 2.

Figure 24. A color comparison between the first 600 ml of water from the 80-cm filter (left) and the first 600 ml from the 50-cm filter (right). As seen in the figure, is the water in the right measuring cylinder black/dark brown from the 50-cm filter. The picture is taken the 5th of April.

In the end, the three biosand filters were disassembled to study the inside. When the filters were taken apart, it was seen that the bottom part of the hose in the 50- and 80-cm filters were colored black, see figure 25. The 80-cm filter had a clearer black color than the 50-cm filter. The hose in the 30-cm filter had a white/grey color.

Figure 25. Picture from when the three biosand filters were disassembled. From the left; 50-cm filter, 80-cm filter, 30-cm filter.

7.2.2 Total coliform bacteria

The amount of total coliform bacteria had a great variation in the river throughout the study, a minimum of 1’000 CFU/100 ml (day 25) to a maximum of 10’000’000 (day 1, 6, 22 and 23). Unfortunately, could not a clear trend be seen in total coliform bacteria reduction in the 30-, 50- and 80 cm filters, see figure 26, 27 and 28. The bacteria content in the effluent water should be equal or less than the influent water. But in some cases, the bacteria content in the effluent water could be higher than the influent. Higher concentration, than the influent, of total coliform bacteria in the effluent water was for the 80-cm filter seen at day 5, 14, 16, 19 and 25. For the 50- cm filter at day 4, 17 and 12. For the 30- cm filter at day 4, 12, 14 and 17.

The lowest reached concentration of total coliform bacteria in the 80-cm filter were 1.0E+04 CFU/100 ml, see figure 26. For the 30- and 50-cm filters, the concentration were 1.0E+03 as lowest, see figure 27 and 28. This means that none of the filter could produce a drinkable water, according to WHO (2011) and The Swedish National Food Agency (2015).

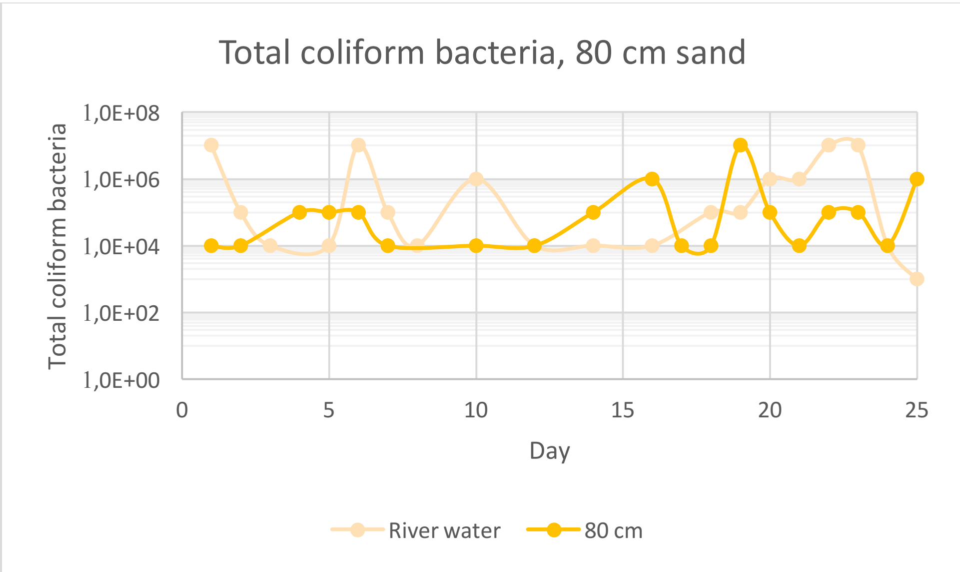


Figure 26. The relationship between the influent water, river water, and the effluent water from 80 cm filter in total coliform bacteria content.

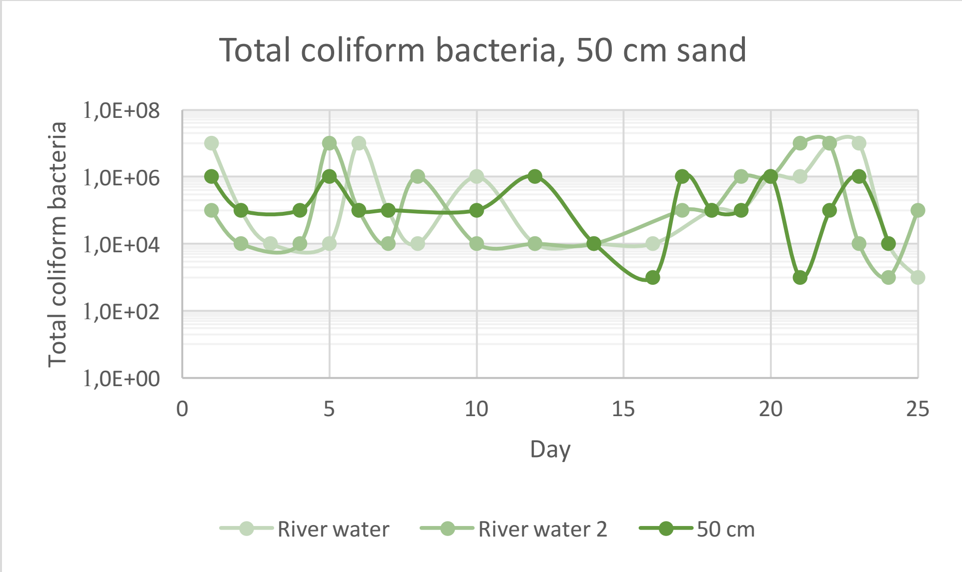


Figure 27. The relationship between the influent water and the effluent water from the 50-cm filter in total coliform bacteria content.

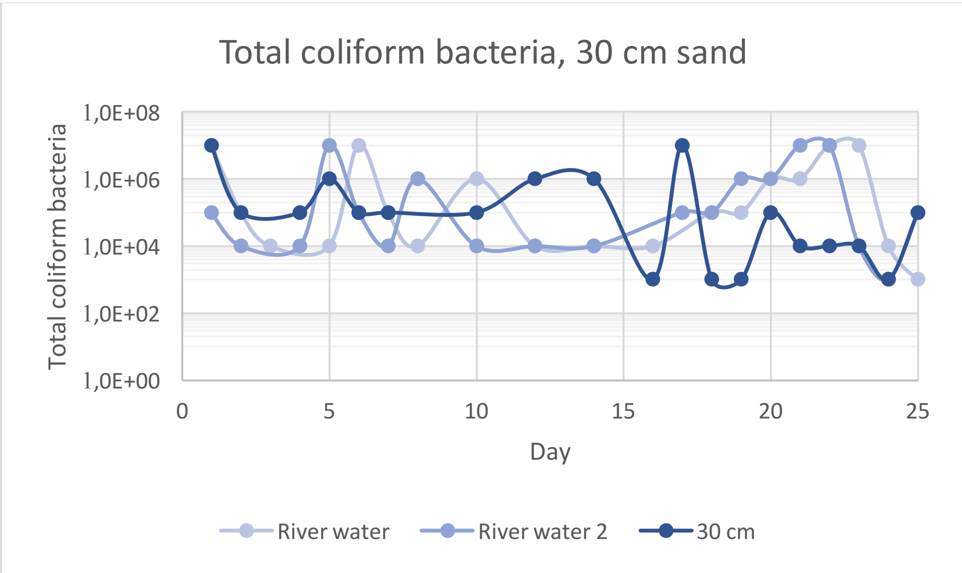


Figure 28. The relationship between the influent water and the effluent water from the 30-cm filter in total coliform bacteria content.

The biosand filters were compared to each other to see which one that had the lowest concentration of total coliform bacteria in the effluent water throughout the tests period. Results showed that the 80-cm filter had the most days with low concentration of total coliform bacteria compared to the other two biosand filters, see figure 29.

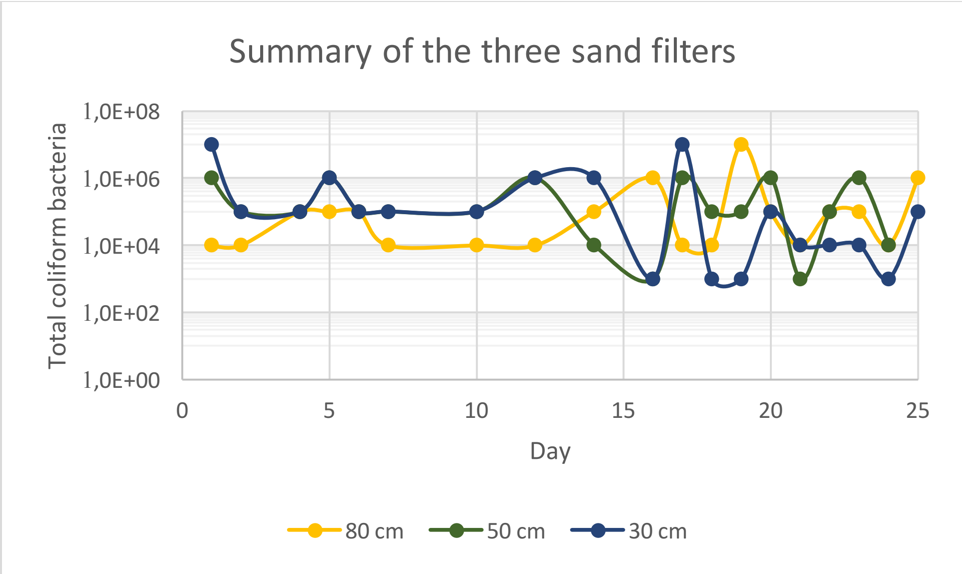


Figure 29. A summary of total coliform bacteria content throughout the test period.

7.2.3 Turbidity

The turbidity levels for the three filters were stable throughout the test period and the effluent water never had a higher turbidity level than the influent, see figure 30, 31 and 32. The turbidity increased in the river when it rained the day before. At day 13, it had rained heavily which caused increased turbidity levels in the river, from 12 NTU to 345 NTU. The 80 cm-filter managed this turbidity change better than the 30- and 50 cm filters, see figure 30 compared to figure 31 and 32. However, none of the biosand filters managed a mean turbidity level of less than 5 NTU, which is the recommendations from WHOs drinking water standard (2011). The 30 cm-filter had a mean turbidity of 13.9 NTU throughout the test period, but did manage a turbidity level lower than recommended at day 1, 2, 18, 17, 19, 20, 21, 22 and 23. Mean turbidity out of the 50-cm filter was 8.1 NTU. The effluent water from the 50-cm filter had a lower turbidity than recommended at day 7, 10, 11, 17, 18, 19 and 22. The 80-cm filter had a mean turbidity level of 7.5 NTU, which is the lowest achieved. But it did only manage to keep a lower turbidity level than recommended at day 1 and 2.

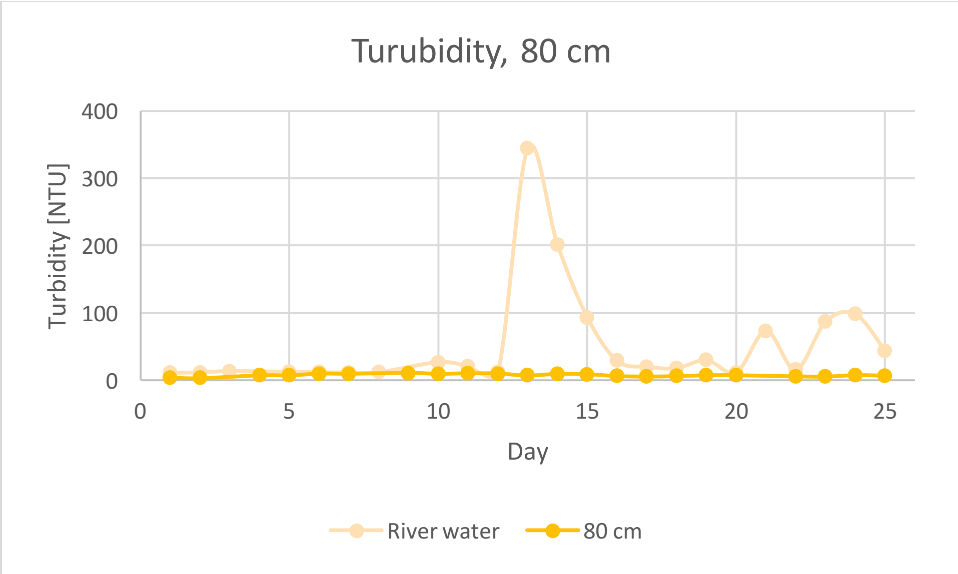


Figure 30. Turbidity levels of the river water and effluent water from the 80- cm filter.

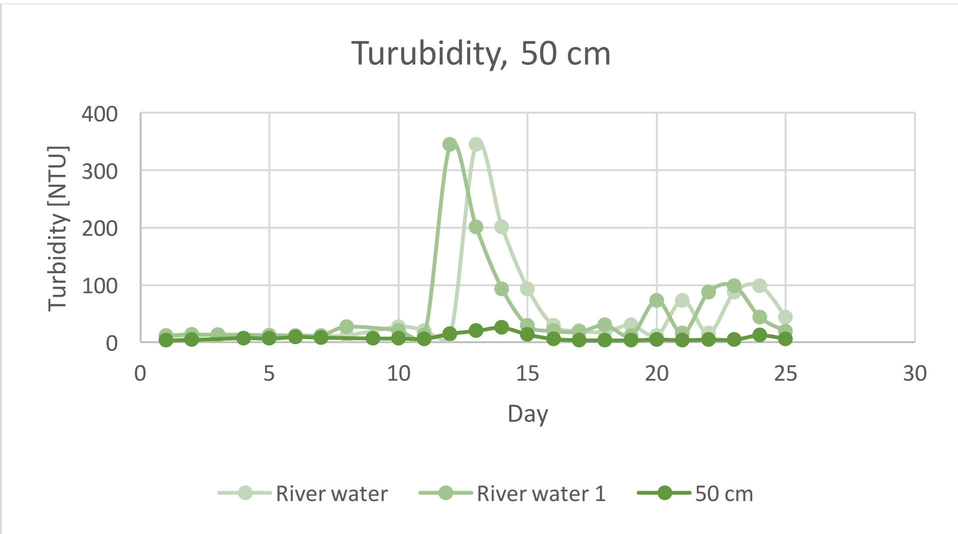


Figure 31. Turbidity levels of the river water and effluent water from the 50- cm filter.

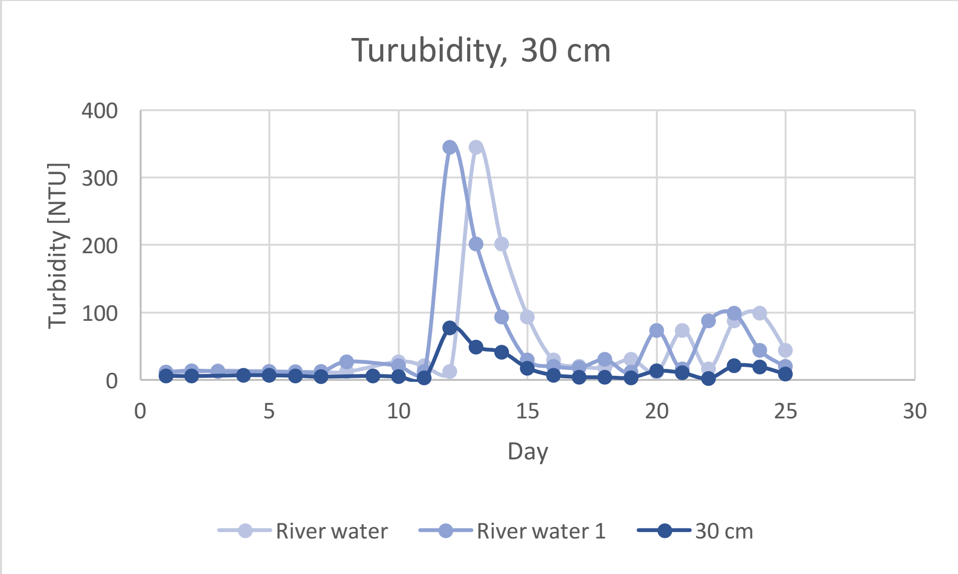


Figure 32. Turbidity levels of the river water and effluent water from the 30- cm filter.

7.2.4 Dissolved oxygen

The mean dissolved oxygen concentration in the river was 3.8 mg/ml throughout the test period. The areated water had a mean dissolved oxygen concentraion of 4.5 mg/l. This is an increasing of about 19%. The dissolved oxygen concentration was always lower in the effluent water than the influent for the three biosand filyters, see figure 33, 34 and 35. The mean value in the effluent water from the 80-cm filter was 2.9 mg/ml, 50-cm filter was 2.5 mg/ml and 30-cm filter was 2.5 mg/ml which is higher than the recommended 3 mg/liter (Huisman et al. 1974).

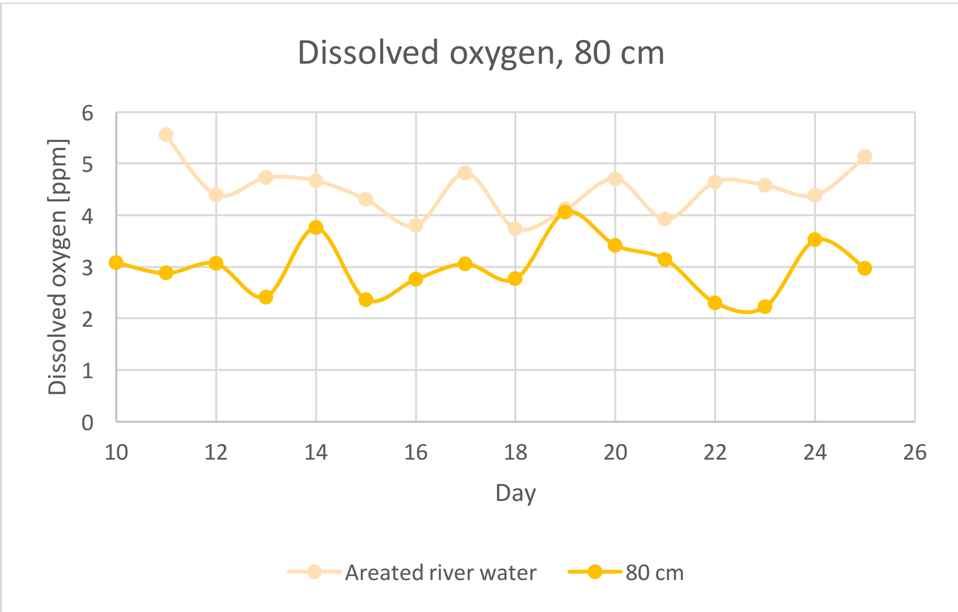


Figure 33. Dissolved oxygen in the river and 80-cm filter.

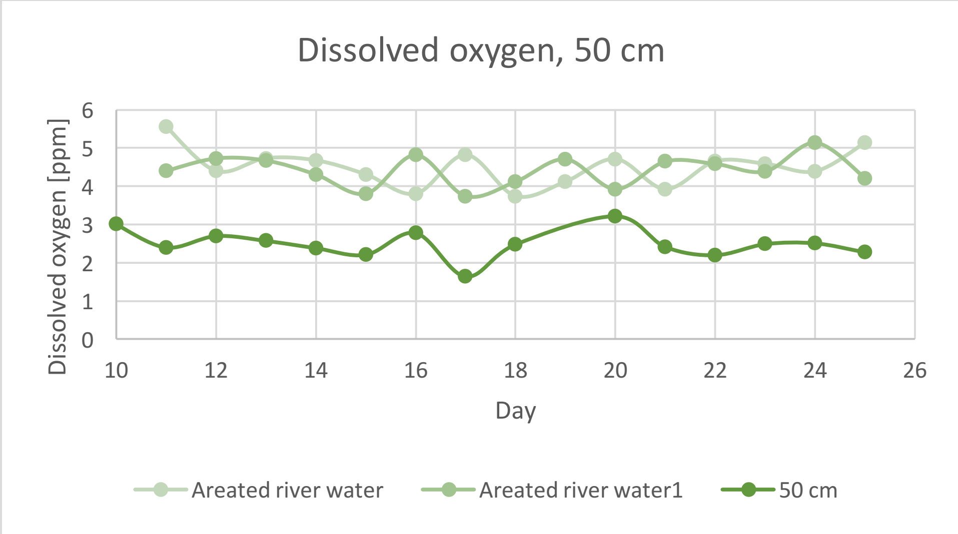


Figure 34. Dissolved oxygen in the river and 50-cm filter.

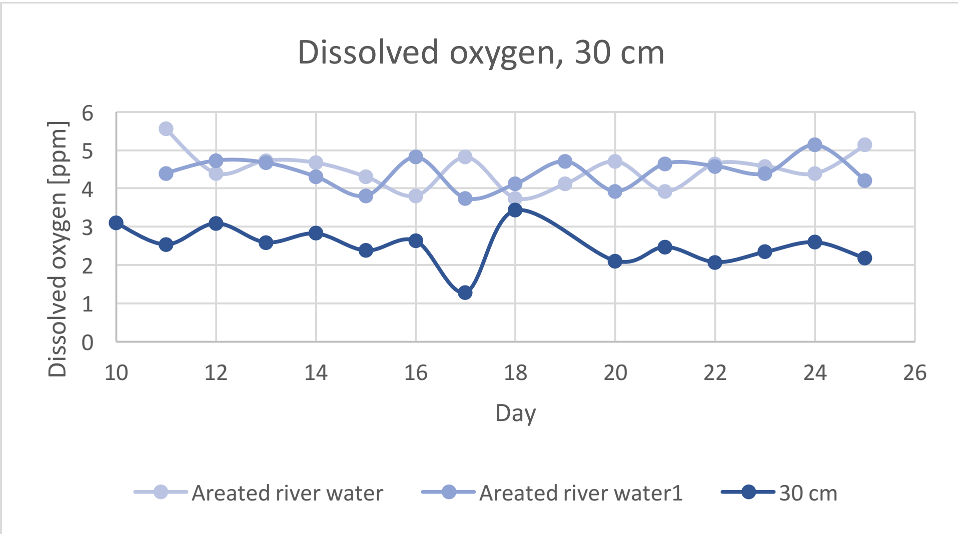


Figure 35. Dissolved oxygen in the river and 30-cm filter.

7.2.5 Suspended solids

The concentration of suspended solids in the effluent water from the 80-cm filter were more stable throughout the test period that the 50- and 30- cm filters, see figure 36. The concentration is low even in the beginning, except for day 5 where the concentration was higher.

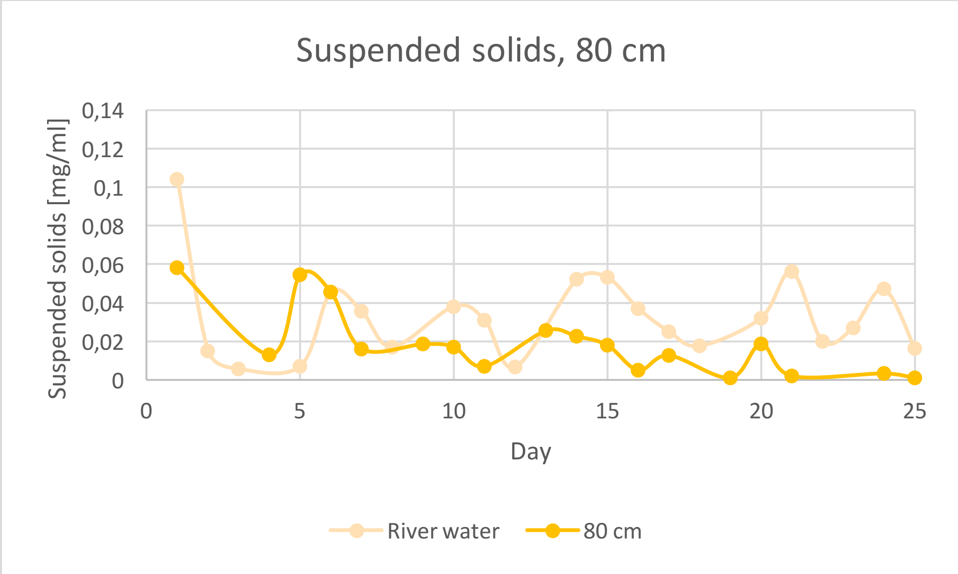


Figure 36. Suspended solids in the influent water from the river and effluent water from the 80- cm filter.

The concentration of suspended solids in effluent water of the 50- and 30-cm filters were higher and more unstable in the beginning of the test period than in the end, see figure 37 and 38. From day 5 and forward is the concentartion of suspended solids of the effluent water lower than the influent, except for the 50- cm filter at day 22.

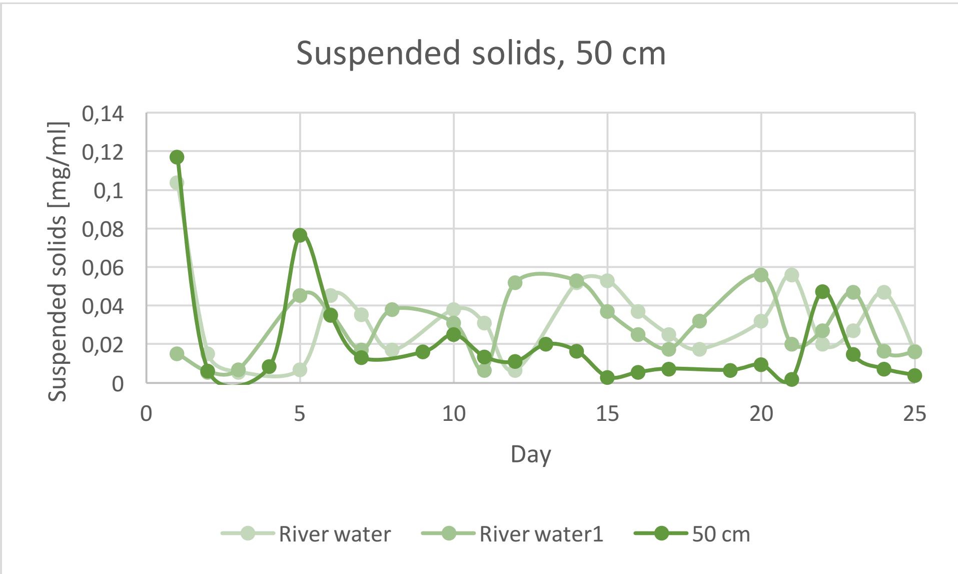


Figure 37. Suspended solids in the influent water from the river and effluent water from the 50- cm filter.

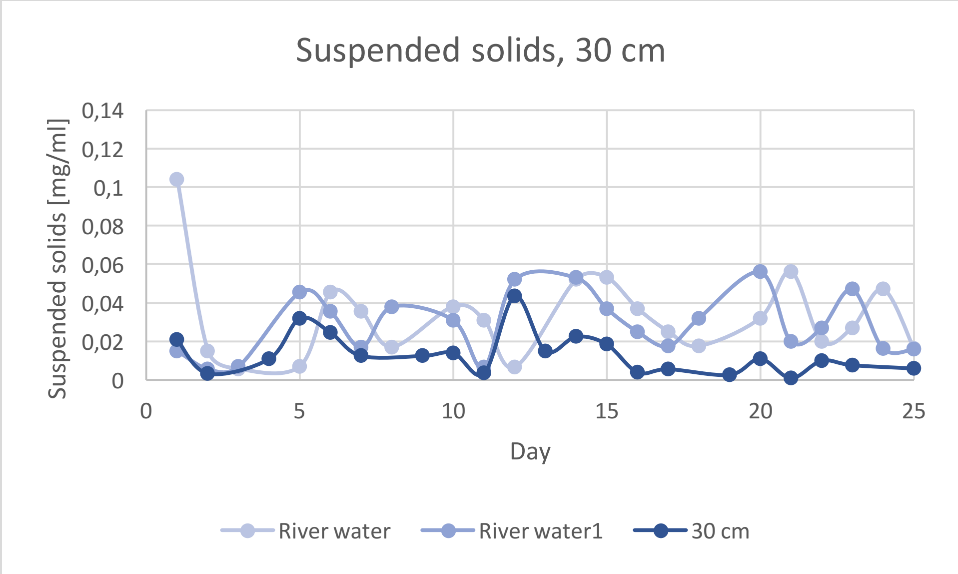


Figure 38. Suspended solids in the influent water from the river and effluent water from the 30- cm filter.

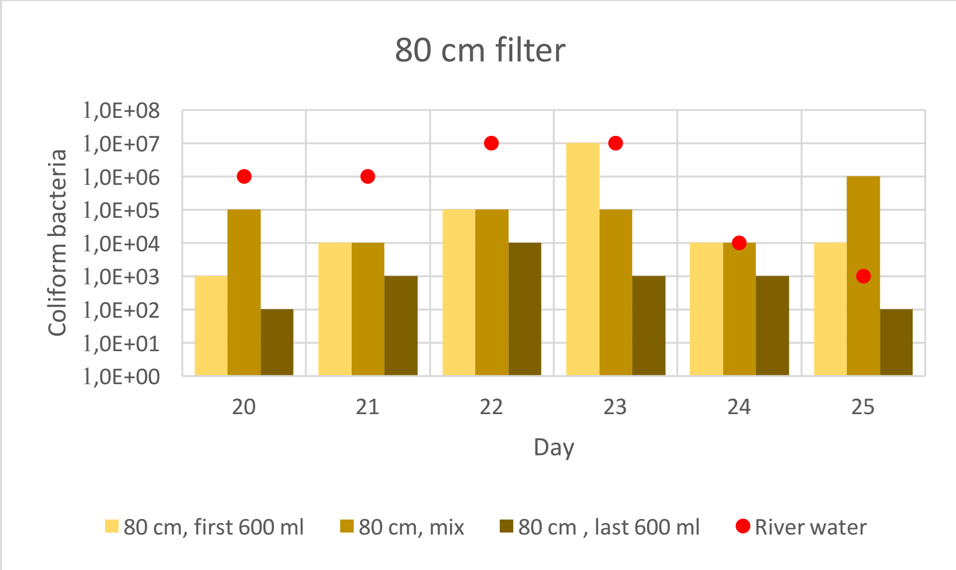
7.2.6 First 600 ml, mix and last 600 ml test

For the 30- and 50-cm filter, the first 600 ml of water out from the filter represent the water poured in the day before (river water, day 1), and the last 600 ml of water represent the water poured in the same day (river water, day 2).

7.2.6.1 Coliform bacteria

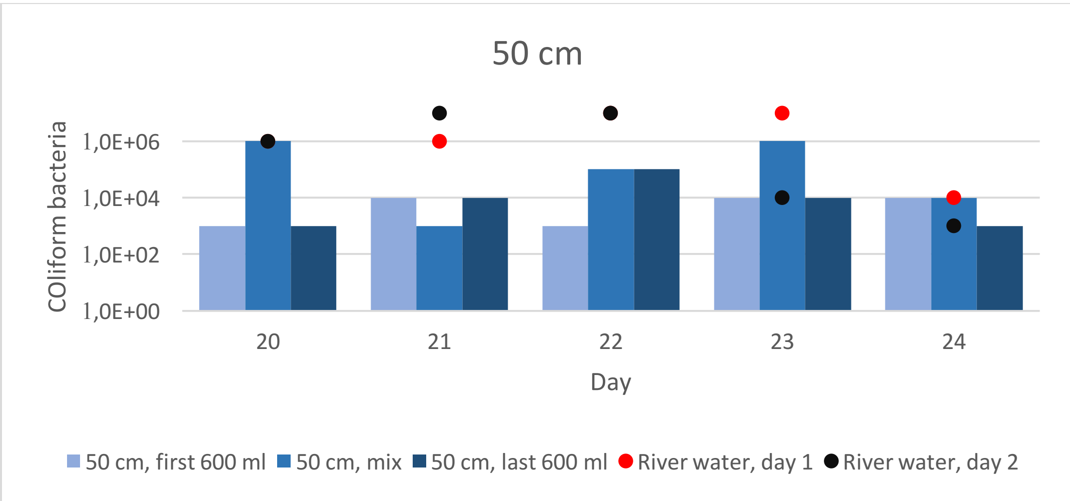
When test was made on the first 600 ml, last 600 ml and the rest, a change could be seen in total coliform bacteria content in all three filters.

In the 80-cm filter, the last 600 ml in the 80-cm filter had the lowest concentration of total coliform bacteria. The last 600 ml of water always had a lower concentration of total coliform bacteria than the influent water. The mixed water had the same or higher concentration than the first 600 ml, except at day 25 where the concentration total coliform bacteria in the mixed water was higher than the influent water. Overall, the mixed water did have the highest concentration of total coliform bacteria, see figure 39.



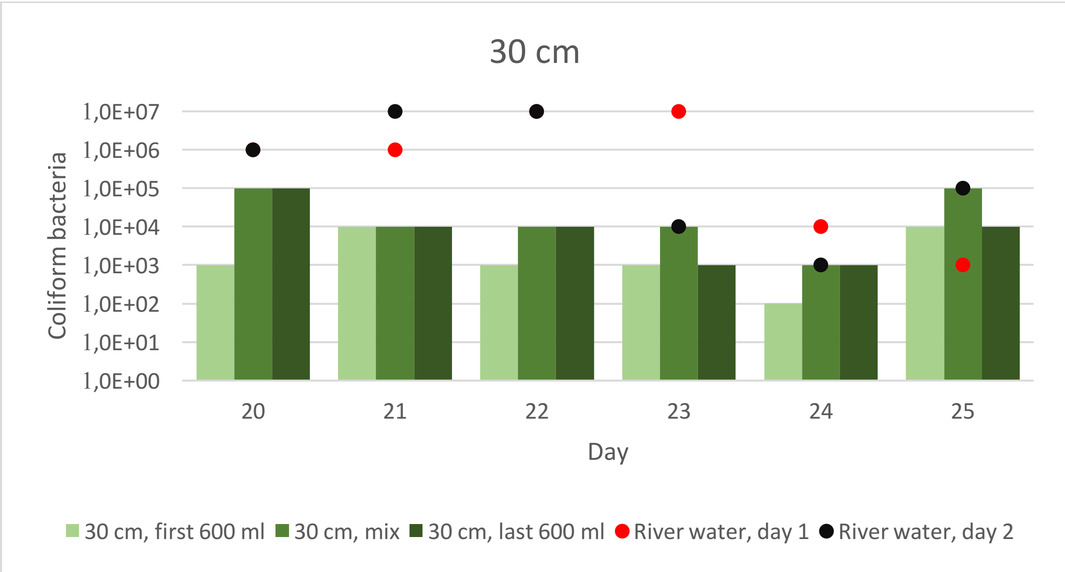
39. Total coliform bacteria content in the first and last 600 ml of water, and the mixed, out from the 80-cm filter.

The first and last 600 ml out of the 50-cm filter often had a lower concentration of total coliform bacteria than the mixed water, except day 21 where the mixed water had a lower concentration. The 50-cm filter did manage to reduce the total coliform bacteria content in the last 600 ml of water from day 20-22, see figure 40. But at day 23 and 24, the last 600 ml had the same concentration of bacteria as the influent water. The first 600 ml of water always had a lower concentration of total coliform bacteria than the influent water, except at day 24 where the concentration was the same. Overall did the mixed water have the highest concentration of total coliform bacteria, see figure 40.



40. Total coliform bacteria content in the first and last 600 ml of water, and the mixed, out from the 50-cm filter.

Result from the 30-cm filter showed that the lowest concentration of total coliform bacteria was found in the first 600 ml of the effluent water. The last 600 ml often had the same or lower concentration than the mixed water. The 40-cm filter did manage to reduce the total coliform bacteria content in the last 600 ml of water from day 20 to day 23 and day 25, see figure 41. But at day 24 was the concentration of the effluent water the same as the influent water. The effluent water did always have the same or lower concentration than the influent water, except day 25 where the concentration of the mixed water was higher than the influent water. Overall did the mixed water have the highest concentration of total coliform bacteria, see figure 41.

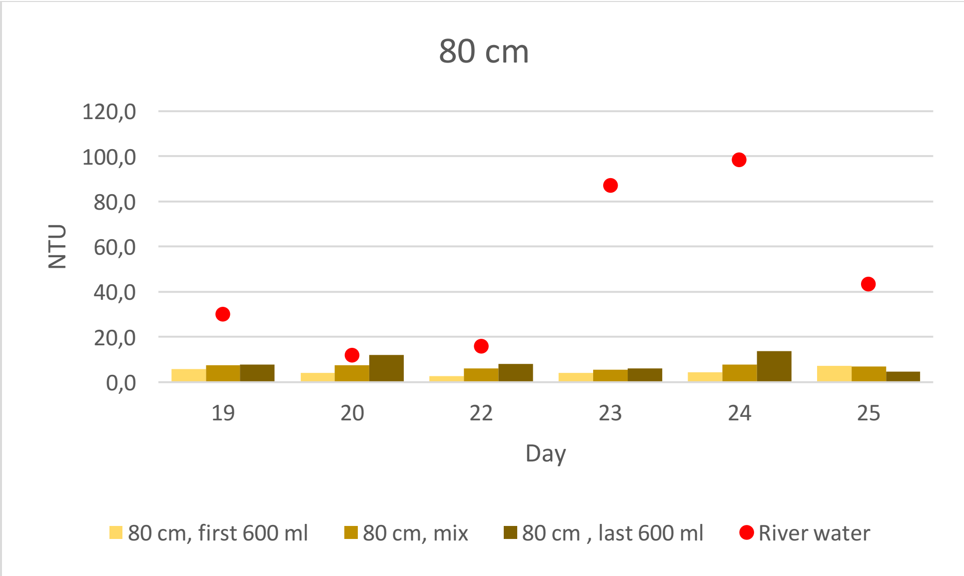


41. Total coliform bacteria content in the first and last 600 ml of water, and the mixed, out from the 30-cm filter.

7.2.6.2 Turbidity

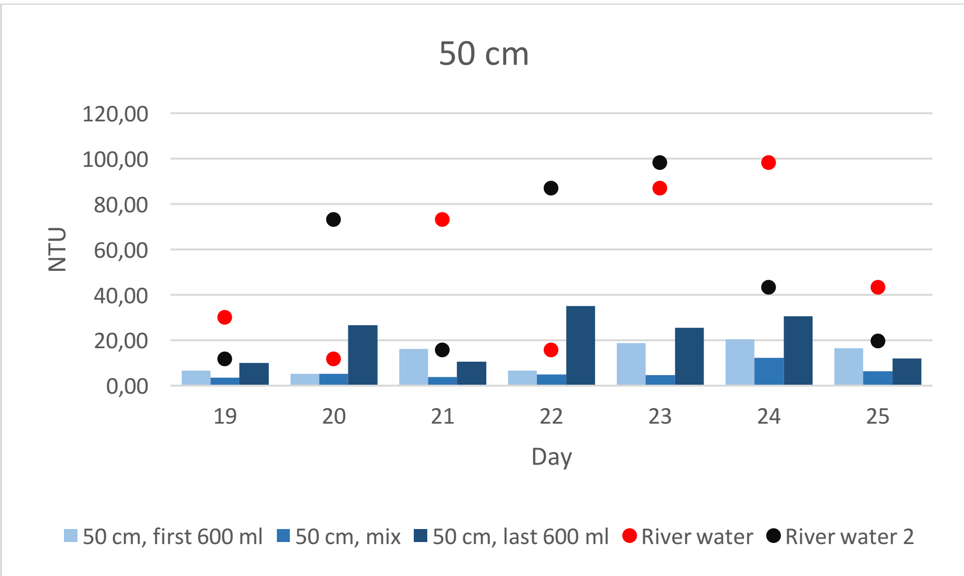
The turbidity level in the 80-cm filter was seen in the first 600 ml of water, except at day 25 where the level was higher than the other. Otherwise, the higher turbidity was found in the last 600 of water, see figure 42.

A trend could be seen in turbidity in the 80-cm filter. The turbidity level was lowest the first 600 ml and highest the last 600 ml of water. Except at day 25 where the turbidity decreased with the amount of water that had come out. The turbidity was always reduced in the 80-cm filter.



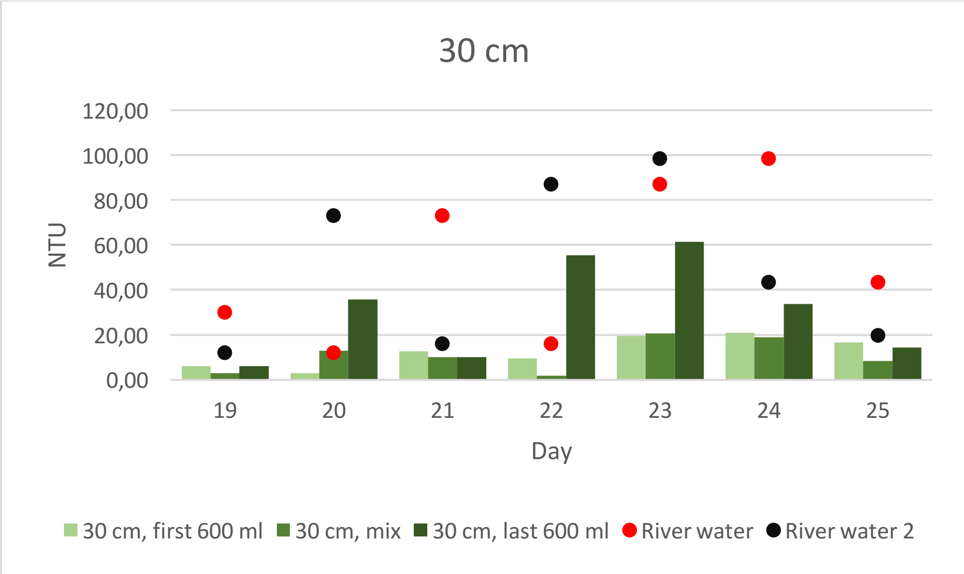
42. Turbidity level in the first and last 600 ml of water, and the mixed, out from the 80-cm filter.

The effluent water from the 50-cm filter is a water mix from two days. The effluent water's turbidity was always lower than the influent water. The first 600 ml of water represent the water that was poured in the day before and the last 600 ml represent the water that was poured in the same day. Even when the turbidity in the influent water was high, was the turbidity in the last 600 ml very low, see figure 43. In the 50-cm filter, the lowest concentration was found in the mixed water, see figure 43.



43. Turbidity level in the first and last 600 ml of water, and the mixed, out from the 50-cm filter.

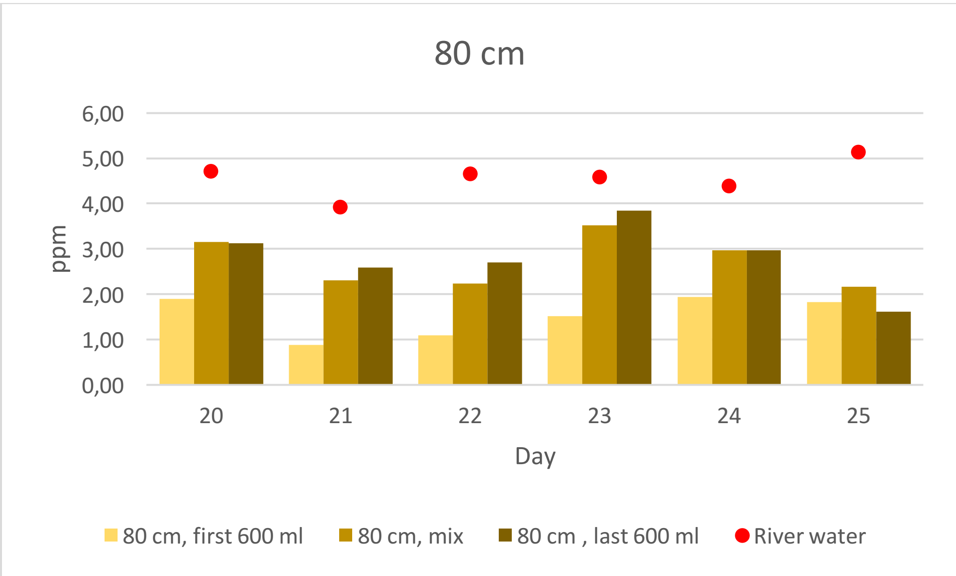
The turbidity in the last 600 ml of water was higher for the 30-cm filter than the 50-cm filter. The last 600 ml of water was always higher than the first batch, except at day 20 where the turbidity of the influent water was higher the day before. The lowest concentration in the 30-cm filter was seen in the mixed water, except day 20 and day 23 where the first 600 ml had the lowest turbidity, see figure 44.



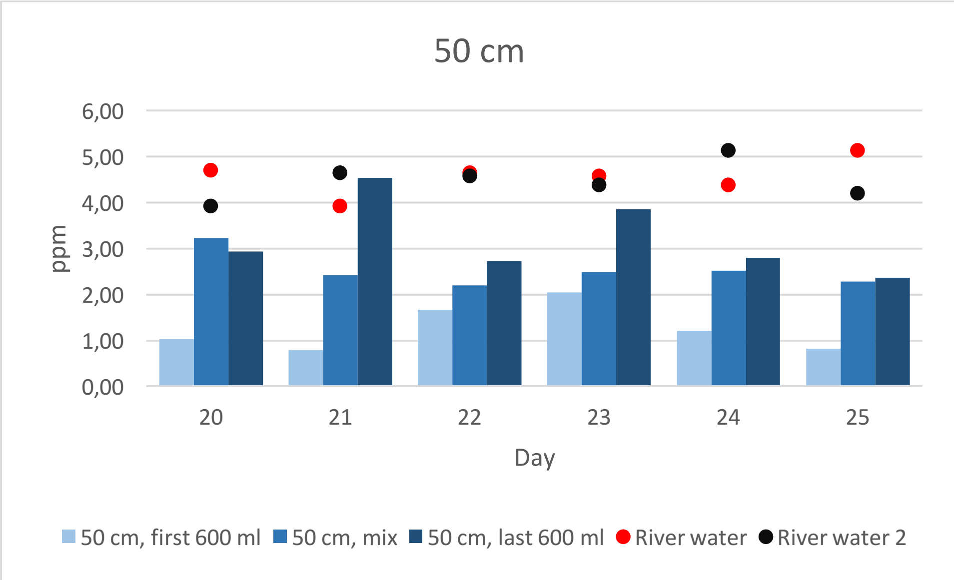
44. *Turbidity level in the first and last 600 ml of water, and the mixed, out from the 30-cm filter.*

7.2.6.3 Dissolved oxygen

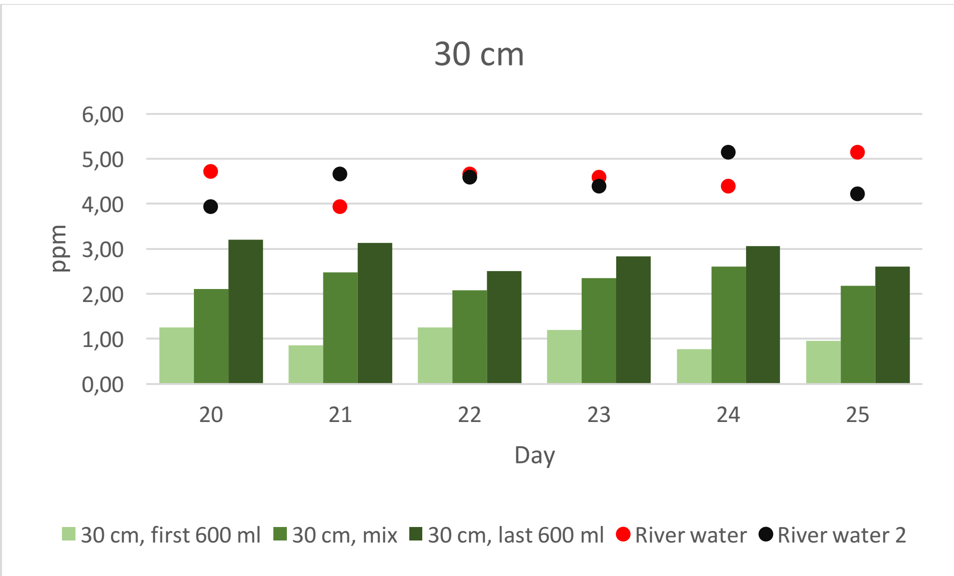
A common trend of dissolved oxygen could be seen in all three filters. The first 600 ml of water did always have a lower concentration of dissolved oxygen than the last 600 ml of water, see figure 45, 46 to 47. Except at day 25 for the 80-cm filter where the first and last 600 ml of water did have approximately the same dissolved oxygen level.



45. Dissolved oxygen concentration in the first and last 600 ml of water, and the mixed, out from the 80-cm filter.



46. Dissolved oxygen concentration in the first and last 600 ml of water, and the mixed, out from the 50-cm filter.

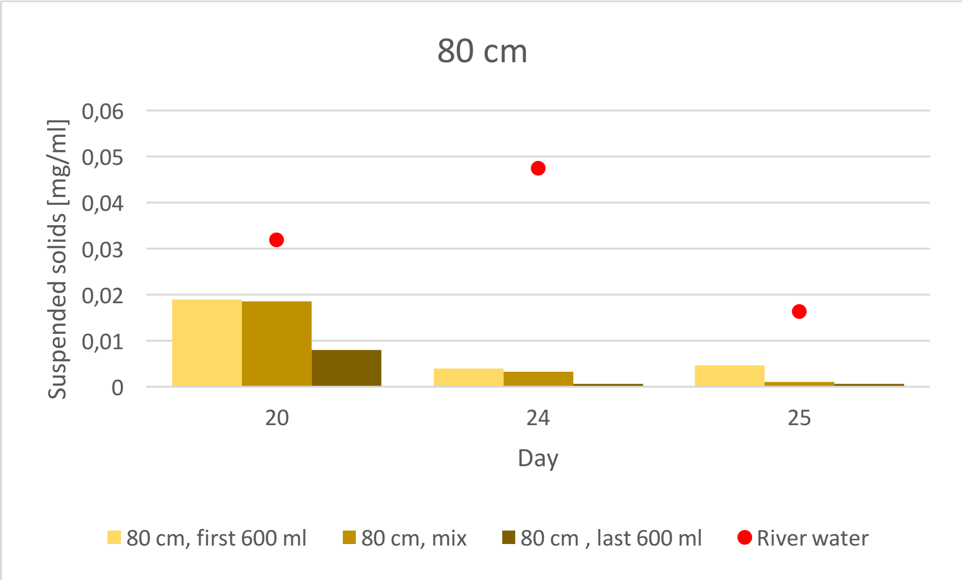


47. Dissolved oxygen concentration in the first and last 600 ml of water, and the mixed, out from the 30-cm filter.

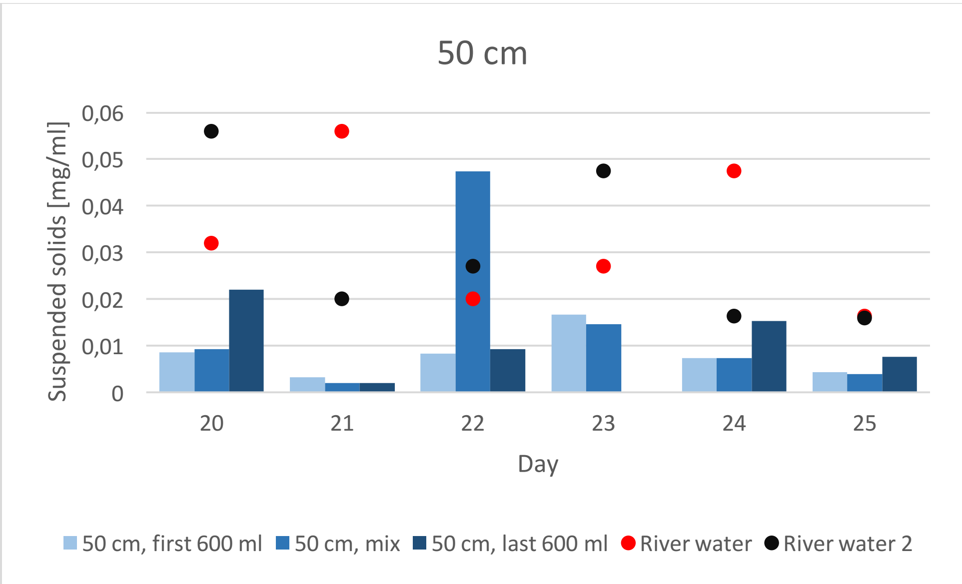
7.2.6.4 Suspended solids

In the 80-cm filter, the suspended solids were lowest in the last 600 ml and highest in the first 600 ml, see figure 48. The suspended solids decreased by the amount of water that had come out.

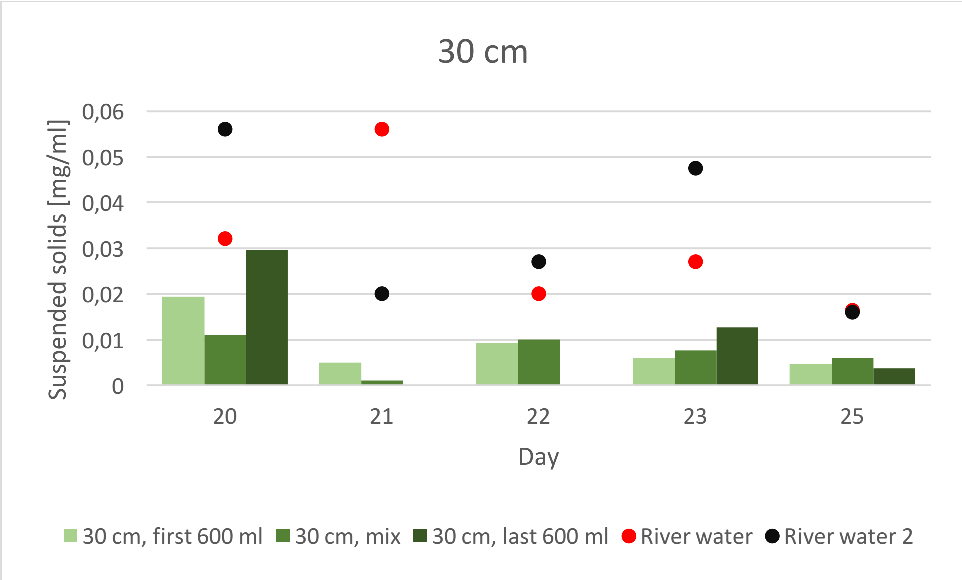
The overall concentration of suspended solids was always lower after filtration, see figure 48, 49 and 50. Except at day 22 for the 50-cm filter where the mixed water had a higher concentration than the influent water.



48. Concentration of suspended solids in the first and last 600 ml of water, and the mixed, out from the 30-cm filter.



49. Concentration of suspended solids in the first and last 600 ml of water, and the mixed, out from the 50-cm filter.



50. Concentration of suspended solids in the first and last 600 ml of water, and the mixed, out from the 30-cm filter.

7.2.7 Microbial analysis

A microbial test was made the 6th of April on the river water and on the first, mid and last effluent water from the 30-, 50- and 80 cm filters. Results showed more detected bacteria colonies in the effluent water from the filters than from the river. Detected bacteria colony in the river water was only Bacillus. In the biosand filters, a variety of bacteria colonies was found in the different batches. At the top, Bacillus was found in all three filters and E. coli in the 30- and 50 cm filter. In the middle, E-coli was seen in all three filters. But Bacillus was detected in the 50-cm filter and Staphylococcus in the 80-cm filter. At the bottom, Staphylococcus and E. coli was found in the 30-cm filter, E. coli in the 50-cm filter and Bacillus in the 80-cm filter.

7.2.8 Flow test

Binnie et al. (2002) recommended a flow rate of 0.1-0.4 $m^3/m^2/h$ and CAWST (2009) recommended a maximum flow rate of 0.4 m2/m2/h.

Mean flow rate values was calculated for the three filters, see table 10. The tests showed that the flow rate through the filter was high, or very high, compared to the recommendations. When the hydraulic head drops to 5 cm above the outlet for the 50- and 80-cm filters it reaches a flow rate around the recommendations, see table 10. The 30-cm filter, on the other hand, reaches a good flow rate when the hydraulic head is lower than 5 cm.

Table 10. Flow rate on the effluent water of the three filters.

	30 cm	**50 cm**	**80 cm**

Hydraulic head [m above the outlet]	Flow rate [$m^3/m^2/h$]	Flow rate [$m^3/m^2/h$]	Flow rate [$m^3/m^2/h$]
0.29	3.1	2.4	2.1
0.24	3.1	2.4	1.8
0.19	2.6	1.8	1.5
0.15	2.1	1.5	1.2
0.10	1.5	1.1	0.9
0.05	0.8	0.5	0.4
0	0.2	0.1	0.1

The last two days, the 7 liters of water was not poured in directly to the diffusor. A volume of 3 liters were first poured in, when 1 liter had came out 1 more liter was poured in and this continued till a total volume of 7 liter had been poured in the biosand filters. This was done in order to study if the total coliform bacteria content in the effluent water would decrease if the flow rate decreased.

The flow rate test showed that the ideal flow should be achived if the hydraulic head was a maximum of 5 cm for the 50- and 80-cm filters, and between 0-5 cm for the 30-cm filter. When the height is limited it means that the area have to change. The ideal flow rate would be achived if the area of the filters was changed.

7.2.9 Costs of a sand filter

Cost of the PVC pipe with a diameter of 6 inch had a cost of 6,25 GHS/feet. The 4-inch pipe could only be bought by 10 feet, which cost 20 GHS. A plumber man at KNUST would take 50 GHS to construct a sand filter.
The construction cost for each filter is presented in table 11.

Table 11. Cost of each constructed sand filter in Ghana.

	30 cm sand filter Cost [GHS]	**50 cm sand filter Cost [GHS]**	**80 cm sand filter Cost [GHS]**
PVC pipe (6 inch) [a]	25	31.25	37.5
Lid (6 inch)	30	30	30
PVC pipe (4 inch)	20	20	20
Lid (4 inch)	9	9	9
Glue	5	5	5
Sand	-	-	-
Gravel	-	-	-
PVC nipple	1	1	1
Hose	3	3	3
90°-bend/PVC fitting	1	1	1
Silicone	10	10	10
Teflon tape (10 meters)	1	1	1

Textile (1mm)	1.5	1.5	1.5
TOTAL COST [GHS]	*106.5*	*112.75*	*119*
TOTAL COST [SEK]	*213*	*225.5*	*238*
TOTAL COST [USD]	*24.495*	*25.9325*	*27.37*

[a] Observe that this was the biggest size easily available on the market.

7.3 The ideal biosand filter

Results from this study have shown that the 80-cm filter is the filter that have operated best compared to the 30- and 50-cm filter. The total coliform bacteria content in the 80-cm filter never decreased to a drinkable level according to the drinking water standards, but comparted to the other the bacteria content was low. The 80-cm filter maintained the turbidity level throughout the test period best compared to the other two filters. The turbidity was low even when the turbidity increased significantly. Therefore, is the 80-cm filter chosen to be redesigned to be the ideal biosand filter.

The ideal biosand filter is presented in figure 51 and would look as follows:
The desired flow rate of 0.4 m3/m2/h was achieved when the hydraulic head was 5 cm above the outlet. If 7.0 liter of water should have a hydraulic head of 5 cm, the filter body will have a minimum diameter of 42 cm. The filter body should be filled with 10 cm of gravel, 5 cm of separating gravel and 80 cm of filter sand. The outlet should be placed 5-cm above the sand bed to maintain a standing water level over the bed of sand to keep it wet. The diffusor should be designed as in this study, but a bigger version.

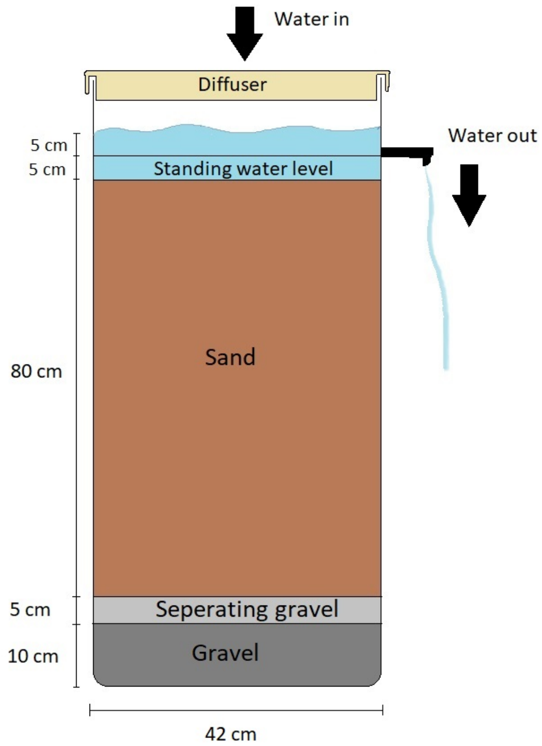


Figure 51. The dimensions of the ideal biosand filter.

A well operating biosand filter, where 7 liters of water is being purified each day, could replace a total amount of 5110 water sachets (500 ml) each year. The biosand filter is also a one-off cost. If 7 liters of water sachets should be purchased each day, the yearly cost would be about 1277 GHS, which is about 2554 SEK and 294 USD.

If the new design would give a volume of 7 liters, classified as satisfying drinkable water, it can replace 14 pcs 500 ml small water bags that each day. It would be a total amount of 5110 plastic bags each year.

8 Discussion

Flow rate tests

The flow rate tests in the small pipes in Sweden showed that the sand height did not have any significant impact on the flow rate when the sand height was over 30 cm, see figure 20. The flow rates were almost the same at each hydraulic head when the sand height was between 40 and 100 cm. The conclusion from these tests were that the sand height did not have a significant effect on the flow rate. Instead, it was the sand properties that was the limiting parameter. This conclusion was also proved true with a higher hydraulic pressure when a hose was connected. The flow rate was significantly higher when the sand height was 30 cm than the height was 50-, 80- and 100-cm at a water column of 15 cm, see figure 21. The flow rate was about the same for the sand height from 50 to 100 cm at a certain hydraulic head.

When a hose was connected to the small pipes in Sweden, a desired flow rate of 0.4 m3/m2/h was achieved when the water column was about 65 cm above the outlet when the sand height was 50 cm. Since the results showed that sand height between 50 and 100 cm had the same flow rate, a higher hydraulic head was not tested at a sand height of 80 cm. The pipes in Sweden were only 140 cm high, which limited the hydraulic head to 20 cm with a sand height of 100 cm.

When the small biosand filter was built in Sweden, if was filled with 80 cm of sand and 15 cm of gravel. Previous tests in the small tubes with a hose resulted in a good recommended flow rate of 0.4 $m^3/m^2/h$ when the hydraulic head was 65 cm and a sand height of 50 cm. Since the results showed that flow rate is independent of sand height, the same flow rate was excepted at a hydraulic head of 65 cm when the sand height was 80 cm. This proved to be wrong for the constructed biosand filter in Sweden. When the hydraulic head was 45 cm above the outlet, a flow rate of 2 $m^3/m^2/h$ was obtained, which was five times as high as the desired flow rate. The desired flow rate was achieved when the hydraulic head was 26 cm above the outlet. One theory to this may be that the pipes had previously been used to something else. Inside the pipes, a thin layer of oil could be seen, which might have caused the water to behave differently and decreased the flow rate.

Once in Ghana, the flow rate was significantly higher than expected. A desired flow rate was not achieved until the hydraulic head was about 5 cm above the outlet for the three biosand filters. The difference in flow rate between Sweden and Ghana may be due to the fact that the sand was not washed in Sweden and/or that the sand was washed too much in Ghana. According to CAWST (2009), the sand should be replaced by sand that has not been washed as many times. But due to lack of time, this was not possible.

On the other hand, the flow rate in the 30-cm filter were significantly higher than in the 50- and 80-cm filters, which also was shown form the test in Sweden. When the hydraulic head was 29 cm above the outlet in the constructed biosand filters in Ghana, the flow rate was about 2 m3/m2/h in the 50- and 80-cm filters while the 30-cm filter had a flow rate of about 3 m3/m2/h. This shows from the flow rates perspective; it is not worth having 80 cm of sand when the same flow rate can be achieved with 50 cm of sand.

Water properties in Ghana

The effluent water from the three filters could never produce water that would be approved by the WHO's drinking water standards or the National Swedish Food Agency's standards. No significant reduction of total coliform bacteria could be seen in any of the filters during the test period, which might be an indicator that it was a lack of biological activity in the filters. According to CAWST (2009), should it take about 30 days before the biofilm is fully developed if the conditions are right, but it is dependent on the water source. The river through KNUST might have been too contaminated for the constructed biosand filters. If a less contaminated water source would have been used, like rainwater that were used in Tanzania (Lindgren et al. 2016), it would be easier for the biosand filter to improve the waters quality.

The results of the total coliform bacteria content in the river varied surprisingly much during the test period. The total coliform bacteria content varied from 10^7 CFU/liter to 10^3 CFU/liter. Since the biosand filter operates best when the conditions are the same in the influent water, the big variations in total coliform bacteria might have been a reason to unstable content of total coliform bacteria in the effluent water. The developed biolayer in the sand becomes adapted to a certain amount of contamination in the influent water. If the influent water has different levels, or types of contamination, the biolayer may not be able to adapt to the conditions or consume all of the pathogens. The big changes in total coliform bacteria in the river may have prevented the biolayer's growth in the biosand filter since it has not been adapted to a certain level of contamination. A previous study in Tanzania, where the reduction of coliform bacteria was achieved, the coliform bacteria varied from 0 to 500 CFU/100 ml in the rainwater tank. Compared to the study in Tanzania, is the variation of total coliform bacteria in the river through KNUST much greater.

When water samples were collected the first and last 600 ml of effluent water, it was seen that the total coliform bacteria content was lower in the last 600 ml of water than the first batch in the 80-cm filter, see figure 39. Also, the last 600 ml of effluent water never had a higher content of total coliform bacteria than the influent water. This might be an indicator of an active biofilm at the top section of the biosand filter. The flow rate was also lowest in the end, which might have helped the total coliform bacteria to get stuck on the grain of filter media and not being flushed out by a high flow rate.

According to Huisman et al (1974), should the average concentration of dissolved oxygen never fall under 3 mg/l (0.003 mg/ml) to ensure aerobic conditions in the biosand filter. None of the three biosand filters had an average concentration lower than this value, which should be a sign of an aerobic environment. However, the effluent water had an odor of rotten egg throughout the test period and the hose was colored black in the 50- and 80-cm filter, it is a sign of production of hydrogen sulfide which can occur when it is an anaerobic environment. This might have been due to a too long pause period where the bacteria consumed all the oxygen. Even though hydrogen sulfide does not have a direct impact on human health at low concentrations, people will not prefer to drink it. The effluent water was pouring out from the filter in to a container. When the water was pouring out from the filter it is being exposed to the air, which increases the content of dissolved oxygen and can be a source of error in the measurements.

The microbial analysis on agar plates that was made on the influent and effluent water showed more detected bacteria in the effluent water than the influent water. Detected bacteria in the influent water was just Bacillus, while E. coli. was detected in the effluent water from all three sand filter and Staphylococcus from the 30- and 80-cm filter. This means that bacteria have been flushed out of the three biosand filters, which might be caused by the high flow rate.

The turbidity was generally low for all three filters thought out the test period, but the 80-cm filter had the lowest turbidity level. At one time, the turbidity increased from 10 NTU to about 345 NTU over a night because of heavily raining. An increased turbidity level in the effluent water could be seen that day in the 30- and 50-cm filters, see figure 31 and 32, but not in the 80-cm filter, see figure 30. The total volume of effluent water from the 80-cm filter had been in the filter for the whole pause period of 24 hours. While a part of the total volume of the effluent water from the 30- and 50-cm filter came out at the same time it was poured in. The turbidity results in the effluent water from the 80-cm filter compared to the 30- and 50-cm filter shows that the time when the water have been in contact with the sand bed is important, but also the sand height. Since the turbidity in the effluent water from the 80- cm filter than from the 30-and 50 cm filter, the same volume as the pore volume should be poured in so the total poured in volume stays in the filter throughout the pause period. During the pause period are transport mechanisms, like sedimentation and diffusion, operating. As well as the attachment- and purification mechanisms. If the contact time between the sand bed and the water are too short the water cannot improve its quality. Also, the 80-cm filter had a higher sand height and a greater sand surface area. When the sand height is high, the particles are more likely to get trapped between the sand grains. A greater sand surface area increases the mechanisms within the filter and the particles have a larger area to be attached to.

The high content of suspended solids in the effluent water from the 50- and 80-cm filter, in the beginning of the test period, might have been due to the fact that small particles had remained in place and some of them had not being flushed out after the sand were placed. Generally, the suspended solids in the water were reduced after filtration in all three biosand filters. But when the influent water had an increased concentration of suspended solids, a small increase in suspended solids in the effluent water could be seen.

The river sand was sieved with a fabric that had a pore diameter of about 1x1 mm to get sand particles smaller than 1 mm. The filtration sand was mostly comprised of sand sizes between 0.25-1 mm. Binnie et al. (2002) recommended a filtration sand size of about 0.2-0,4 mm, while CAWST (2009) recommended a sand size of about 0.7 mm. Which means that the sieved sand was approximately the recommended. But since the flow rate was greater than recommended, the sand size would have preferably been smaller. A smaller sand size would reduce the flow rate at the same time as the straining mechanisms would be improved.

Implementation of well operating biosand filters in Ghana for household use would reduce the production and consumption of water sachets. A biosand filter that produces 7 liters of water each day, can replace up to about 5100 water sachets each year. The reduced consumption of water sachets would reduce the plastic on the streets and in the sea, which would be a good way towards an environmentally good future. It would also be a lower yearly cost for the consumer if the water came from a biosand filter since it is a one-time cost.

I think that the main reason for the poor filtrated water results is mainly due to the high flow rate through the filters. As previously stated, a recommended flow rate of 0.4 $m^3/m^2/h$ was achieved when the hydraulic head were about 5 cm above the outlet for all three filters, see table 10. When the hydraulic head were about 30 cm above the outlet, the flow rate were around 3 $m^3/m^2/h$ for the 30-cm filter and about 2 $m^3/m^2/h$. According to Huisman et al. (1974) should the flow rate be around 5-15 $m^3/m^2/h$ for a rapid sand filter. The flow rate through the filters are not that high, but almost.

The new design of the filter is dimensioned for achieve a recommended flow rate. Therefore, are the diameter of the biosand filter greater than before, but it has the same heights of sand and gravel as the constructed 80-cm biosand filter in Ghana.

By the new design, a recommended flow rate should be achieved. But it should be kept in mind that the new design does not solve the lack of oxygen within the filter. The presence of oxygen is important to avoid anaerobic conditions which causes a rotten egg odor, but also for the development of the biofilm. A solution to the dissolved oxygen problem could be to have a continuous flow through the filter, but then the contact time between the water and the bed of sand will be reduced.

The operation of the biosand filter should be adjusted by the characteristics of the water. If the water source has a too high turbidity level, it might be in need of a pre-treating method. Or if the water source is too contaminated by bacteria, it might be in need of treatment after filtration. However, it is important that the cleanest available water source, with an even contamination level, should be poured in the biosand filter for the best operations. Also, if a biosand filter is being installed, it is important that regular tests take place to see if the water is drinkable so no one gets sick.

Further research

One suggestion for further work could be to construct the new presented design of the biosand filter, i.e. when the diameter is 39 cm and sand height 80 cm. The new design would have a maximum flow rate of 0.4 $m^3/m^2/h$ which is the recommended value according to CAWST (2009) which probably will result in that bacteria are not being flushed out. Further research could investigate if the new design could achieve a drinking water standard.

Further research could investigate the impact of water quality by shorter or longer pause period than 24 hours. According to Elliot et al. (2008), the pause period is one of the more important parameters since pathogens are consumed by the biofilm during this time.

It would be interesting to do an interview study to see if Ghanaian people would be interested in installing a biosand filter in their households. If they would be interested, how much are they ready to pay for it and how much maintenance would they be ready to put on the biosand filter?

9 Conclusions

This study has shown that the constructed biosand filters in Ghana did not improve water's quality to a low health risk. The constructed biosand filter had a too high hydraulic head which caused a higher flow rate through the filter than recommended. The high flow rate might be the reason to the bad results in total coliform bacteria in the effluent water, which is not suitable for drinking. The recommended flow rate was achieved when the hydraulic head was about 5 cm above the outlet. If 7 liters of water should be poured in a filter and have a hydraulic head of about 5 cm, the diameter should have been about 42 cm.

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