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MICROBIAL REGROWTH IN DRINKING WATER TREATED WITH GRAVITY-DRIVEN ULTRAFILTRATION

A Field Study in Kenya

Saga Perron

ABSTRACT

Microbial regrowth in drinking water treated with gravity-driven ultrafiltration, a field study in Kenya.

Saga Perron

Access to safe drinking water is a necessity for all human life and has been declared a human right by the United Nations. Yet for many people, access to safe drinking water is an every-day struggle and many people in the developing world routinely face water scarcity and contaminated water sources.

In recent years, efforts have been made to develop decentralized treatment methods of processing drinking water, targeting people in developing countries. At the Department of Water and Sanitation in Developing Countries (Sandec), at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), research is currently investigating the use of gravity-driven membranes (GDM) as an alternative treatment technique. Based on the operation of ultrafiltration membranes in a dead-end mode, with gravity as only driving force, the vision is to develop a small scale filtering unit to be implemented on household scale in low income countries. In 2010, a first filtering prototype was developed and in May 2011 field try-outs begun in targeted areas around Nairobi, Kenya.

This master thesis was carried out as a field study under the framework of the ongoing GDM-project carried out at Eawag. The objective was to investigate microbial regrowth, and potential factors linked with microbial regrowth, in the first filtering prototype. Technical performance was assessed by monitoring different indicator bacteria and biofilm formation was studied at critical locations within the prototype. On-site, measurements of common water quality parameters were made and general field observations were noted.

Results from the monitoring indicated a general trend towards regrowth in the clean water tank for all investigated bacteria except for *E. coli*. However, big difficulties were encountered when trying to distinguish regrowth from recontamination, which subsequently affected the interpretation of the results. Biofilm formation was detected at all investigated locations but no significant correlation could be linked to microbial regrowth. ANOVA tests indicated no significant difference between microbial regrowth and water source.

Field observations underlined the exposure of the tap as a weak point in the treatment process. Unsanitary conditions and lack of maintenance in some households were also linked to increased microbiological counts.

Keywords: Gravity-Driven Membrane filtration, Ultrafiltration, Microbial regrowth, Indicator bacteria, Eawag, Kenya

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REFERAT

Mikrobiell återväxt i dricksvatten framställt med gravitationsdrivna ultrafiltreringsmembran, en fältstudie i Kenya.

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Dricksvatten är en nödvändighet för allt mänskligt liv men är idag långt ifrån en självklarhet för alla. Trots att man 2010 förklarade tillgången till säkert dricksvatten en mänsklig rättighet tampas dagligen miljontals människor världen över med en bristande vattentillgång och förorenade vattenkällor. Framförallt utbrett är problemet i utvecklingsländer där dricksvattenkvaliteten ofta har en stark koppling till bristande sanitet.

På senare år har många satsningar gjorts på utvecklingen av decentraliserade vattenreningsmetoder för att förbättra livsvillkoren för fattiga människor. Vid Avdelningen för Vatten och Sanitet i Utvecklingsländer (Sandec) vid det Schweiziska Federala Institutet för Vatten och Teknik (Eawag) läggs för närvarande stort fokus på gravitationsdriven membranteknik som en alternativ lösning. Visionen är att utveckla en småskalig reningsanläggning för dricksvatten, anpassad till fattiga hushåll i låginkomstländer. År 2010 togs en första filterprototyp fram och från och med maj 2011 bedrivs en utvärderande fältstudie i områden runt Nairobi, Kenya.

Detta examensarbete genomfördes inom ramen för det pågående dricksvattenprojekt som drivs för gravitationsdrivna dricksvattenmembran vid Eawag. Arbetet genomfördes i form av en fältstudie med syfte att utvärdera mikrobiell återväxt, och potentiellt bidragande faktorer till återväxt, i den första framtagna filterprototypen. Teknisk prestanda undersöktes genom övervakning av indikatororganismer och potentiella samband med mikrobiell återväxt undersöktes för bildning av biofilm och råvattenkälla. Vid provtagning noterades även observationer av rådande förhållanden i fält och mätningar genomfördes för generella vattenkvalitetsparametrar.

Resultat påvisar en generell tendens till återväxt i det framställda dricksvattnet för alla indikatororganismer utom för *E.coli*. Dock uppkommer stora svårigheter i att urskilja återväxt från återkontaminering. Bildning av biofilm detekterades vid alla undersökta provpunkter men inget signifikant samband med återväxt kunde påvisas. ANOVA-tester fann heller inte något signifikant samband mellan återväxt och råvattenkälla. Observationer av rådande förhållanden i fält underströk exponeringen av kranen som en möjlig källa till återkontaminering. Bristande underhåll av filterprototypen ansågs också leda till högre detektioner av indikatororganismer.

Nyckelord: Gravitationsdriven membran teknik, ultrafiltrering, mikrobiell återväxt, indikatororganismer, Eawag, Kenya

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POPULÄRVETENSKAPLIG SAMMANFATTNING

Mikrobiell återväxt i dricksvatten framställt med gravitationsdrivna ultrafiltreringsmembran, en fältstudie i Kenya.

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Dricksvatten är en nödvändighet för allt mänskligt liv men är idag långt ifrån en självklarhet för alla. Trots att man 2010 förklarade tillgången till säkert dricksvatten en mänsklig rättighet tampas dagligen människor världen över med en bristande vattentillgång och förorenade vattenkällor. I nuläget uppskattas 884 miljoner människor på daglig basis sakna tillgång till säkert dricksvatten (WHO & UNICEF, 2010) och 1,8 miljoner människor årligen dö till följd av vatten-relaterade sjukdomar (WHO, 2007).

Framförallt utbrett är problemet i utvecklingsländer där dricksvattenkvaliteten ofta har en stark koppling till bristande sanitet. Detta leder till att arbetet med att förbättra dricksvatten-kvaliteten i många fall blir en komplex fråga, och parallellt behöver stor vikt läggas vid att förbättra sanitetsförhållandena.

År 2000 samlades FN:s medlemsländer kring ett antal mätbara millenniemål med syfte att förbättra livskvaliteten för världens fattiga. Ett av dessa rörde frågan om dricksvatten och man enades kring ett gemensamt mål om att halvera proportionen människor utan tillgång till rent vatten och grundläggande sanitet innan år 2015. Med tre år kvar ser det globalt sett ut som att målet med avseende på dricksvatten kommer att uppnås och stora förbättringar har skett framförallt i Asien och Latinamerika. För länder i Afrika söder om Sahara ser dock utvecklingen betydligt sämre ut och enligt Världshälsoorganisationen rapporteras att endast 60% av befolkningen har tillgång till en säker dricksvattenkälla.

Strävan efter att förbättra dricksvattenkvaliteten har lett till utvecklingen av många alternativa vattenreningsmetoder. På senare tid har många satsningar framförallt gjorts på småskaliga och decentraliserade lösningar för hemmabruk för att komma åt befolkningen på lands-bygden och befolkningen i stadsnära områden. Klorering, soldesinfektion och keramiska filter är några av de tekniker som idag marknadsförs och tillämpas.

En teknik som i detta sammanhang fortfarande är relativt outforskad, men som tros ha en stor potential, är membrantekniken. Konventionellt används membrantekniken idag som en extra barriär vid rening av både avlopp- och dricksvatten. Dock är den ofta förknippad med höga driftskostnader och hög energiförbrukning. Som ett resultat av senare tids effektiviseringar och ökade efterfrågan har dock tillverkningskostnaderna, och därmed priserna, för membran avsevärt minskat. Detta är något som det Schweiziska Federala Institutet för Vatten och Teknik (Eawag) tagit fasta på och forskning bedrivs just nu på användandet av membran som alternativ reningsmetod att tillämpa i utvecklinsländer.

Idén baseras på användandet av ultrafiltreringsmembran utan externa energikällor och utan desinfektion med kemikalier. Detta uppnås genom att låta vatten filtrera genom membranet enbart med hjälp av sin egen gravitationskraft. Vidare undviks desinfektion genom att låta

den påväxt som med tiden bildas på membranytan ligga kvar, då tidigare studier visat att flödet ej avstannar helt.

År 2010 togs en första filtreringsprototyp fram och från och med maj 2011 planerades en utvärdering av denna i fält. Filterenheter placerades ut i 25 olika hushåll i områden runt Nairobi, Kenya. Syftet med denna studie var att utvärdera mikrobiell återväxt, och potentiellt bidragande faktorer till återväxt, i prototypen. Teknisk prestanda undersöktes genom övervakning av olika indikatororganismer, och potentiella samband med mikrobiell återväxt undersöktes för bildning av biofilm och råvattenkälla. Utöver provtagning noterades även observationer av rådande förhållanden i fält och mätningar genomfördes för generella vattenkvalitetsparametrar.

Resultaten påvisar en generell tendens till återväxt i renvattentanken för alla indikator-organismer utom E coli. Dock uppkommer stora svårigheter att urskilja återväxt från åter-kontaminering. Bildning av biofilm observerades vid alla undersökta punkter men inget signifikant samband med återväxt kunde påvisas. Statistiska tester fann heller inte något signifikant samband mellan återväxt och råvattenkälla. Observationer av rådande förhåll-anden i fält underströk kranen som en möjlig källa för återkontaminering. Bristande underhåll och rådande sanitära förhållanden ansågs också vara en möjlig källa till högre halter av mikrober.

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ABBREVIATIONS AND DEFINITIONS

ANOVA Analysis of Variance

cfu Colony forming unit

CWT Clean water tank

DO Dissolved Oxygen

Eawag Swiss Federal Institute of Aquatic Science and Technology

EC *Escherichia coli* (*E. coli*)

ETC Enterococci

GDM Gravity – Driven Membrane

KWAHO Kenya Water for Health Organization

MT Membrane tank

Sandec Department of Water and Sanitation in Developing Countries

ST Storage tank

TC Total Coliforms

TVC Total Viable Counts

UNICEF United Nations Children's Fund

WHO World Health Organization

One – way ANOVA Statistical method used for comparison of means between different groups. The null hypothesis states that all samples are drawn from the same population.

Box-and-whisker diagram (Also called box plot). A Statistical technique used to graphically present a sample distribution. The distribution is depicted as a rectangular box indicating within what range the middle 50 % of the data lies (interquartile range). Whiskers are then extending from the box reaching out to the upper and lower 25% of the distribution. The median is depicted as a straight horizontal line through the box and can be viewed as an indication of the skewness of the sample distribution. Other values not touched by the box or whiskers counts as outlier values and are marked with an asterix.

Dead-End mode All feed water is pressed through the membrane, in contrast to cross-flow operation.

1 INTRODUCTION

Access to safe drinking water is a direct necessity for all human life and has been declared a human right by the United Nations. Yet for many people, access to safe drinking water is an everyday struggle and many people in the developing world routinely face water scarcity and contaminated water sources. At present, 884 million people regularly drink unhealthy and unsafe water (WHO & UNICEF, 2010) and 1.8 million people die every year as a consequence of water related diseases (WHO, 2007).

In the year of 2000, 193 UN member states and 23 international organizations agreed around eight measurable development goals to be reached before 2015. One of these goals concerned the matter of drinking water and a target was fixed around halving the proportion of people having no access to safe drinking water. Globally, with three years remaining, the outlooks are promising and four regions have already met this development goal: Northern Africa, Latin America and the Caribbean, Eastern Asia and South-Eastern Asia. Worse though are the outcomes for sub-Saharan Africa where the development has not significantly improved. Reports from WHO and UNICEF states that only 60% of the population in this region has access to a safe drinking water source (WHO & UNICEF, 2010). Nevertheless, it is important to remember that even with the development goals reached, 672 million people will still lack of safe drinking water.

In recent years, many efforts have been made to develop decentralized treatment methods of processing drinking water, targeting people in the developing world. In order to reach people in rural and peri-urban areas research has been emphasizing interventions of Household drinking water and safe storage (HWTS), enabling people to treat water in their own homes. Chlorination (Aquatabs), Solar disinfection (SODIS, Solvatten), and ceramic filters (Tulip water filter) are some of the interventions currently on the market.

At the Department of Water and Sanitation in Developing Countries (Sandec), at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), research is presently investigating the use of gravity-driven membranes (GDM) as an alternative treatment technique. The idea is based on the operation of ultrafiltration membranes with gravity as only driving force. This generates a cost-efficient and energy-independent system capable of treating viruses as well as bacteria. Additionally, in contrast to other techniques, turbidity is significantly reduced.

Underlying studies at Eawag have been carried out in close collaboration with the Department of Process Engineering and the Department of Environmental Microbiology and in 2010, a first filtering prototype was realized. With the purpose of investigating the prototype in its intended context, field try-outs begun in May 2011 when 25 filter units were deployed in different households in areas around Nairobi, Kenya. This Master thesis constitutes a part of this ongoing project.

1.1 OBJECTIVE

The objective of the study was to investigate microbial regrowth and potential factors linked to microbial regrowth in the first filtering prototype, when being used in field. Specific aims were developed in order to assess the technical performance and in order to gain insight of the different field conditions prevailing in the target areas.

Hypotheses:

- Regrowth of microorganisms occur in the clean water tank.
- The formation of biofilm in the permeate tube influences regrowth.
- Regrowth is more likely to occur when using surface water sources.

1.1.1Research questions

Following research questions were set up in order to attain the objective of the study:

- How does the filter prototype perform when being employed in the field regarding microbial regrowth?
- Which conditions are most crucial for enabling the microorganisms to regrow?
- Does the formation of biofilm have an impact on microbial regrowth?
- Are there some feed waters that are more conductive to regrowth than others?
- What are the weak points in the treatment process regarding microbial regrowth?

1.1.2 Limitations

The time span of the field study was limited to eight weeks and no calculations were based on flux values or user frequencies. No samples were taken directly from the clean water tank due to the risk of recontamination.

1.1.3 Thesis layout

Project background and concepts of Gravity Driven Membranes are presented in Chapter 2. The filter prototype and some of the underlying research are explained explicitly. Chapter 3 lists some basic concepts related to the study and should be considered as supplementary material. Methods are described in Chapter 4 and results are presented in Chapter 5. The discussion in Chapter 6 is followed by some concluded recommendations in Chapter 7. Lastly conclusions are listed in Chapter 8.

All collected data are attached in appendix.

2 PROJECT BACKGROUND

Sandec, the Department of Water and Sanitation in Developing Countries, is a part of the Swiss Federal Institute of Aquatic Science and Technology (Eawag) focusing on sustainable solutions in water supply and environmental sanitation. Its mandate is to assist developing countries in development and implementation of sustainable solutions adapted to the different physical and socio-economic conditions prevailing in the actual country. Research is emphasizing low-cost approaches and strategic environmental planning (Sandec, 2011).

In 2001, research at Sandec started to look into the possibility of treating water with gravity-driven membrane (GDM) techniques. The vision was to develop a decentralized system, independent of energy-supply and chemicals, capable of treating water on a household scale. Targeted populations were people in urban and peri-urban communities of the developing world.

Research resulted in the development of Gravity Driven Membrane Disinfection (GDMD) and the first filtering prototype was realized in 2010. In order to assess the behavior of the filter when being placed in the intended context, 25 filter units were deployed in areas around Nairobi, Kenya, for a try-out period of one year.

2.1 GDMD-TECHNIQUE

The concept of Gravity-Driven Membrane Disinfection (GDMD) is based on the idea of operating ultrafiltration-membranes (UF-membranes) in a dead end mode with gravity as only driving force (Figure 1). This implies that all water has to go through the ultrafiltration membrane since there is no other outlet. Through this practice, a high removal of bacteria and viruses can be obtained and the use of external energy sources can be avoided. Since the system is run with no back-washing, the formation of a fouling layer on the membrane surface is a subsequent result. As expected, an increased fouling layer decreases the flux through the membranes. However, underlying research has shown that flux values do not necessarily cease with time but stabilizes around a constant value (Peter-Varbanets et al., 2010). Furthermore it has been shown that a heterogeneous fouling layer containing high bacteriological activity and predation has a positive effect on the flux values through the membrane (Peter-Varbanets et al., 2010). Thus, in order to preserve activity in the fouling layer, no chemicals are used for disinfection.

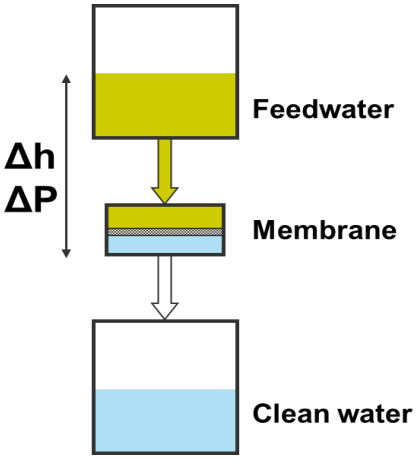

Figure 1 Basic outline of the GDM-Technique. Feed water is driven through the membrane by its own pressure.

2.1.1 Filter prototype

The first GDMD prototype consists of two water tanks on top of each other, one upper tank where the UF-membranes are placed and one lower tank for filtered clean water (Figure 2).

Optionally, a smaller tank with a sieving cloth can be placed on top of the unit to get rid of unwanted solids such as branches and sand. The clean water tank is dimensioned for a total volume of 10 liters whilst the membrane tank is dimensioned for 20 liters.

When operating the unit, feedwater is poured in to the membrane tank and driven through the membrane sheets by its own pressure. Water is then led to the clean water tank through a silicon tube connected to a permeate removal pipe (Figure 3), located at the center of the ultrafiltration membranes sheets (Figure 4). The central location of the permeate removal pipe keeps water levels in the membrane tank at a minimum volume of 10 liters, which keeps the membranes from drying out and the clean water tank from over flowing.

Figure 2 First GDMD prototype.

BIO-CEL® membrane sheets with a pore size of 40 nm are placed vertically inside the membrane tank (Figure 4). The sheets are manufactured by Microdyn-Nadir and are usually employed in membrane bioreactors for wastewater treatment. The total surface area obtained is 0.69 m^2 and the sheets consist of permanently hydrophilic polyethersulfon (PES), a heat-resistant engineered plastic.

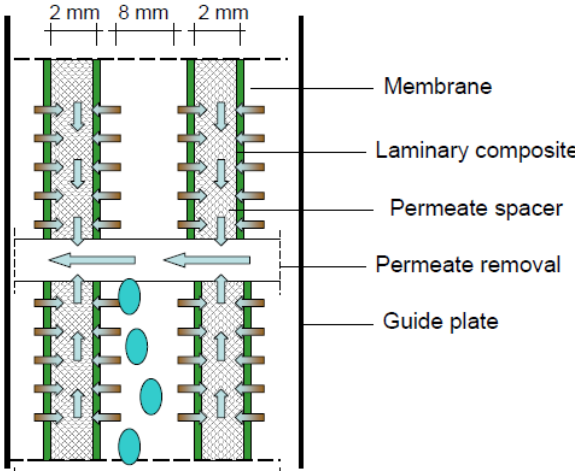

Figure 3 BIO-CEL® membrane and module.

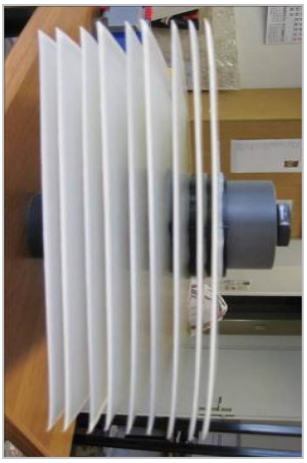

Figure 4 BIO-CEL® membrane sheets.

2.1.2 Operation and maintenance

The outline of the overall process from water source to clean water storage is described in Figure 5. Water is collected from a source in an arbitrary jerry can. It is then transported to the

household where it is stored or immediately poured into the filtering unit. Because of the small pore size of the ultrafiltration membranes, a wide variety of organisms hazardous to health can be removed. This implies that the prototype is capable of treating a large variety of water sources, surface waters as well as groundwaters.

Maintenance of the filter unit comprises regular cleaning of the tap in order to avoid recontamination. Also, a regular surveillance of the clean water tank is needed in order to avoid overflow.

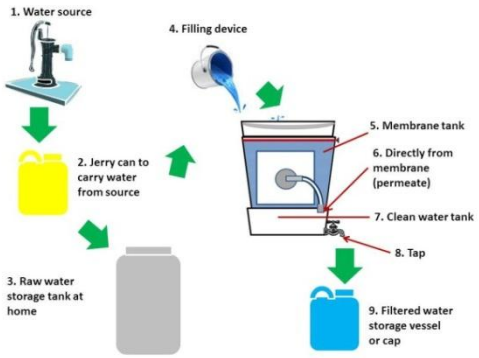

Figure 5 Operation of the GDM-prototype.

2.1.3 Lifespan and cost

The lifespan of a household filter is estimated to about 5 years and the production cost is calculated to 30 € (Sandec, 2011). Assuming an average filtering of about 10 liter/day and household, this corresponds to a price of 0.0016 €/liter.

In order to get around the high initial cost of the household filter, other financial options such as rental, leasing or possible extension of microcredit loans will be investigated (Sandec, 2011).

2.2 UNDERLYING STUDIES

Underlying studies at Sandec has been carried out in close collaboration with the Department of Process Engineering and the Department of Environmental Microbiology.

2.2.1 Stabilization of flux

Previous studies at Eawag have investigated the stabilization of flux through ultrafiltration membranes when using feed water of different organic loads. Membranes have been operated and studied without any flushing or cleaning. The example illustrated in Figure 6, depicts how flux stabilizations were observed for river water, lake water and diluted wastewater over a period of 30 days. The fluxes stabilized after approximately one week and were observed at stable levels for several months of operation (Peter-Varbanets et al., 2010). Resulting flux levels varied between 4-10 L/(hm^2). Additionally, deeper assessment of river water has indicated stable flux levels, independent of the transmembrane pressure, in the range 40-500 mbar (Figure 7). The latter corresponding to a pressure head between 0.4 – 5.0 m.

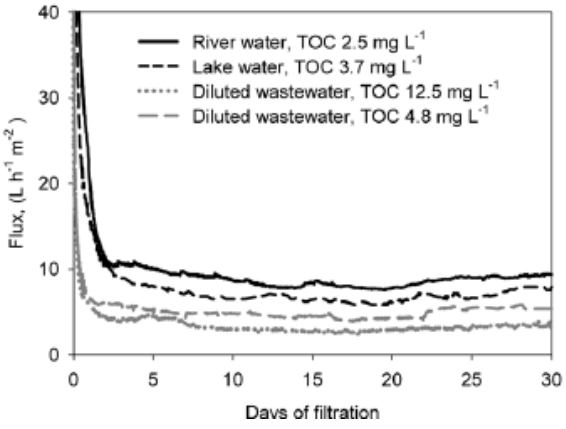

Figure 6 Stabilization of flux observed for a range of different feed waters (Peter-Varbanets et al., 2010).

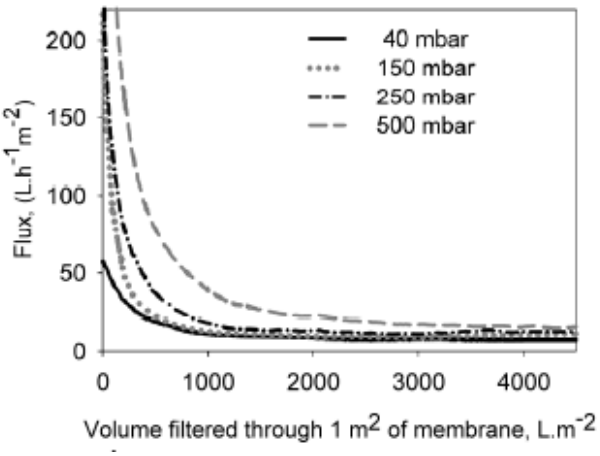

Figure 7 Membrane flux of riverwater using different pressure heads (Peter-Varbanets et al., 2010).

2.2.2 Fouling layer formation

Studies have also been carried out on formations of fouling layers on the surface of the membranes. It is concluded that structural changes due to high biological activity, in terms of cavities and channels, are increasing the flux levels (Figure 8).

In an attempt to study the formation in of the fouling layer in absence of biological activity, sodium azide was added to the water. This resulted in a homogenous fouling layer (Figure 9) followed by decreased flux values (Peter-Varbanets et al., 2010).

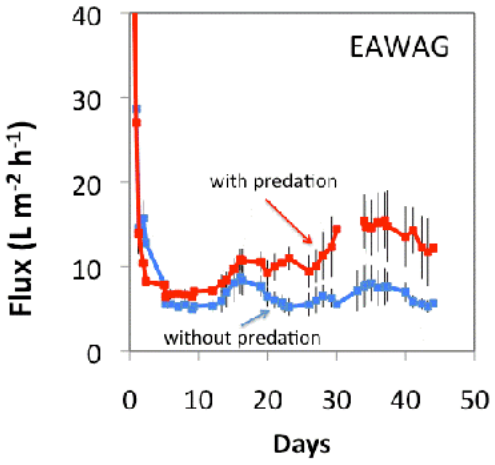

Figure 8 Increased flux levels due to high biological activity (Sandec, 2011).

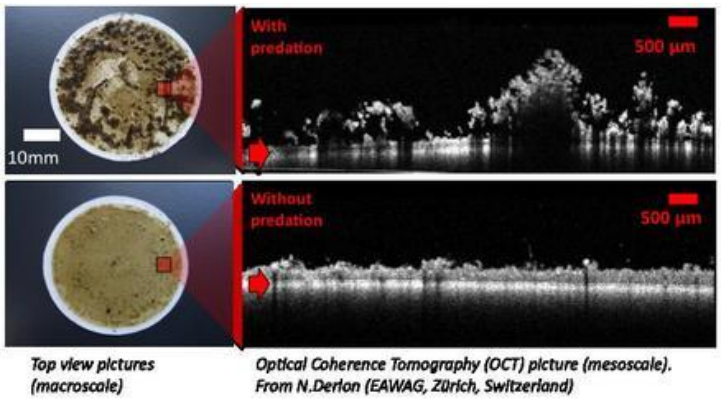

Figure 9 Heterogeneous fouling layer with a high biological activity (upper). Formation of homogenous biofilm after adding sodium azide (lower), (Sandec, 2011).

2.2.3 Running field studies

Field studies of the filtering prototype started in May 2011 and will be carried out for one year. Targeted areas lie in Nairobi, Kenya, and surrounding regions (Figure 10). Filter units have been deployed in 25 low-income households, representing different potential users. Both urban and rural areas are represented along with a range of different water sources. Field test are being conducted in partnership with Kenya Water for Health Organization.

Figure 10 Selected locations of field try-outs.

Target areas

Five filter units have been deployed in Thika, mainly using water from the passing-through river. Surroundings are dominated by plantations along the river valley.

Kajiado, as a rural masai region, comprises two subareas: Esokota and Oloosuyian. In total 15 filter units have been deployed. The environment is characterized by steppe and savannah and water sources constitute of dug ponds and shallow wells. A borehole is also being operated in Oloosuyian.

Filter units in Nairobi are installed in order to observe the behavior when using piped water.

3 THEORY

3.1 WATER QUALITY CHARACTERISTICS

This subchapter presents common monitoring parameters used when assessing drinking-water quality and treatment. Microbiological parameters, nutrients and general quality measurements are presented separately.

3.1.1 Microbiological parameters

One of the greatest microbiological risks linked with drinking water is associated with ingestion of fecal contaminated water. Presence of pathogenic bacteria, viruses and protozoa, derived from human or animal digestive systems, results in a wide range of water-borne diseases. Because of the large variety of pathogenic organisms, performing test for presence of each of these organisms would be both time consuming and expensive. Therefore microbial water testing is usually performed for a series of indicator bacteria, organisms known to behave in a similar way as the pathogens.

Criteria derived for the selection of fecal indicator bacteria postulates that the investigated bacteria itself should not be pathogenic. Furthermore, approved bacteria should:

- be universally present in feces of humans and animals in large numbers;
- not multiply in natural waters;
- persist in water in a similar manner as fecal pathogens;
- be present in higher numbers than fecal pathogens
- respond to treatment processes in a similar fashion as fecal pathogens;
- be readily detected by simple, inexpensive methods.

❖ Source: World Health Organization, 2011[1]

This concludes that indicator bacteria also should be able to give indications of treatment efficiencies and system integrities. However, considering different indicator bacteria for different purposes has been shown to be an advantage (WHO, 2011)

The most common indicator bacteria are derived from two bacteria groups, coliforms and fecal streptococci (EPA, 2012). Below follows a description of three common indicator bacteria used in drinking water treatment.

Escherichia Coli (E. coli)

E. coli is a single species in the fecal coliform group and is specifically bound to fecal material from humans and warm-blooded animals (EPA, 2012). Since their presence in feces are found at

[1] World Health Organization, cited in *Guidelines for Drinking Water Quality*, 2011, p. 148

high rates, the concept of using *E. coli* as indication of fecal pollution has become a well-established method when monitoring drinking water quality (WHO, 2011). The United States Environmental Protection Agency also recommends *E. coli* as the best indicator of health risks in water treatment.

However, recent studies of waterborne disease outbreaks have shown that assumptions made uniquely on absence or presence of *E. coli* might, in some cases, be insufficient (WHO, 2011). The major drawback lies in the fact that some pathogens, mostly derived from enteric viruses and protozoa, tend to show more resistant properties to disinfection and other stress factors than *E. coli*.

Total Coliform bacteria

Unlike *E .coli*, Total Coliforms consists of a group of bacteria. They occur in human or animal feces but are also naturally found in the environment, where they are likely to be detected in soil and vegetation (EPA, 2012). Since this group of bacteria is not uniquely bound to fecal contamination, their use as indicator organisms for pathogens is somehow deficient. Anyhow, detection of coliforms is still considered as a standard test in drinking water treatment since their presence indicates contamination by an outside source (EPA, 2012). Another common application is in the assessment of integrity and cleanliness of i.e. a distribution system or when trying to indicate biofilm formations (WHO, 2011).

Enterococci

Enterococci are a subgroup within the fecal streptococcus group and can be distinguished by their ability to grow in saline waters (EPA, 2012). High detections are more human-specific then other organisms within the same bacterial group. The indicator value is useful since Enterococci are more resistant to external stress factors than *E. coli*.

3.1.2 Nutrients

Nitrate and Nitrite

Nitrate (NO_3^-) and nitrite (NO_2^-) substitute two different compounds of the nitrogen cycle and originates from two different steps in the nitrification process of ammonia. Both can be found naturally in the environment depending on the prevailing conditions.

Nitrate in surface and groundwater is normally found as a consequence of agricultural activities and excess application of fertilizers (WHO, 2011), but it can also be found through oxidation of nitrogenous waste products from human and animal feces (WHO, 2011). In surface waters, nitrogen concentrations are typically very low (less than 1 mg/l), but concentrations are likely to vary rapidly due to the direct exposure to runoff from vegetation. Groundwater concentrations do not show the same fluctuations.

Nitrite is found in reducing environments where oxygen levels are not sufficient enough for bacteria to form nitrate.

As high contents of nitrate and nitrite can cause Blue Baby syndrome (methaemoglobinaemia in bottle-fed infants), guideline values for nitrate and nitrite contents in drinking water has been set up by the World Health Organization. These comprise 11 mg/l for nitrate-N and 0.9 mg/l for nitrite-N. Since there is a possibility of simultaneous occurrence of these components, the summarized ratio of each parameter to its guideline value should not exceed 1.

Orthophosphate

Orthophosphate, sometimes referred to as reactive phosphorus, is the most stable kind of in-organic phosphates fond in aquatic systems. In natural environments orthophosphates are quickly taken up and "stored" by plants and animals leaving low concentrations left in natural waters. High levels of dissolved phosphates can be an indication of pollution or environmental stress

3.1.3 General quality measurements

Dissolved oxygen

Dissolved oxygen (DO) is related to biological activity and chemical processes in the water, and is usually measured in mg/l. Levels of DO are reduced by high temperature and salinity. Furthermore, when more oxygen is consumed by organisms than what is produced, DO levels decline and aerobic organisms die off (EPA, 2012). Warm water holds less DO than cold water.

Turbidity

Turbidity is the main concern when it comes to physical parameters and is basically a measure of how water clarity is affected by finely divided and suspended solids in water. The solids are typically generated from clay particles, plankton, silt and sand. Measuring unit is Nephleometric Turbidity Units (NTU).

Turbidity primarily affects the color of water but can also increase temperatures as the suspended particles are capable of absorbing heat. This in turn can result in lower concentration of dissolved oxygen (DO) since warm water is not able to hold as much DO as cold water (EPA, 2012). Furthermore, high turbidity can have a suppressing effect on photosynthesis since the amount of light entering the water is reduced.

A high turbidity is not directly linked to severe health impacts. However, high turbid waters can indicate pollution and possible spreading of pathogens, since pathogens can be shielded by clay particles and escape eventual disinfectant treatments (EPA, 2001). More commonly, high turbidity affects the acceptability of water to consumers (EPA, 2001).

pH

By definition, pH is a term used for measuring the logarithmic concentration of hydrogen ions. The pH scale is derived from the ionization constant of water and ranges from 0-14 where a low

value indicates acid water and a high value indicates alkaline water. Most waters ranges between 6.5-8.0 but variations are likely to occur throughout the year (EPA, 2001).

pH values mainly effect biological activity and chemical processes. A low pH value reduces biological diversity since most organisms are customized to the earlier described range of 6.5-8.0. Moreover, low pH values can also increase the concentrations of toxic elements in the water since the solubility of certain chemical compounds are affected (EPA, 2012)

Electric conductivity

Electric conductivity is a measure of a materials ability to express an electric current. In water treatment, measurements in electric conductivity are equivalent to measurements in ionic content. The basic measuring unit is expressed in micro Siemens/cm (µS/cm).

Measuring the electric conductivity is important through different perspectives. Through a chemical perspective, the ionic content can determine how a specific substance is likely to appear. Through a biologically perspective, the electric conductivity can be an indication of the range of organisms thriving in the water (EPA, 2001). Measuring electric conductivity can also give an indication of alkalinity and water hardness.

3.2 ULTRAFILTRATION

Ultrafiltration is a membrane based separation process commonly used in industry and research for purification and concentration of macromolecular solutions. The technology is based on the physical fact that larger particles are prohibited to pass through due to the smaller pore size. From a technical aspect there is no fundamental difference between ultrafiltration, microfiltration and nanofiltration other than the operating pore size (Figure 11).

Most ultrafiltration membranes are built up by polysulfone and cellulose acetate but there exists a large variety of materials designed for different areas of commercial use. Most customary, ultrafiltration membranes are categorized by membrane "cut-off". This corresponds to the weight of the smallest molecule retained by the membrane and is measured in atomic mass units (Daltons) (HOH Vattenteknik AB, 2004).

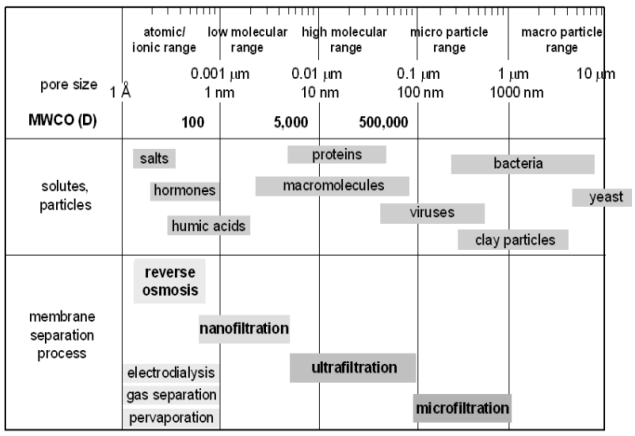

Figure 11 Different filtration techniques vs. pore size (Peter-Varbanets, 2010).

Operation of ultrafiltration membranes can be executed either in dead-end mode or in cross-flow mode. In conventional drinking water treatment or when treating water with low turbidity, dead-end mode is pre-ferable since it requires less pumping energy. One of the biggest issues when applying ultrafiltration is the fouling layer formation. This is normally avoided by regular backwashing or flushing.

4 METHODS

Microbial regrowth in the GDM-filter prototype was investigated in two separate ways. Primarily, water quality characteristics throughout the filtering process were assessed by monitoring of different filter units having been deployed in field. Secondarily, experiments were set up in a laboratory studying the microbial behavior of the filter prototype under controlled conditions. Resulting data and general observations from the field then served as information to identify main factors linked to microbial regrowth.

The field study and laboratory experiments were conducted from October 24 to December 19 2011. Measurements and sampling in field were carried out in collaboration with Kenya Water for Health Organization (KWAHO) who already were monitoring the deployed filter units on a monthly basis. KWAHO also helped organizing transport of water for the laboratory experiments.

All samples were collected and analyzed within 48 hours in the project laboratory. Resulting data was statistically evaluated and plotted.

4.1 MONITORING OF FILTERS IN FIELD

Based on previous measurements and field experience from Eawag and KWAHO, 6 out of 25 deployed filter units were chosen for closer monitoring (Table 1). Aspects such as water source, location and detection of previous microbial regrowth were considered when targeting these filters. Monitoring took place at four different occasions for each unit with at least one week in between.

Table 1 Monitored filter units in the study.

Monitoring	Area	Filter unit	Main water source
Field study	Oloosuyian	KJP 01	Borehole
Field study	Oloosuyian	KJP 07	Pond
Field study	Esokota	KJE 12	Pond
Field study	Esokota	KJE 14	Shallow well
Field study	Thika	THR 24	River
Field study	Thika	THR 25	River/Rainwater

In order to study microbial and nutrient flow patterns, water samples were collected at different locations throughout the filtering process and on-site measurements were made for general water quality parameters. Additionally, the formation of biofilm was studied at critical locations within the filter prototype. All investigated parameters in the field monitoring are described in Table 2

and further details are found in the preceding theory chapter. Microbial samples are measured in colony forming units (cfu).

Table 2 Investigated parameters in field monitoring.

Sample/measurement	Targeted parameter	Unit
Water sample (microbial)	*E. coli* (EC)	cfu / 100 ml
	Total coliforms (TC)	cfu / 100 ml
	Enterococci (ETC)	cfu / 100 ml
	Total Viable Counts (TVC)	cfu / 1 ml
Water sample (nutrient)	Ammonium, NH_4^+	mg/l NH_4^+
	Nitrite, NO_2^-	mg/l $NO_2^- - N$
	Nitrate, NO_3^-	mg/l $NO_3^- - N$
	Orthophosphate, PO_4^{3-}	mg/l PO_4^{3-}
Biofilm sample	*E. coli* / 1 ml	cfu / 1 ml
	Total coliforms / 1 ml	cfu / 1 ml
	Total Viable Counts / 1 ml	cfu / 1 ml
On-site measurement	Turbidity	NTU
	Electric conductivity	µS/cm
	Dissolved oxygen (DO)	mg/l
	Adenosine triphosphate (ATP)	RLU[2]
	pH	

4.1.1Water sampling and measurements

Due to the different ways of transporting and handling both treated and untreated water within the different households, six common sampling locations were agreed upon in order to be able to compare the resulting data in a feasible way (Table 3). No samples were taken from the clean water tank due to the risk of recontamination.

Water samples for analysis were collected in 50 ml Greiner tubes and 100 ml Whirl-pak bags. During monitoring, all samples were stored in a cooling box before being taken back to the lab. When monitoring filters in Esokota and Oloosuyian, samples were temporary stored in a refrigerator over night. Duplicates and blanks were taken repeatedly to guarantee the quality of the sampling work.

[2] Relative Luminescence Units

Measurements on-site were made for general water quality parameters such as turbidity, electric conductivity and dissolved oxygen. Moreover, measurements were made for microbial activity by measuring of ATP. No on-site measurements were made in the household cup.

Table 3 Targeted locations for water sampling.

Location	Description
Water source (WS)	Water from a river, well, pond or borehole.
Storage tank (ST)	Tank used for storage of the collected water (before using filter unit).
Membrane tank (MT)	Tank where the ultrafiltration membrane is placed.
Permeate	The water coming out directly after the membrane.
Tap	Water coming directly from the tap.
Household cup	Water from a random, cleaned cup in the household.

4.1.2 Biofilm sampling

Biofilm samples were taken with ATP swabs (Appendix G) at five different locations within the filter prototype (Table 4). Both expected points such as the ultrafiltration membrane and critical points such as inside the tap were investigated.

Table 4 Targeted locations for biofilm sampling.

Location	Description
Membrane tank wall	Sample from a wall in the membrane tank.
Membrane	Sample directly from the membrane.
Permeate tube	Sample from the inside of the permeate tube.
Clean water tank wall	Sample from a wall in the clean water tank.
Tap surface	Sample from inside the tap.

4.1.3 Field observations

In order to relate prevailing field conditions to the resulting data, general field observations were made from each household. Factors such as maintenance, handling and spatial placement were particularly of interest. Used water source since last monitoring was noted and pictures were taken of the membrane tank.

4.2 CONTROL STUDY

Four filter units where assembled and set up in the project laboratory in order to observe microbial behavior when minimalizing the risk of recontamination. Water was collected and transported from a water source in the nearby area. Filling of filters, water sampling and measurements were carried out at six different occasions. All investigated parameters are reported in Table 5.

Table 5 Investigated parameters in controlled study.

Flow pattern	Targeted parameter	Unit
Microbial	*E. coli*	cfu / 100 ml
	Total Coliforms	cfu / 100 ml
	Total Viable Counts	cfu / 1 ml
	Adenosine triphosphate (ATP)	ATP / RLU

4.2.1 Experimental set-up

Filter units were assembled, numbered (Figure 12), and grouped in pairs of two with Filter 1 and 2 using a different raw water load than Filter 3 and 4. In order to investigate the potential impact of sun light two different designs were used for the membrane tank within each set-up pair. One non-transparent design and one transparent design (Figure 12).

Figure 12 Assembled filter units in the control study.

In order to find a raw water source with high biological activity water sources in the nearby area were analyzed for COD and indicator bacteria. Eventually a ditch located close to the KWAHO office was selected.

4.2.2 Preparations and actions taken to prevent recontamination

Before executing the experiment the pre-impregnated glycerol on the membranes in the filter units was removed by rinsing with several fillings of tap water. The tap water was poured in intermittently during a period of five days which resulted in a total flushing of 112 liters for each filter unit. In a last step, all filter units were filled with a solution of fine particle clay (kaolin) in order to examine the integrity of the membranes. Turbidity was then measured before and after the membrane tank. Finally the clean water tanks were all disinfected with bleach.

To prevent microbial recontamination following actions were taken:

- A plastic shield was put around the membrane and clean water tanks to avoid recontamination from spillage. The plastic shield was also covering the tap.
- The clean water tanks were well sealed with tape and were then never opened.

- The filtering unit and the surrounding area were continuously kept clean by dusting and disinfecting.
- The clean water tanks were always emptied before the new fillings in order to avoid overflow of the unit.

4.2.3 Water sampling and measurements

Sampling locations in the experiment were similar to those in the field study with the exception of sampling from the bucket (Table 6). ATP measurements were made at each of the sampling locations.

Table 6 Targeted locations for biofilm sampling.

Location	Description
Bucket	Bucket with collected water from the source.
Membrane tank	Tank where the ultrafiltration membrane is placed.
Permeate	The water coming out directly after the membrane.
Tap	Water coming directly from the tap.

4.3 ANALYSES

Analyses of water and biofilm samples took place in a project laboratory previously set up by Eawag. Collected samples were analyzed within 48h of the sampling and in the meantime stored in a refrigerator. Information on analyzing equipment is found in Appendix G.

4.3.1 Microbiological analysis

Microbial analyses were made with Compact Dry plates, a ready-to-use plating method designed to grow and pigment different kinds of microbial colonies. Different Compact Dry plates and incubation times were used to detect different indicator bacteria (Table 7).

For each sampled location, both unfiltered 1 ml samples and filtered 100 ml samples were plated onto the Compact dry plates. Duplicates and field blanks were plated in a similar way.

Table 7 Incubation times and temperatures for investigated indicator bacteria.

Indicator Bacteria	Type of plate	Incubation temperature	Incubation time (h)	Color
E. coli	Compact Dry EC	35	24	blue
Total Coliform	Compact Dry EC	35	24	purple
Enterococci	Compact Dry ETC	35	24	blue
Total Viable Counts	Compact Dry TC	35	48	red

Filtering of the 100 ml samples was made through sterile membranes with a volumetric colonial flask. When plating the samples the Compact Dry plates were activated with 1ml of unfiltered water where-after the resulting filtered membrane were placed upon the plate.

When plating the unfiltered 1 ml samples, water was pipetted directly on to the plates without activation water.

4.3.2 Nutrient analyses

Nutrient analyses were conducted using a HACH photometer 2800-1. Analyzing methods and measuring ranges for each parameter are described in table 8.

Table 8 Nutrient analysis and methods.

Parameter	Method	Measuring range
Nitrate	Cadmium reduction method	0.01 - 0.5 mg/l
Nitrite	USEPA Deazotization	0.002 - 0.30 mg/l
Orthophosphate	USEPA Phosver 3 (ascorbic acid) method	0.02 - 2.5 mg/l
Ammonium	LCK 304	0.015 – 2.0 mg/l

4.3.3 General parameters

Measurements of electric conductivity, dissolved oxygen and pH were made with a Hach multi-meter. Each electrode was calibrated regularly. Turbidity was measured with a turbidimeter, calibrated before each field excursion, and ATP was measured with a Lumitester and LuciPac Pens (Appendix G).

4.3.4 Biofilm formation

The pre-set sample volume of 1 ml from the ATP swabs were plated directly on to Compact Dry plates for EC and TC respectively (Table 7). For the Compact Dry TC, samples taken from the walls of the membrane tank and from the membrane were diluted 1:10 with bottled mineral water (Maisha, pure drinking water) to get more accurate results.

4.3.5 Statistical analysis

Statistical analysis and plotting was carried out with Excel 2010 and Minitab 15 Statistical Software.

When assessing microbial samples the lower detection limit was considered as < 1 colony forming units (cfu). Thus, when calculating the log reduction values and performing ANOVA-tests, samples not detecting any colony forming units were set to 0.5.

Results from the nutrient analysis were set to the lower respectively upper detection limits when obtaining values out of range.

5 RESULTS

Results from the field monitoring showed that 79% of *E. coli* and none of Enterococci samples met the recommended WHO guideline values regarding fecal coliforms in drinking water. At permeate level 33% of samples detected *E. coli* and 56% detected Enterococci, both indicating integrity deficiencies in the filter prototype. Regrowth of microorganisms was indicated for Enterococci and Total Coliforms but factors of recontamination were likely to have affected the results.

Assessment of factors linked to regrowth could only give indications of possible correlations. No statistical relationships could be established.

In order to relate resulting data to prevailing field conditions, observations from the field are presented separately before presenting the results from the monitoring. Collected data can be found in appendix A-C and E.

5.1 FIELD OBSERVATIONS

Field observations regarding maintenance, handling and spatial placement were noted and written down at each monitoring occasion. Pictures were taken of the membrane tank and water samples were taken from a random cleaned cup in the household. All monitored filter units are listed in Table 1, Chapter 4.

5.1.1 General field observations

Collection of source water was made with 10 - 20 L jerry cans (Figure 13 and Figure 14), most of them stored for a period of time in the households with or without a lid. In most households several jerry cans were used in parallel, thus sampling of the same storage tank was not always consistent.

Figure 13 Stationary storage tank used for borehole water in Oloosuyian (blue storage tank in the middle).

Figure 14 Storage tank used for river water in Thika.

Due to the wide range of water sources used, big differences could be seen between the fouling layer formations on the surface of the membranes. Filter units using surface water were generally characterized by a thicker fouling layer than filter units using groundwater. This was particularly highlighted when comparing the river-using filter THR 24 (Figure 17) to the borehole-using filter KJP 01 (Figure 26). Yet, a sufficient flow rate was obtained from all filter units and all units were regularly in use.

As a result of a period with shorter rains during mid-November, some households occasionally started to use rainwater instead of their regular water source. Rain-water was then collected from iron sheets placed on the roofs and thereby led into a storage tank.

Figure 15 Mud house in Oloosuyian.

Roughly, two main types of house constructions could be distinguished in the targeted areas. One construction based on the use of metal sheets and one construction based on a mix of mud and cow dung (Figure 15). Livestock was frequently seen walking in and out of the houses and cooking often took place in close connection to the filter unit.

5.1.2 Filter specific observations

THR 24 (Thika)

Filter unit THR 24 was placed in the common room right next to the entrance. When monitoring the filter, presence of bugs was recognizable between the membrane tank and the clean water tank. Bugs were also seen on the parts of the ultrafiltration membrane not submerged in water. A thick redish fouling layer was covering the whole membrane (Figure 17).

Figure 16 Monitored household THR 24 in Thika.

Figure 17 Filter unit THR 24.

THR 25 (Thika)

Filter unit THR 25 was placed in a dark storage room of a house built of metal sheets (Figure18). Rainwater was used on the second and third monitoring but appeared to have been used more frequently when looking at the formation of the fouling layer on the membrane (Figure 19). The unit was generally kept clean and no insects were present when monitoring.

Figure 18 Filter placement of THR 25.

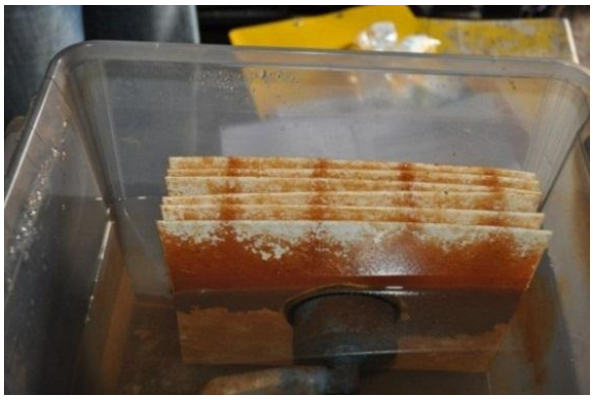

Figure 19 Resulting fouling layer when altering river and rainwater.

KJE 14 (Esokota)

KJE 14 in Esokota had a protected shallow well as main water source. The well depth was estimated to about 10 m and iron was suspected to precipitate from the pumping device. The filter unit was placed inside a mud house and rainwater had been used at two occasions. Generally, many bugs were seen on the filter unit and many particles had been accumulating inside the membrane tank.

Figure 20 Filter unit KJE 14 placed on a shelf in a mud house (Manjiatta).

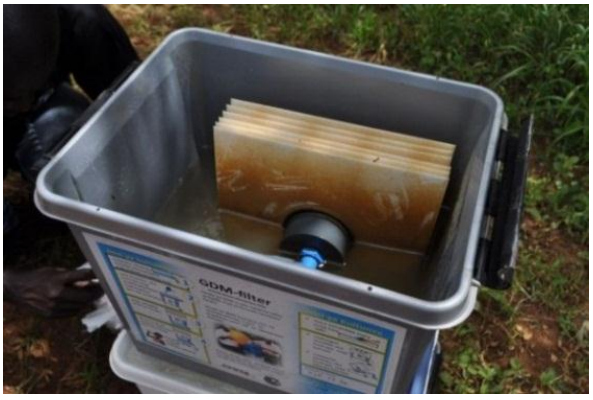

Figure 21 Indication of a red fouling layer on the ultrafiltration membrane.

KJE 12 (Esokota)

KJE 12, pond-using filter in Esokota, was placed in the cooking area of an iron house (Figure22). The filter unit was generally very dirty and had previously had suspicious problems with hypoxia. No sign of hypoxia was noted during the field visits. Rainwater was used at one occasion during the monitoring period and the fouling layer covering the ultrafiltration membrane was thick and grey colored (Figure 23).

Figure 22 Placement of filter unit KJE 12.

Figure 23 Greyish fouling layer on KJE 12.

KJP 07 (Oloosuyian)

KJP 07 was placed in a mud house and used pond water as principal water source. Occasionally the pond dried out (Figure 24) and borehole water was used instead. During the monitoring period, this happened at one occasion. The fouling layer on the membrane was thick and grey colored (Figure 25).

Figure 24 Dried-out pond in Oloosuyian in the beginning of November.

Figure 25 Coating on the ultrafiltration membrane resulting from the use of pond water.

KJP 01 (Oloosuyian)

Oloosuyian filter KJP 01, as the only filter unit using borehole water, showed little sign of coating on the ultrafiltration membrane (Figure 26). The filter unit was placed in the corner of a common room and was kept exceptionally clean at all monitoring occasions. Due to an unpaid electrical bill from the community, the operated borehole was closed during the last monitoring. Water was then bought from the owner of a private borehole in the same region.

Figure 26 Filter unit using borehole water in Oloosuyian.

5.1.3 Measurements in household cups

Measurements of indicator bacteria in household cups showed that Total Coliforms were present at higher rates in THR 24, KJE 14, KJE 12 and KJP 07 (Table 9), all mud houses. Generally, Enterococci showed a higher presence than *E. coli*. Recontamination was indicated in all household cups except for Enterococci in THR 25 and KJP 01 (Table 10).

Table 9 Average detections of indicator bacteria made in a random household cup.

Filter unit	Main water source	EC [cfu/100 ml]	TC [cfu/100 ml]	ETC [cfu/100 ml]	TVC [cfu/100 ml]
THR 24	River	10	16809	604	6000
THR 25	River	50	262	35	6467
KJE 14	Well	51	16544	450	30800
KJE 12	Pond	136	6603	33	40000
KJP 07	Pond	2	2800	11	10300
KJP 01	Borehole	3	9	5	6533

Table 10 Average LRV between tap and household cup.

Filter unit	Main water source	EC	TC	ETC	TVC
THR 24	River	-1.05	-1.46	-1.28	-0.22
THR 25	River	-0.65	-1.23	0.60	-0.08
KJE 14	Well	-0.35	-1.16	-2.70	-0.01
KJE 12	Pond	-1.35	-0.86	-1.52	0.42
KJP 07	Pond	-0.36	-0.52	-0.09	-0.11
KJP 01	Borehole	-0.42	-0.50	1.30	-0.12

5.2 MONITORING OF WATER QUALITY CHARACTERISTICS

Microbial processes and nutrient fluctuations were assessed by analyzing water samples collected at the different locations described in Table 2. Resulting data are reported in Appendix A and B along with results of general water quality measurements from the field in Appendix C.

Box-and-whisker diagrams were drawn up for *E. coli*, Enterococci and Total Coliforms in order to depict the overall distributions resulting from the different sampling locations. Individual value plots were used when further assessing the distributions. The upper line at log 4.6 in the box-and-whisker diagrams is representing the detection limit of the analyzing method.

In the figures, results from the water source, membrane tank and storage tank are referred to as: WS, ST and MT. Moreover, all sampling locations are connected by a logarithmic mean value.

5.2.1 Microbial water quality

Microbial water quality was measured for *E. coli*, Total Coliforms and Enterococci, further described in Chapter 3. Additionally, bacterial content and biological activity were measured by monitoring Total Viable Counts and ATP, both HyServe methods and further described in Appendix E.

When investigating microbial processes and bacterial content, average log reduction values (LRV) were calculated between each sampled location. These are referred to as LRV:s and are reported in Appendix D. The LRV over the ultrafiltration membrane corresponds to the difference in detections between the membrane tank and the permeate. Regrowth is assessed as the LRV between the permeate and the tap, since no samples were taken directly from the clean water tank. A positive LRV indicates that microbial counts were lower at the second sampling point; a negative LRV indicates an increase. This value should only be considered as an indication of regrowth.

E. coli

A wide distribution of *E. coli* was detected in the sampled water sources (Figure 27), reflecting the large variety of sources used in the different target areas. Surface waters generally showed higher contents of *E. coli* than groundwater (Figure 28). The pond in Oloosuyian (Figure 28d) showed lower detection of *E. coli* than other surface waters.

An increase of *E. coli* was detected in storage tanks when source water had low levels of contamination. This applied for the two households using groundwater and the household using pond water in Oloosuyian (Figure 28b, c, d).

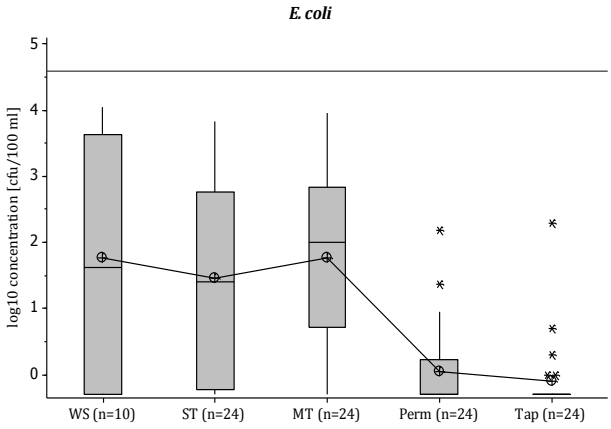

Figure 27 Distribution of detected *E. coli* at different sampling locations.

The average LRV over the ultrafiltration membrane was 1.7, which corresponds to an average *E. coli* reduction of 98%. This should be considered as a minimum value due to upper and lower detection limits of raw and filtered water. Higher LRV were obtained in filters using surface waters. Eight samples out of 24 detected *E. coli* in the permeate, with a maximum of 153 cfu/100 mL (Appendix A, Figure 27).

Regrowth of *E. coli* in the clean water tank was indicated in THR 24, KJE 12, KJE 14 and KJP07 (Appendix A). At tap level 79 % of the samples met the WHO guideline value of no detect-able *E. coli* in a 100 mL sample for drinking water.

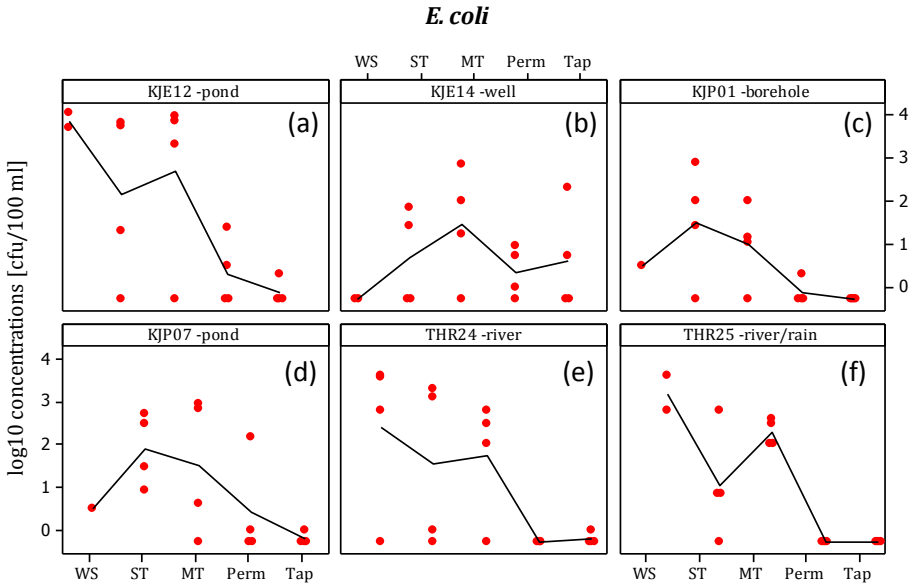

Figure 28 Individual value plots for *E. coli* in monitored filter units.

Total Coliforms

Due to limitations in the analyzing method, upper limit truncation affected the sample distributions of Total Coliforms originating from the water source, storage tank and membrane tank (Figure 29). Still a wide distribution of Total Coliforms could be seen throughout the whole filtering process.

Similar to *E. coli*, increased detection occurred in the storage tank whenever a less contaminated water source had been used (Figure 30b, c, d).

The average LRV obtained over the ultrafiltration membrane was 2.5, corresponding to a reduction of 99.7 %. However, presence of

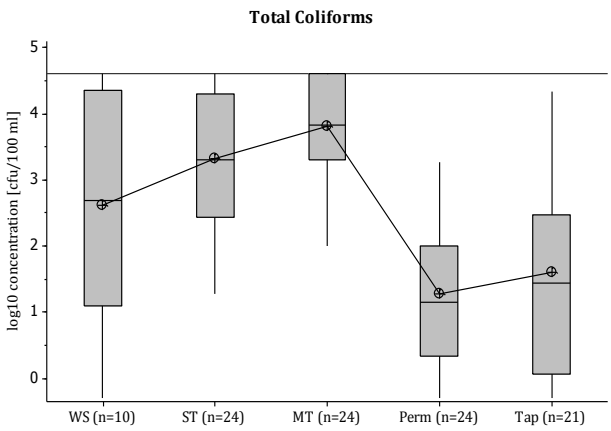

Figure 29 Distribution of detected Total Coliforms at different sampling locations.

Total Coliforms in the permeate were still detected in 23 out of 24 sampling (Appendix A). Similarly, 23 samples out of 24 also detected Total Coliforms from the tap. Regrowth was indicated at least once in every filter unit.

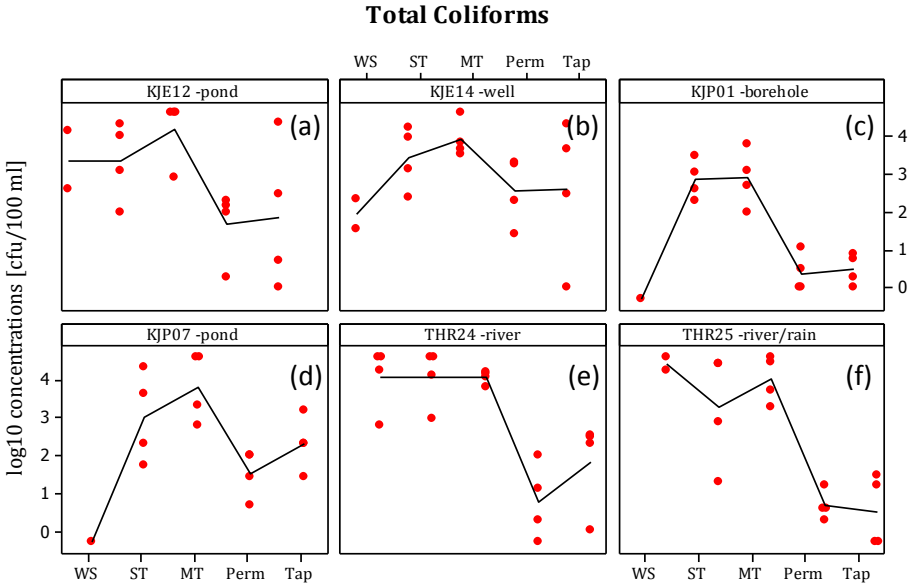

Figure 30 Individual value plots for Total Coliforms in monitored filter units.

Enterococci

The low sample size and the fact that only river water was sampled for Enterococci was reflected in the narrow distribution of the water source sampling (Figure 31 and 32).

Average LRV obtained over the ultrafiltration membrane attained 2.0 but still 9 samples out of 13 detected Enterococci in the permeate. All samples were detecting Enterococci from the tap (Appendix A).

No samples passed WHO guideline values for drinking water. Regrowth in the clean water tank was indicated in 8 samplings out of 12, at least once in every filter unit (Appendix A).

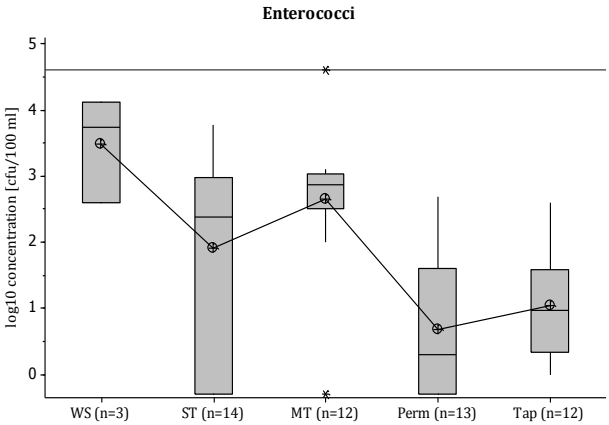

Figure 31 Distribution of Enterococci at different sampling locations.

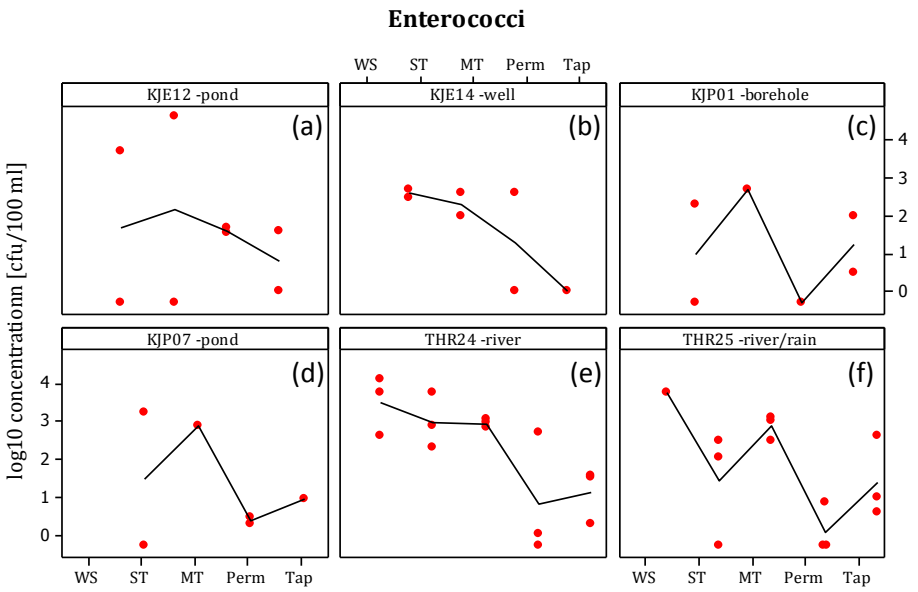

Figure 32 Individual value plots for detected Enterococci in monitored filter units.

Total Viable Counts and ATP

Detections of Total Viable Counts were high throughout the whole treatment process and all samples were more or less affected by upper limit truncation (Figure 33). Hence, a representative picture of the distributions in the different sample locations could not be obtained. This applied especially for the membrane tank. As a result, the average LRV attained 0.5 over the ultrafiltration membrane.

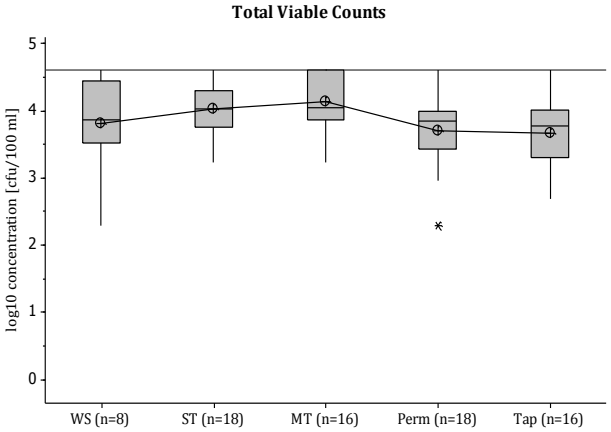

Figure 33 Distribution of Total viable counts at different sampling locations.

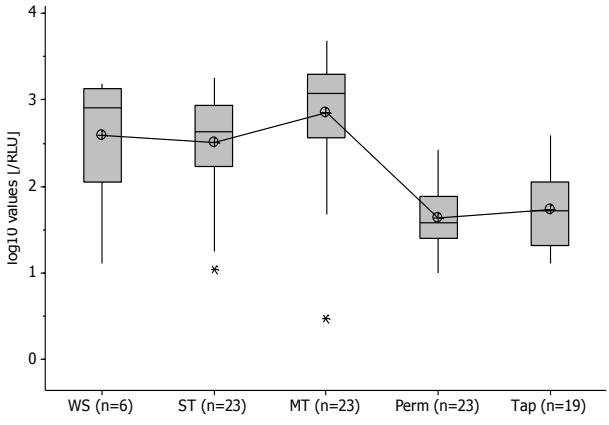

Figure 34 ATP distributions of at different sampling locations.

The pond in Oloosuyian (KJP 07) showed higher detection of Total Viable Counts compared to the same detections of *E. coli* and Total Coliforms (Appendix A). Increased detections in the storage tank occurred for the filters using groundwater (KJE 14 and KJP 01). Regrowth in clean water tank was indicated in 9 samplings out of 16 (Appendix A).

Detections of ATP followed a similar pattern to those of Total Viable Counts with high detections at permeate and tap levels (Figure 34). The average LRV over the ultrafiltration membrane obtained 1.2.

5.2.2 Nutrients

Nutrient fluctuations were monitored for Ammonium (NH_4^+), Nitrate (NO_3^-), Nitrite (NO_2^-) and orthophosphate (PO_4^{3-}). All parameters further described in Chapter 3.

Ammonium

Ammonium accumulation occurred in the membrane tank (Figure 35), where the highest detections were found from the two filter units using pond water (KJE 12 and KJP 07), and the one filter unit using the well (Appendix B). The borehole filter showed almost no detection of ammonium.

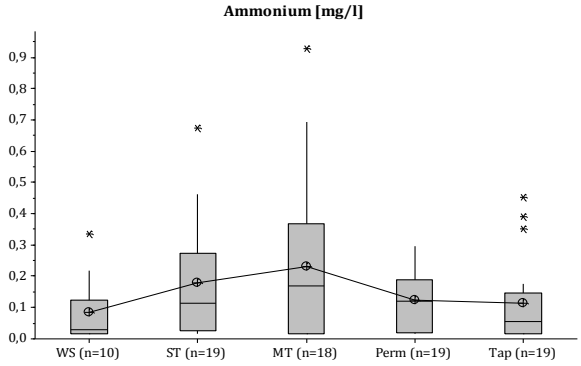

Figure 35 Ammonium distribution at different sample locations.

Nitrite and Nitrate

Nitrite and Nitrate concentrations were generally low throughout the whole treatment process. All detections, at all locations, passed WHO guideline values for drinking water stating a limit of 11 mg/l for nitrate-N and 0.9 mg/l for nitrite-N.

A small increase in nitrite concentration occurred in the membrane tank (Figure 36). This was in line with the DO drops further described in Figure 39. The outlier values were from two sampling series in KJP 07 and THR 24, both using surface water (Appendix B).

Nitrate concentrations were increasing towards the end of the filtering process (Figure 37), indicating a certain degree of nitrification. The highest detections of nitrate at tap level occurred in THR 24, KJE 14, KJE 12 and KJP 07, all surface waters except for KJE 14 used well (Appendix B). Outlier values in the storage tank originated from the filter using borehole water.

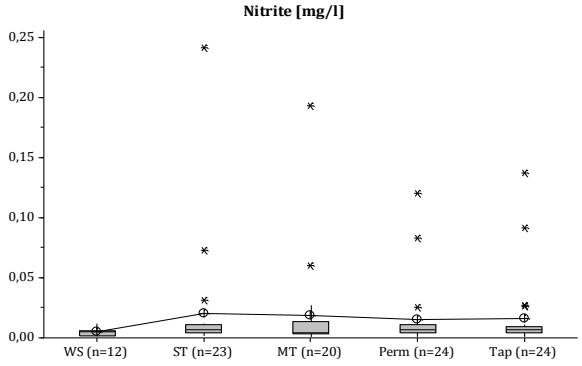

Figure 36 Nitrite distribution throughout filtering process.

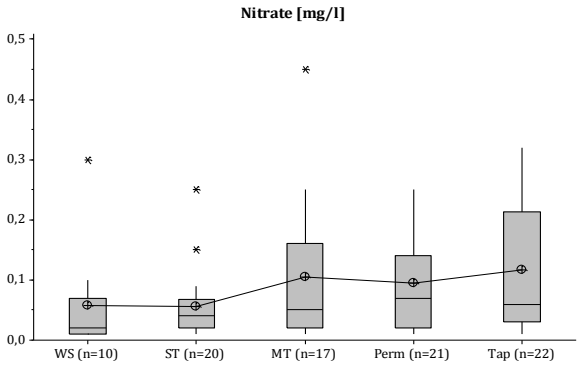

Figure 37 Nitrate distribution throughout filtering process.

Orthophosphate

Higher values of orthophosphate were detected at water source levels (Figure 38), mainly originnating from surface water sources (Appendix B). Outlier values at tap level are derived from KJP 07 and KJP 01.

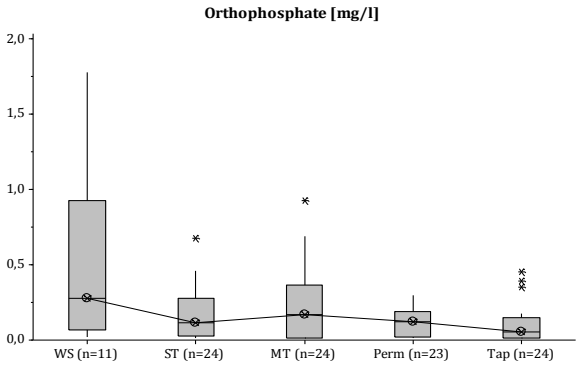

Figure 38 Distribution of orthophosphate throughout filtering process.

5.2.3 General quality measurements

In addition to microbial and nutrient sampling, on-site measurements were made for DO, turbidity, pH and electric conductivity.

Dissolved Oxygen

Large DO drops in the membrane tanks were indicating high biological activity (Figure 39). Higher activity was found in filters using surface waters and in the filter using well water (Appendix C). DO levels go back to original levels in permeate and tap. 17% of samples in the membrane tank contained < 2 mg/l DO, and could be considered hypoxic. All hypoxic samples originated from surface water sources.

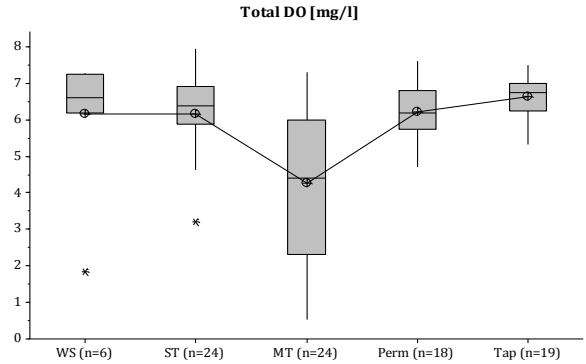

Figure 39 Measurements of dissolved oxygen.

Turbidity

Highest turbidities were found in surface waters. LRV:s increased with elevated turbidity loads in the membrane tank (Table 11).

Table 11 Average turbidity measurements and log reduction values in each filter unit.

Filter unit	Main water source	Turbidity in membrane tank [NTU]	Turbidity in permeate [NTU]	LRV
THR24	River	84.25	0.02	3.6
THR25	river/rain	7.89	0.08	2.0
KJE 14	Well	42.96	0.18	2.4
KJE 12	Pond	288.00	0.93	2.5
KJP 07	Pond	270.54	1.39	2.3
KJP 01	Borehole	4.11	0.27	1.2

pH and Electric conductivity

pH levels were detected within a range of 6.9 and 8.8 with borehole and well water slightly higher than the other sources. The borehole filter showed the highest electric conductivity, indicating a higher ionic content (Table 12).

Table 12 Average measurements of electric conductivity and pH in different households.

Filter unit	Main water source	Electric conductivity [µS/cm]	pH
THR 24	River	173	7.2
THR 25	river/rain	30	6.9
KJE 14	Well	485	8.0
KJE 12	Pond	65	7.5
KJP 07	Pond	993	8.4
KJP 01	borehole	1519	8.8

5.3 BIOFILM FORMATION

The density of different indicator bacteria (*E. coli*, Total Coliforms and Total Viable Counts) was measured in biofilms at different locations: the permeate tube, tap and walls of clean water tank. To complement the picture, samples were also taken directly from the ultrafiltration membrane and from the walls of the membrane tank. All targeted locations are described in table 3.

Total Viable Counts were detected at higher rates then both *E. coli* and Total Coliforms at all sampled locations (Figure 27). The highest detection of *E. coli* and Total Coliforms were acquired from the walls of the membrane tank and from the ultrafiltration membrane.

No *E. coli* detections were made in the permeate tube and from the walls of the clean water tank (Appendix E). Detections of Total Coliforms were made in 3 samples out of 20 in the permeate tube and in 6 samples out of 24 from the clean water tank. All filter units detected Total Coliforms from inside the tap and 3 out of 24 samples also detected *E. coli* at this level.

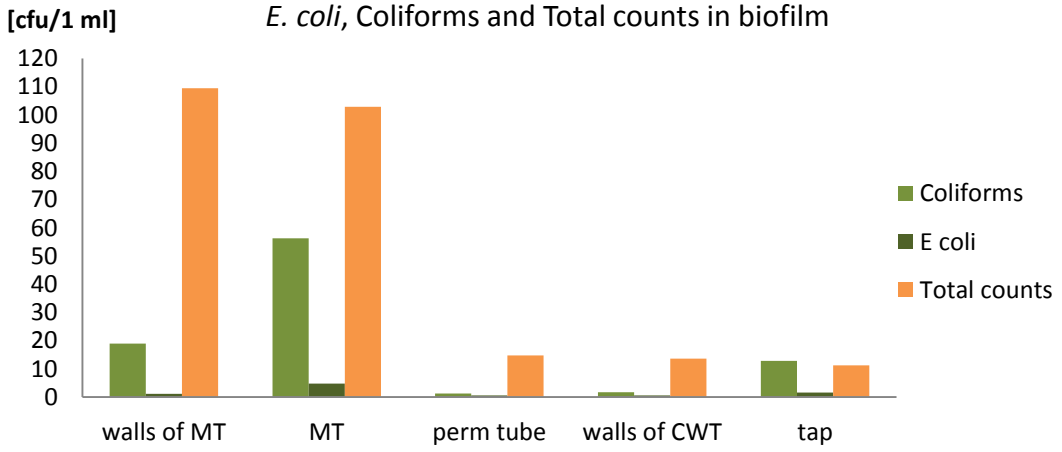

Figure 40 Biofilm detection at investigated parts of filter prototype, geometrical mean values.

Filter specific detections

Highest detections of Total Coliforms, at all investigated locations, were acquired in THR 24, KJE 14 and KJE 12 (Table 13). *E. coli* at tap level were detected twice in THR 24 and once in KJP 01 (Appendix E).

Table 13 Biofilm detections in different filter units.

Filter unit	Water source	Permeate tube [cfu/1 ml]			Walls of CWT [cfu/1 ml]		
		EC	TC	TVC	EC	TC	TVC
THR 24	River	0	45	101	0	10	72
THR 25	River	0	0	62	0	0	150
KJE 14	Well	0	100	100	0	200	20
KJE 12	Pond	0	0	184	0	101	39
KJP 07	Pond	-	-	-	0	0	121
KJP 01	Borehole	0	0	137	0	0	126

Filter unit	Water Source	Tap [cfu/1 ml]		
		EC	TC	TVC
THR 24	River	43	302	167
THR 25	River	0	1	83
KJE 14	Well	0	204	6
KJE 12	Pond	0	242	122
KJP 07	Pond	0	100	200
KJP 01	Borehole	3.5	54	4

5.4 ASSESSMENT OF FACTORS LINKED TO REGROWTH

Detections made for *E. coli*, Total Coliforms and Total Viable Counts at permeate and tap level were assessed by estimating possible relations to biofilm formation and originally used water source. Factors of correlation were investigated with yes/no diagrams and Analysis of Variance (ANOVA). Yes/no- diagrams and F and p values from the ANOVA tests can be found in Appendix F.

5.4.1 Microbial detections vs. biofilm formation

Correlation between microbial detection in biofilm and microbial detection in sampled water was investigated for *E. coli*, Total Coliforms and Total Viable Counts. Targeted locations were permeate and tap levels. Because of the low sample size, simple yes/no diagrams were drawn up in order to roughly determine which parameters likely to show the highest potential of correlation.

Permeate level

At permeate level, highest indication of possible correlation was found for Total Viable Counts. Most detections were made between 2-3 log cfu:s (Figure 41). No correlations were indicated for *E. coli* and Total Coliforms.

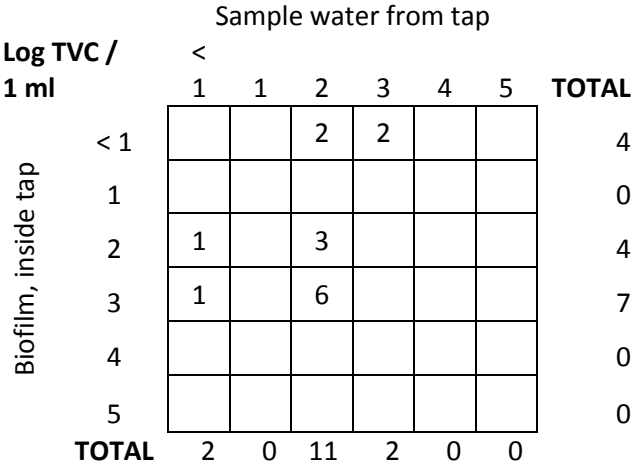

Figure 41 Distribution of detected Total Viable Counts in permeate

Tap level

Yes/no diagrams indicated correlations for Total Coliforms and Total Viable Counts. Generally, high detections in the sample water coincided with high detection in the biofilm (Figure 42 and Figure 43), thus no statistical significance could be stated. In 8 samples out of 24, Total Coliforms were detected in biofilm when no detections were made from the sample water.

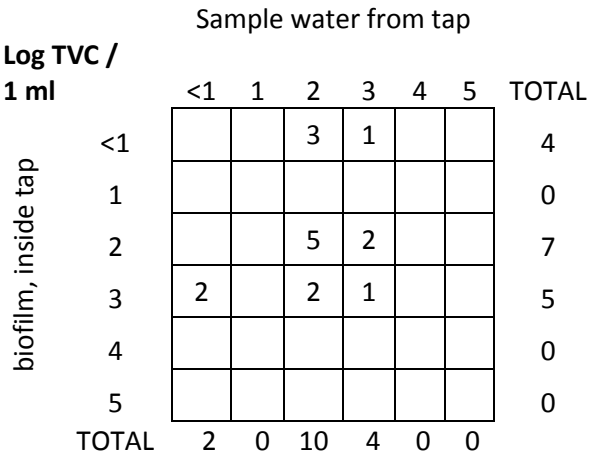

Figure 42 Log relationship between Total Viable Counts in biofilm inside tap, versus Total Viable Counts in sample water.

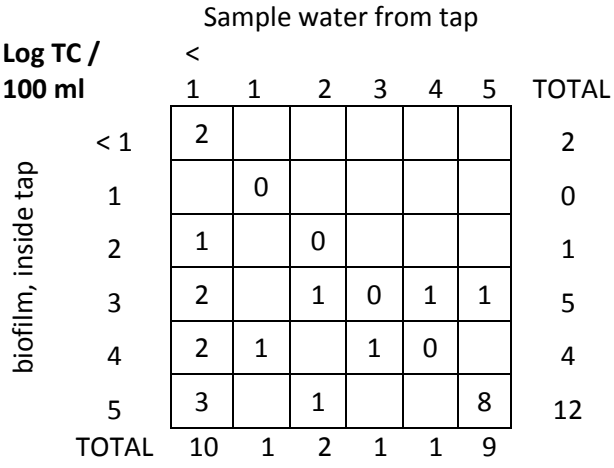

Figure 43 Log relationship between detected Total Coliforms inside tap and detected Total Coliforms in sample water.

Assuming a normal distribution of the collected data, ANOVA-tests performed separately for each indicator organism, could only state a significant difference for coliform biofilm formation inside the tap compared to other coliform detections.

5.4.2 Microbial regrowth vs. water source

Microbial regrowth linked to water source was investigated by sub-dividing the main water sources into three categories: groundwater, surface water and rainwater. Frequencies of re-growth, based on the indications made from the LRV (Appendix D), were calculated and ANOVA was used to determine significant differences.

Table 14 Frequencies of detected regrowth in different water sources based on negative LRV.

	Groundwater [%]	Surface water [%]	Rain [%]
E. coli	17	27	0
Total Coliforms	83	73	71
Enterococci	*100	80	50
Total Viable Counts	50	67	50

* Only one measurement

Results from the ANOVA-tests could not state any significant difference between different water sources when using these categories. Negative LRV are more likely to occur as a consequence of recontamination.

5.5 CONTROL STUDY

5.5.1 E. coli

Compared to the field samplings, no accumulation of *E. coli* were indicated in the membrane tank. 3 samplings out of 20 detected *E. coli* in the permeate and 2 samplings out of 24 detected *E. coli* from the tap. Regrowth was indicated at 2 occasions..

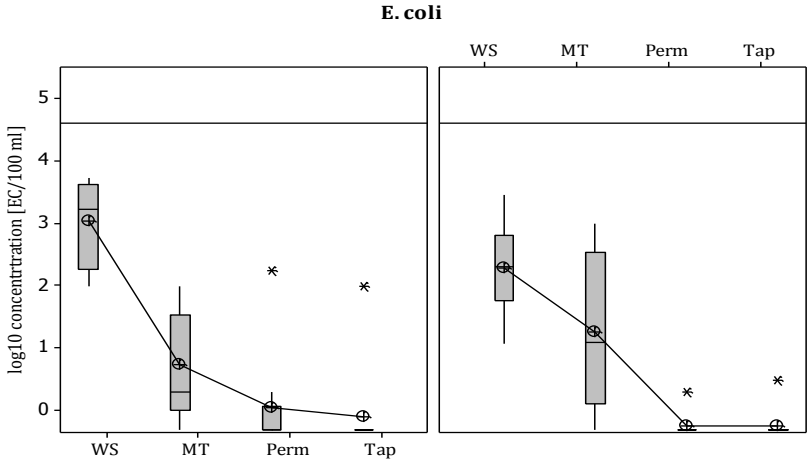

Figure 44 *E. coli* distribution at different sampling locations. Filter 1 and 2 (left), filter 3 and 4 (right).

5.5.2 Total Coliforms

Same as for *E. coli*, no accumulation was indicated in the membrane tank. Even though, the original load of Total Coliforms were higher in the control study than generally in field. All samples detected Total Coliforms in the permeate and 22 samples out of 24 detected Total Coliforms from the tap. Regrowth was indicated in 9 samplings out of 20.

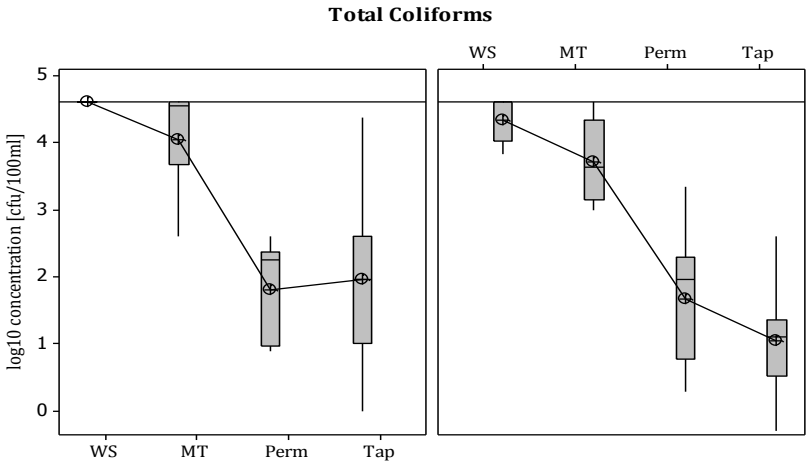

Figure 45 Distribution of Total Coliforms at different sampling locations. Filter 1 and 2 (left), filter 3 and 4 (right).

5.5.3 Total Viable Counts

Detections were generally higher than for other indicator bacteria throughout the treatment process. Permeate and tap levels were detecting less than in the field study. Regrowth was indicated in 8 out of 16 samplings.

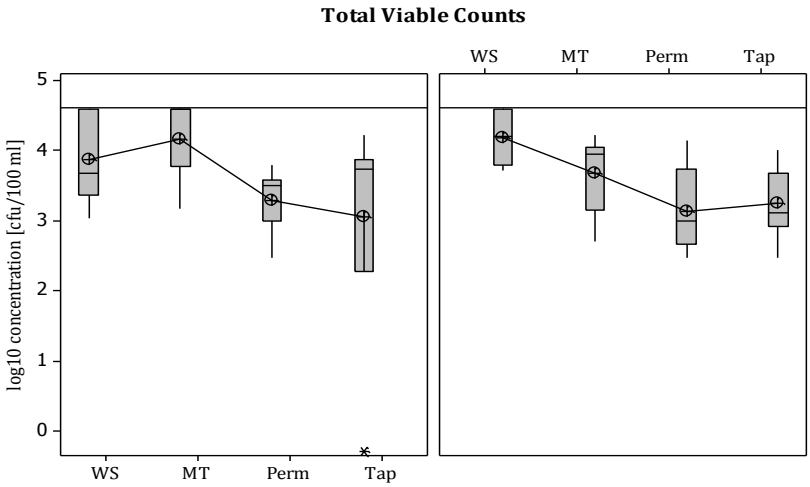

Figure 46 Distribution of Total viable counts at different sampling locations. Filter 1 and 2 (left), filter 3 and 4 (right).

6 DISCUSSION

6.1 MONITORING OF WATER QUALITY CHARACTERISTICS

Assessing water quality throughout the filtering process becomes more complex when external factors, in terms of poor hygiene and handling, are taken into account. Even if water undergoes treatment, maintenance of the filter unit and storing of the water, might be determining for the resulting product. In this study, 33.3% of *E coli* 71.4% of Enterococci samples taken directly from the storage tank detected more than 100 cfu/100 ml, emphasizing the fact that water treatment in these areas is an urgent need since this water is what probably would have been consumed without the GDM filtration.

6.1.1 Microbial processes

Regrowth and recontamination

The first problem encountered when investigating microbial regrowth in the filter prototype occurs when trying to distinguish regrowth from recontamination. Recontamination is defined as elevated detections of indicator bacteria as a result of exposure to external factors, such as handling or poor maintenance. Regrowth on the other hand, is defined as an increase of biological activity due to favorable conditions for certain organisms e.g. temperature or availability of limiting nutrients.

One aspect to consider when assessing microbial patterns in field is the differences in frequencies between the fecal indicator organisms (*E. coli* and Enterococci) and organisms naturally occurring in the environment (Total Coliforms and Total viable counts). The latter are more likely to be present at higher rates which subsequently results in higher detections. Moreover, the filter prototype is not designed to produce a bacteria free water, but concerned with removing potential health-threatening microorganisms. WHO guideline values for drinking water states that no detections of fecal indicator bacteria should be made in 100 ml water samples.

Contamination due to poor hygiene and handling is clearly indicated in the storage tanks when water has been collected from a source with low microbial activity e.g. groundwater or rainwater. This is in line with previous studies made by Rufener et al. (2010) and Wright et al. (2004) and is particularly clear for *E. coli* and Total Coliforms in Figure 14 and Figure 15. Likewise recontamination is also shown for all indicator organisms in samples made from household cups (Table 13 and 14), stressing the impact of sanitary conditions prevailing in field.

Detections made at tap level are generally higher for Total Coliforms, Enterococci and Total viable counts and lower for *E. coli* (Appendix A). This might be a result of recontamination due to the exposed position of the tap. Comparing this to the control study, detections made for Total Coliforms are about twice as high in the field than in the project laboratory.

Looking at permeate level, the average differences of Total Coliform bacteria between permeate and tap levels are resulting in a tenfold increase for filter units used in the field.

A summary of the LRV between permeate and tap is shown in Table 15. These values were consulted when assessing regrowth but were only regarded as possible indications of regrowth, keeping the low sample size and recontamination risks at the tap in mind.

Table 15 Average LRV between permeate and tap. Negative sign indicates potential regrowth.

FILTER UNIT	Main water source	*E. coli*	Total Coliforms	Enterococci	Total viablecounts
THR 24	River	-0.08	-1.05	-0.33	-0.22
THR 25	River	0.00	0.16	-1.32	-0.08
KJE 14	Well	-0.26	-0.05	0.00*	-0.01
KJE 12	Pond	0.46	-0.19	0.81	0.42
KJP 07	Pond	0.62	-0.77	-0.48*	-0.11
KJP 01	borehole	0.15	-0.11	-2.30*	-0.12
Average		0.15	-0.34	-0.60	-0.02

Regrowth was primarily indicated for Total Coliforms and Enterococci (Table 15). Though, as previously discussed the presence of Total Coliforms is likely to be naturally higher. Enterococci detections on the other hand, were significantly higher than *E. coli* detections at both permeate and tap level. This could be an indication of microbial regrowth but also underlines the resistance of Enterococci to stress factors that might prevail in the clean water tank.

Membrane integrity

Total Coliforms and Total viable counts were detected at high levels in the permeate, both when assessing the field filters and when monitoring the control filters. Since Total Coliforms occur naturally in the environment, and Total viable counts encounters a range of different bacteria, these elevated detections might not be surprising. Still, reductions of Total Coliforms over the ultrafiltration membrane averaged > 99.7 % in field and > 99.4 % for the controlled filters. Total viable counts were affected by upper limit truncation and thus averaged > 68.4 % in field and > 87.5 % in the control study. Due to limitations in the analyzing method reductions are likely to be much higher but are not able to be calculated.

Detections of *E. coli* in the permeate were higher in the field than in the control study, although no statistical difference could be stated with ANOVA. Since Enterococci were not measured in the control study no comparison could be made. In field, *E. coli* was reduced to 98 % and Enterococci 99%. However, higher detections were still made for Enterococci in the permeate than for *E. coli*. This might be the result of a low sample size regarding Enterococci. A certain risk of recontamination at permeate level was also present since the membrane tank had to be separated from the clean water tank during sampling.

Filter specific observations

At a filter specific level, THR 24, KJE 14 and KJE 12, all mud houses, were generally detecting higher rates of indicator organisms and regrowth in the clean water tank, to some extent also KJP 07. This also joints the detections made for biofilm formation in Table 11. Regarding the different water sources used in these filter units compared to borehole water and River-rain water used in THR 25 and KJP 01, this could be a result of heavier contaminated feed water. Although, the control study and field observations, as to measurements made in household cups, could also indicating a possible relation to environmental impacts, such as housing conditions or lacking maintenance.

6.1.2 Nutrient fluctuations and general water quality

Measurements of nutrients and general water quality characteristics did not show any particular abnormalities. Levels of nitrite and nitrate were low and pH levels and electrical conductivity were within a typical range. Ammonium accumulation and DO drops in the membrane tank are indicating possibilities of microbial activity around the ultrafiltration membranes. Subsequently, a certain factor of nitrification might be suspected from the membrane tank and onwards.

A good reduction of turbidity was obtained which clearly was observed during monitoring.

6.2 BIOFILM FORMATION

Biofilm is present at all investigated locations in the filter prototype. This is particularly highlighted by the high presence of Total viable counts in the sampled locations. To determine what organisms contribute to the biofilm formations, further assessment is needed. However, according to field samplings, *E. coli* show no tendency of being operative in the biofilm formation inside the permeate tube and on the walls of the clean water tank (Figure 26). Given the fact that Enterococci were detected at higher rates in sample water from the permeate and tap, Enterococci in the biofilm might be detected at higher rates than *E. coli*. Further investigations are needed.

Filter specific observations

Scaling down to asses biofilm formation qualitatively on filter specific level, similar patterns can be distinguished to those earlier discussed when assessing regrowth and recontamination. Highest rates of detected Total Coliforms in the permeate tube, on the walls of the clean water tanks and inside the tap occur in THR 24, KJE 14 and KJE 12 (Table 11), all previously showing the highest indications of regrowth in the clean water tank.

6.3 ASSESSMENT OF POSSIBLE FACTORS LINKED TO REGROWTH

Statistical relationships for microbial detection and biofilm formation could not significantly be determined. However, detection and biofilm comparisons of Total Viable Counts at permeate and tap level, and Total Coliforms at tap level, were indicating a correlating factor. One must however bear in mind that all results were affected by a low sample size and that a significantly different outcome could arise when up-scaling the investigations.

ANOVA tests performed when linking groundwater, surface water and rain water to microbial regrowth could not state any significant differences between the water sources. Although, other sub-categories might give a different result. Because of the low sample size, no statistical tests could be performed for each water source individually.

6.4 SAMPLING METHOD AND ANALYSIS

Field blanks for microbial analysis taken at the different monitoring occasions are showing no detections of microbial activity, predicting a good quality of the sampling procedure and sampling technique. A certain risk of regrowth and nutrient fluctuations still remains when storing the samples in the cooling box after collection. Microbial processes might still be carried out within the sample bags and affect the results.

7 RECOMMENDATIONS

Further investigations of microbial regrowth and factors linked to regrowth are recommended. Samplings directly from the clean water tank would probably say more about the prevailing conditions for microorganisms. Assessment of Assimilated Organic Carbon might be an option to initialize what factors are sustaining microbial regrowth.

Given the high rate of detections made for Enterococci in permeate water, assessment of Enterococci growing in the biofilm would be recommended.

For future development of the filter unit, redesigning of the tap might help preventing recontamination risks and biofilm formation at this level.

8 CONCLUSIONS

When putting the resulting drinking water in relation to its original state, the technical performance of the filter prototype suffices to produce water of good drinking quality. After six months operation, filters are still in use and no permeate flows have ceased because of membrane fouling.

Regrowth in the clean water tank is hard to distinguish since factors of recontamination are highly present. Although, on an average basis, indications of regrowth are slightly present for Total Coliforms and Enterococci.

Recontamination risks appear mainly due to handling before and after the treatment but are also known to arise when performing some of the samplings in field. Nevertheless, field observations are strongly indicating high recontamination factors linked with maintenance and unsanitary conditions.

Biofilm formations were detected at all investigated locations within the filter prototype but no significant correlation could be made with microbial detection in sample water. Results were likely to be affected by the low sample size. Possible relationships could however be indicated for Total Viable Counts at permeate and tap level, and for Total Coliforms at tap level. Further investigations are needed in order to establish a relationship. Due to the high detections of Enterococci made in the sample water originating from the permeate, presence of Enterococci in biofilm would be interesting to look more into.

Differences in the presence of indicator organisms could be associated with the provenance of the feed water. Although, no significant differences could be stated between use of different water sources and microbial regrowth when using groundwater, surface water and rain as subcategories. Other categories along with an increased sample size might give different a result.

The tap can be considered a weak point in the filter prototype. Considering its exposed position to recontamination, alternative designs might be an option to consider in the future.

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APPENDIX A. MICROBIAL DATA

Table A1. *E. coli* detections at different sample locations. ***E COLI***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [cfu/100 ml]	Storage tank [cfu/100 ml]	Membrane tank [cfu/100] ml)	Permeate [cfu/100 ml]	Tap [cfu/100 ml]	HH cup [cfu/100 ml]
THR24	02-nov	river	600	< 0.5	< 0.5	< 0.5	< 0.5	18
THR24	15-nov	river	3800	2000	600	< 0.5	< 0.5	18
THR24	29-nov	rain	< 0.5	1	100	< 0.5	< 0.5	3
THR24	14-dec	river	4100	1300	300	< 0.5	1	2
THR25	02-nov	river	-	< 0.5	300	< 0.5	< 0.5	< 0.5
THR25	15-nov	rain	-	7	100	< 0.5	< 0.5	< 0.5
THR25	29-nov	rain	-	7	100	< 0.5	< 0.5	200
THR25	14-dec	river	-	600	400	< 0.5	< 0.5	< 0.5
KJE14	07-nov	well	-	< 0.5	< 0.5	5	200	181
KJE14	21-nov	rain	-	26	700	9	5	18
KJE14	05-dec	rain	< 0.5	< 0.5	16	1	< 0.5	4
KJE14	13-dec	well	< 0.5	71	100	< 0.5	< 0.5	< 0.5
KJE12	07-nov	pond	-	< 0.5	< 0.5	< 0.5	< 0.5	-
KJE12	21-nov	rain	-	20	2100	23	< 0.5	7
KJE12	06-dec	pond	11000	6700	7300	3	< 0.5	2
KJE12	13-dec	pond	5000	5700	9000	< 0.5	2	400
KJE07	08-nov	pond	-	8	< 0.5	< 0.5	< 0.5	-
KJE07	22-nov	rain	-	30	4	153	< 0.5	6
KJE07	06-dec	borehole/pond	3	300	900	1	< 0.5	< 0.5
KJE07	13-dec	other pond	-	500	700	< 0.5	1	1
KJE01	08-nov	borehole	-	< 0.5	< 0.5	2	< 0.5	-
KJE01	22-nov	borehole	-	100	14	< 0.5	< 0.5	9
KJE01	06-dec	borehole	3	800	11	< 0.5	< 0.5	< 0.5
KJE01	13-dec	borehole	-	25	100	< 0.5	< 0.5	< 0.5

Detection limit 0.5 - 40 000 cfu/100 ml sample water

APPENDIX A. MICROBIAL DATA *continued*

Table A2. Detections of Total Coliforms at different sample locations. ***TOTAL COLIFORMS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [cfu/100 ml]	Storage tank [cfu/100 ml]	Membrane tank [cfu/100 ml]	Permeate [cfu/100 ml]	Tap [cfu/100 ml]	HH cup [cfu/100 ml]
THR24	02-nov	river	> 40000	> 40000	6600	< 0.5	356	> 40000
THR24	15-nov	river	> 40000	> 40000	14800	13	200	26800
THR24	29-nov	rain	600	900	16400	100	300	400
THR24	14-dec	river	18500	13600	11700	2	1	36
THR25	02-nov	river	> 40000	26800	40000	4	< 0.5	348
THR25	15-nov	rain	-	800	2000	16	30	100
THR25	29-nov	rain	-	19	5300	4	16	600
THR25	14-dec	river	18500	28000	28400	2	< 0.5	< 0.5
KJE14	07-nov	well	-	9000	4300	1900	20000	> 40000
KJE14	21-nov	rain	-	1400	6700	25	304	14100
KJE14	05-dec	rain	222	237	3300	200	1	174
KJE14	13-dec	well	36	17000	> 40000	1800	4500	11900
KJE12	07-nov	pond	-	100	800	2	5	-
KJE12	21-nov	rain	-	1200	> 40000	200	1	108
KJE12	06-dec	pond	400	20800	> 40000	100	300	1200
KJE12	13-dec	pond	13300	10300	> 40000	142	21400	18500
KJE07	08-nov	pond	-	200	600	5	26	-
KJE07	22-nov	rain	-	57	2200	99	200	600
KJE07	06-dec	borehole/pond	< 0.5	4300	> 40000	27	1500	500
KJE07	13-dec	other pond	-	22300	> 40000	100	205	7300
KJE01	08-nov	borehole	-	200	100	1	8	-
KJE01	22-nov	borehole	-	400	6300	1	2	14
KJE01	06-dec	borehole	< 0.5	1100	1200	3	6	9
KJE01	13-dec	borehole	-	2900	500	12	1	3

Detection limit 0.5 - 40 000 cfu/100 ml sample water

APPENDIX A. MICROBIAL DATA *continued*

Table A3. Detections of Enterococci at different sample locations. ***ENTEROCOCCI***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [cfu/100 ml]	Storage tank [cfu/100 ml]	Membrane tank [cfu/100 ml]	Permeate [cfu/100 ml]	Tap [cfu/100 ml]	HH cup [cfu/100 ml]
THR24	02-nov	river	5600	800	700	< 0.5	2	79
THR24	15-nov	river	13500	5900	900	1	32	132
THR24	29-nov	rain	400	200	1100	500	37	1600
THR24	14-dec	river	-	-	-	-	-	-
THR25	02-nov	river	-	< 0.5	1000	< 0.5	4	5
THR25	15-nov	rain	-	117	300	< 0.5	10	< 0.5
THR25	29-nov	rain	-	300	1300	7	400	100
THR25	14-dec	river	-	-	-	-	-	-
KJE14	07-nov	well	-	300	100	400	-	400
KJE14	21-nov	rain	-	500	400	1	1	500
KJE14	05-dec	rain	-	-	-	-	-	-
KJE14	13-dec	well	-	-	-	-	-	-
KJE12	07-nov	pond	-	< 0.5	< 0.5	34	39	-
KJE12	21-nov	rain	-	4800	40000	47	1	33
KJE12	06-dec	pond	-	-	-	-	-	-
KJE12	13-dec	pond	-	-	-	-	-	-
KJE07	08-nov	pond	-	< 0.5	-	2	-	-
KJE07	22-nov	rain	-	1700	800	3	9	11
KJE07	06-dec	borehole/pond	-	-	-	-	-	-
KJE07	13-dec	other pond	-	-	-	-	-	-
KJE01	08-nov	borehole	-	< 0.5	-	-	3	-
KJE01	22-nov	borehole	-	200	500	< 0.5	100	5
KJE01	06-dec	borehole	-	-	-	-	-	-
KJE01	13-dec	borehole	-	-	-	-	-	-

Detection limit 0.5 - 40 000 cfu/100 ml sample water

APPENDIX A. MICROBIAL DATA *continued*

Table A4. Detections of Total Viable Counts at different sample locations. ***TOTAL VIABLE COUNTS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [cfu/100 ml]	Storage tank [cfu/100 ml]	Membrane tank [cfu/100 ml]	Permeate [cfu/100 ml]	Tap [cfu/100 ml]	HH cup [cfu/100 ml]
THR24	02-nov	river	-	20000	8000	-	-	-
THR24	15-nov	river	-	-	7000	3800	5800	-
THR24	29-nov	rain	4300	5600	10000	2000	2700	5200
THR24	14-dec	river	> 40000	> 40000	> 40000	6700	14700	6800
THR25	02-nov	river	-	-	-	-	-	-
THR25	15-nov	rain	-	5900	7200	2100	2700	4900
THR25	29-nov	rain	-	7400	11000	6000	3200	12500
THR25	14-dec	river	-	15200	16000	200	500	2000
KJE14	07-nov	well	-	-	-	-	-	-
KJE14	21-nov	rain	-	6400	11200	11500	1600	> 40000
KJE14	05-dec	rain	3000	1700	> 40000	3000	> 40000	> 40000
KJE14	13-dec	well	200	11600	1700	14500	8300	12400
KJE12	07-nov	pond	-	-	-	-	-	-
KJE12	21-nov	rain	-	> 40000		9400	6000	> 40000
KJE12	06-dec	pond	16500	13800	-	8000	1800	> 40000
KJE12	13-dec	pond	13200	17300	> 40000	8700	-	-
KJE07	08-nov	pond	-	-	-	-	-	-
KJE07	22-nov	rain	-	2900	> 40000	> 40000		-
KJE07	06-dec	borehole/pond	33200	22000	> 40000	8400	15000	10300
KJE07	13-dec	other pond	-	8200	6900	11500	10800	-
KJE01	08-nov	borehole	-	-	-	-	-	-
KJE01	22-nov	borehole	-	4100	8200	7300	6200	7900
KJE01	06-dec	borehole	4300	10000	-	4700	6500	10000
KJE01	13-dec	borehole	-	> 40000	16400	900	1800	1700

Detection limit 0.5 - 40 000 cfu/100 ml sample water

APPENDIX B. NUTRIENT DETECTIONS

Table B1. Ammonium detections at different locations. ***AMMONIUM***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [mg/l]	Storage tank [mg/l]	Membrane tank [mg/l]	Permeate [mg/l]	Tap [mg/l]
THR24	02-nov	river	0.044	0.026	0.105	0.019	0.017
THR24	15-nov	river	0.072	0.113	0.421	0.281	0.352
THR24	29-nov	rain	0.219	0.253	0.215	0.189	0.118
THR24	14-dec	river	-	-	-	-	-
THR25	02-nov	river	-	0.164	0.195	0.165	0.147
THR25	15-nov	rain	-	0.274	0.350	0.239	0.102
THR25	29-nov	rain	-	0.186	0.210	0.240	0.146
THR25	14-dec	river	-	-	-	-	-
KJE14	07-nov	well	0.015	0.463	0.244	0.170	0.177
KJE14	21-nov	rain	-	0.205	0.693	0.298	0.453
KJE14	05-dec	rain	-	0.357	0.144	0.119	0.054
KJE14	13-dec	well	0.092	0.104	0.026	0.015	0.015
KJE12	07-nov	pond	-	0.015	0.015	0.015	0.015
KJE12	21-nov	rain	-	0.675	-	0.114	0.098
KJE12	06-dec	pond	0.337	0.369	0.928	0.037	0.015
KJE12	13-dec	pond	-	-	-	-	-
KJE07	08-nov	pond	0.015	0.015	0.102	0.120	0.016
KJE07	22-nov	rain	-	0.061	0.015	0.032	0.015
KJE07	06-dec	borehole/pond	0.015	0.015	0.462	0.188	0.390
KJE07	13-dec	other pond	-	-	-	-	-
KJE01	08-nov	borehole	0.015	0.065	0.015	0.096	0.015
KJE01	22-nov	borehole	-	0.041	0.015	0.018	0.015
KJE01	06-dec	borehole	0.015	0.015	0.015	0.015	0.015
KJE01	13-dec	borehole	-	-	-	-	-

Detection limit: 0.015 – 2.0 mg/l

APPENDIX B. NUTRIENT DETECTIONS *continued*

Table B2. Nitrite detections at different locations. ***NITRITE***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [mg/l]	Storage tank [mg/l]	Membrane tank [mg/l]	Permeate [mg/l]	Tap [mg/l]
THR24	02-nov	river	0.005	0.073	0.193	0.120	0.137
THR24	15-nov	river	0.005	0.241	0.003	0.007	0.006
THR24	29-nov	rain	0.008	0.009	0.027	0.007	0.001
THR24	14-dec	river	0.012	0.012	0.002	0.007	0.005
THR25	02-nov	river	-	0.004	-	0.003	0.003
THR25	15-nov	rain	-	0.011	0.013	0.004	0.005
THR25	29-nov	rain	-	0.004	0.004	0.003	0.004
THR25	14-dec	river	-	0.011	0.004	0.004	0.003
KJE14	07-nov	well	0.002	0.005	0.004	0.006	0.007
KJE14	21-nov	rain	-	0.007	0.017	0.025	0.003
KJE14	05-dec	rain	-	0.008	0.003	0.006	0.007
KJE14	13-dec	well	0.002	0.031	0.001	0.004	0.007
KJE12	07-nov	pond	-	0.002	0.002	0.006	0.005
KJE12	21-nov	rain	-	0.007	0.005	0.014	0.027
KJE12	06-dec	pond	0.002	-	-	0.011	0.004
KJE12	13-dec	pond	0.002	0.002	-	0.008	0.011
KJE07	08-nov	pond	0.006	0.007	0.014	0.011	0.010
KJE07	22-nov	rain	-	0.003	0.003	0.003	0.008
KJE07	06-dec	borehole/pond	0.005	0.005	0.003	0.015	0.026
KJE07	13-dec	other pond	-	0.002	0.060	0.083	0.091
KJE01	08-nov	borehole	0.006	0.008	0.004	0.009	0.007
KJE01	22-nov	borehole	-	0.007	-	0.003	0.005
KJE01	06-dec	borehole	0.005	0.002	0.004	0.001	0.005
KJE01	13-dec	borehole	-	0.005	0.006	0.004	0.008

Detection limit: 0.002 – 0.3 mg/l WHO guideline value: 0,9 mg/l NO_2-N

APPENDIX B. NUTRIENT DETECTIONS *continued*

Table B3. Nitrate detections at different locations. ***NITRATE***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [mg/l]	Storage tank [mg/l]	Membrane tank [mg/l]	Permeate [mg/l]	Tap [mg/l]
THR24	02-nov	river	-	-	-	-	-
THR24	15-nov	river	0.30	-	0.25	0.14	0.10
THR24	29-nov	rain	0.10	0.05	-	0.06	0.08
THR24	14-dec	river	0.06	0.07	0.45	0.25	0.32
THR25	02-nov	river	-	-	-	-	-
THR25	15-nov	rain	-	0.06	0.16	0.24	0.17
THR25	29-nov	rain	-	0.04	0.13	0.17	0.15
THR25	14-dec	river	-	0.06	0.16	0.14	0.05
KJE14	07-nov	well	0.01	0.06	0.02	-	0.02
KJE14	21-nov	rain	-	0.03	0.25	0.04	0.32
KJE14	05-dec	rain	-	0.08	0.04	0.08	0.30
KJE14	13-dec	well	0.01	0.09	-	0.02	0.02
KJE12	07-nov	pond	-	0.01	0.01	0.01	0.01
KJE12	21-nov	rain	-	0.04	0.05	0.25	0.30
KJE12	06-dec	pond	-	-	-	0.14	0.22
KJE12	13-dec	pond	0.01	0.01	-	0.14	0.06
KJE07	08-nov	pond	0.02	0.02	0.04	0.02	0.03
KJE07	22-nov	rain	-	0.02	0.05	0.07	0.03
KJE07	06-dec	borehole/pond	0.02	0.02	0.02	0.04	0.06
KJE07	13-dec	other pond	-	0.01	0.10	0.12	0.21
KJE01	08-nov	borehole	0.02	0.02	0.01	0.02	0.03
KJE01	22-nov	borehole	-	0.25	-	0.02	0.03
KJE01	06-dec	borehole	0,02	0.02	0.02	0.02	0.06
KJE01	13-dec	borehole	-	0.15	0.02	0.01	0.01

Detection limit: 0.01 – 0.5 mg/l WHO guideline value: 11 mg/l as NO3-N

APPENDIX B. NUTRIENT DETECTIONS *continued*

Table B4. Detections of orthophosphate at different locations. ***ORTHOPHOSPHATE***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [mg/l]	Storage tank [mg/l]	Membrane tank [mg/l]	Permeate [mg/l]	Tap [mg/l]
THR24	02-nov	river	0.070	0.090	0.180	0.130	0.110
THR24	15-nov	river	0.280	0.420	0.120	0.100	0.030
THR24	29-nov	rain	0.080	0.030	0.200	0.990	0.050
THR24	14-dec	river	1.780	0.110	0.140	0.270	0.040
THR25	02-nov	river	-	0.020	0.057	0.020	0.020
THR25	15-nov	rain	-	0.070	0.160	0.340	0.150
THR25	29-nov	rain	-	0.100	0.020	0.090	0.080
THR25	14-dec	river	-	0.850	0.006	0.100	0.200
KJE14	07-nov	well	0.960	3.500	0.320	-	0.260
KJE14	21-nov	rain	-	0.130	0.200	0.200	0.100
KJE14	05-dec	rain	-	0.130	0.130	0.090	0.130
KJE14	13-dec	well	0.020	0.386	0.020	0.020	0.020
KJE12	07-nov	pond	-	0.110	0.210	0.210	0.140
KJE12	21-nov	rain	-	0.100	0.370	0.170	0.580
KJE12	06-dec	pond	-	1.420	1.880	0.640	0.510
KJE12	13-dec	pond	0.924	0.870	2.500	0.241	0.020
KJE07	08-nov	pond	0.070	0.090	1.280	0.320	0.140
KJE07	22-nov	rain	-	0.150	0.400	0.240	1.850
KJE07	06-dec	borehole/pond	0.530	0.190	1.780	1.860	0.058
KJE07	13-dec	other pond	-	2.500	2.500	1.970	1.930
KJE01	08-nov	borehole	0.070	0.080	0.080	0.110	0.050
KJE01	22-nov	borehole	-	0.130	0.220	1.240	1.830
KJE01	06-dec	borehole	0.530	0.010	0.060	0.140	0.130
KJE01	13-dec	borehole	-	2.500	0.090	0.140	0.260

Detection limit: 0.02 -2.5 mg/l

APPENDIX C. GENERAL QUALITY MEASUREMENTS

Table C1. Dissolved oxygen measured at different locations. ***DISSOLVED OXYGEN***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [mg/l]	Storage tank [mg/l]	Membrane tank [mg/l]	Permeate [mg/l]	Tap [mg/l]
THR24	02-nov	river	6.4	5.0	1.6	-	-
THR24	15-nov	river	6.8	6.5	4.1	-	-
THR24	29-nov	rain	7.2	7.1	6.0	7.5	7
THR24	14-dec	river	7.26	6.38	4.92	6.8	6.75
THR25	02-nov	river	-	6.2	5.6	0.0	0.0
THR25	15-nov	rain	-	5.2	4.4	0.0	0.0
THR25	29-nov	rain	-	6.6	6.5	6.8	7.1
THR25	14-dec	river	-	0.0	0.0	0.0	0.0
KJE14	07-nov	well	-	6.7	5.3	-	-
KJE14	21-nov	rain	-	6.9	3.7	5.9	6.8
KJE14	05-dec	rain	-	6.44	3.07	5.74	5.31
KJE14	13-dec	well	1.83	5.89	4.55	5.79	6.25
KJE12	07-nov	pond	-	3.2	4.3	-	-
KJE12	21-nov	rain	-	6.9	2.3	5.9	6.5
KJE12	06-dec	pond	6.12	5.9	1.98	6.3	5.95
KJE12	13-dec	pond	-	4.62	0.9	5.05	6.93
KJE07	08-nov	pond	-	5.5	4.2	-	-
KJE07	22-nov	rain	-	7.0	5.2	6.9	7.5
KJE07	06-dec	borehole/pond	-	7.94	2.07	5.38	6.87
KJE07	13-dec	other pond	-	5.98	0.52	4.71	5.87
KJE01	08-nov	borehole	-	6.4	6.9	-	-
KJE01	22-nov	borehole	-	7.1	7.3	7.6	7.5
KJE01	06-dec	borehole	-	5.89	6.31	6.6	6.75
KJE01	13-dec	borehole	-	6.31	6.11	6.18	6.45

APPENDIX C. GENERAL QUALITY MEASUREMENTS *continued*

Table C2. Turbidity measured at different sample locations. ***TURBIDITY***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [NTU]	Storage tank [NTU]	Membrane tank [NTU]	Permeate [NTU]	Tap [NTU]
THR24	02-nov	river	67.1	22.6	48.5	-	0.19
THR24	15-nov	river	-	110	84.7	-	0.58
THR24	29-nov	rain	4.1	0.76	171	0.04	0.00
THR24	14-dec	river	101	21.7	32.8	0.00	0.1
THR25	02-nov	river	-	1.53	3.88	-	0.27
THR25	15-nov	rain	0.00	1.64	17.62	-	-
THR25	29-nov	rain	-	1.43	2.18	0.08	0.41
THR25	14-dec	river	-	-	-	-	-
KJE14	07-nov	well	-	0.00	27.1	-	-
KJE14	21-nov	rain	-	2.17	86.4	0.27	0.32
KJE14	05-dec	rain	-	6.7	3.32	0.02	0.00
KJE14	13-dec	well	1.82	122	55	0.25	1.11
KJE12	07-nov	pond	-	49.8	56	-	2.57
KJE12	21-nov	rain	-	4.42	184	0.41	0.32
KJE12	06-dec	pond	644	681	OR	1.15	2.69
KJE12	13-dec	pond	-	792	624	1.24	-
KJE07	08-nov	pond	-	0.48	5.03	-	-
KJE07	22-nov	rain	-	14.41	5.14	0.75	1.16
KJE07	06-dec	borehole/pond	-	1.77	320	0.45	0.48
KJE07	13-dec	other pond	-	636	752	2.96	1.94
KJE01	08-nov	borehole	-	0.51	2	-	-
KJE01	22-nov	borehole	-	1.3	3	0.03	0.17
KJE01	06-dec	borehole	-	1.48	8.99	0.43	0.22
KJE01	13-dec	borehole	-	5.95	2.45	0.34	0.09

OR – Over measuring range

APPENDIX C. GENERAL QUALITY MEASUREMENTS *continued*

Table C3. pH measured at different sample locations. ***pH***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [pH]	Storage tank [pH]	Membrane tank [pH]	Permeate [pH]	Tap [pH]
THR24	02-nov	river	-	-	-	-	-
THR24	15-nov	river	-	7.4	6.9	-	7.5
THR24	29-nov	rain	6.8	7	6.2/6.6	6.8	7.1
THR24	14-dec	river	7	7.8	7.4	7.5	7.5
THR25	02-nov	river	-	-	-	-	-
THR25	15-nov	rain	-	6.4	6.7	-	6.8
THR25	29-nov	rain	-	7.4	6.7	7.1	6.9
THR25	14-dec	river	-	-	-	-	-
KJE14	07-nov	well	-	7.6	7.8	-	-
KJE14	21-nov	rain	-	7.9	8	8.4	8.2
KJE14	05-dec	rain	-	7.7	7.9	8.2	8.4
KJE14	13-dec	well	7.6	8.6	7.9	8.3	8.1
KJE12	07-nov	pond	-	7.7	7.9	-	-
KJE12	21-nov	rain	-	7.4	7	7.2	7.5
KJE12	06-dec	pond	7.6	7.7	7.8	7.6	7.7
KJE12	13-dec	pond	-	7.2	7.1	7.2	7.7
KJE07	08-nov	pond	-	8.5	8.5	-	-
KJE07	22-nov	rain	-	8.9	8.6	8.6	8.3
KJE07	06-dec	borehole/pond	-	8.6	8.2	8.2	8.5
KJE07	13-dec	other pond	-	8.4	7.9	8.3	8
KJE01	08-nov	borehole	-	8.8	8.8	-	-
KJE01	22-nov	borehole	-	8.6	8.5	9	8.8
KJE01	06-dec	borehole	-	8.7	9	9	9.1
KJE01	13-dec	borehole	-	8.4	8.7	9	8.7

APPENDIX C. GENERAL QUALITY MEASUREMENTS *continued*

Table C4. Electric conductivity measured at different sample locations. ***ELECTRIC CONDUCTIVITY***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Water source [µS/cm]	Storage tank [µS/cm]	Membrane tank [µS/cm]	Permeate [µS/cm]	Tap [µS/cm]
THR24	02-nov	river	238	683	307	-	-
THR24	15-nov	river	111.8	151.2	72,7	-	76.9
THR24	29-nov	rain	9.65	12.4	14	14.11	15.1
THR24	14-dec	river	68.9	294	288	292	298
THR25	02-nov	river	-	12.55	20.91	0	0
THR25	15-nov	rain	0	14.43	17.79	0	19.4
THR25	29-nov	rain	-	11.53	15,36	17.8	14.21
THR25	14-dec	river	0	0	0	0	0
KJE14	07-nov	well	-	51.8	1145	-	1261
KJE14	21-nov	rain	-	37.6	579	540	773
KJE14	05-dec	rain	-	32.1	970	525	1039
KJE14	13-dec	well	2.48	361	1516	1491	1306
KJE12	07-nov	pond	-	2.77	2.41	-	2.29
KJE12	21-nov	rain	-	24.5	116.9	147.6	143.1
KJE12	06-dec	pond	49.1	47.5	68.6	82.3	79.4
KJE12	13-dec	pond	-	62.5	73.7	82	56.5
KJE07	08-nov	pond	-	1863	1386	-	1432
KJE07	22-nov	rain	-	30.4	1471	1346	1465
KJE07	06-dec	borehole/pond	-	1735	965	915	880
KJE07	13-dec	other pond	-	321	355	355	378
KJE01	08-nov	borehole	-	1740	1852	-	1863
KJE01	22-nov	borehole	-	916	1845	1787	1858
KJE01	06-dec	borehole	-	1274	1082	1114	1114
KJE01	13-dec	borehole	-	1663	1559	1546	1578

APPENDIX D. LOG REDUCTION VALUES

Table D1. Log reduction values of *E. coli* between different sample locations. ***E COLI***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Original detection at WS	WS vs. ST	ST vs. MT	MT vs. Perm	Perm vs. Tap	Tap vs. HH cup
THR24	02-nov	river	2.8	3.1	0.0	0.0	0.0	-1.6
THR24	15-nov	river	3.6	0.3	0.5	3.1	0.0	-1.6
THR24	29-nov	rain	-0.3	-0.3	-2.0	2.3	0.0	-0.8
THR24	14-dec	river	3.6	0.5	0.6	2.8	-0.3	-0.3
THR25	02-nov	river	2.8	3.1	-2.8	2.8	0.0	0.0
THR25	15-nov	rain	-	-	-1.2	2.3	0.0	0.0
THR25	29-nov	rain	-	-	-1.2	2.3	0.0	-2.6
THR25	14-dec	river	3.6	0.8	0.2	2.9	0.0	0.0
KJE14	07-nov	well	-	-	0.0	-1.0	-1.6	0.0
KJE14	21-nov	rain	-	-	-1.4	1.9	0.3	-0.6
KJE14	05-dec	rain	-0.3	0.0	-1.5	1.2	0.3	-0.9
KJE14	13-dec	well	-0.3	-2.2	-0.1	2.3	0.0	0.0
KJE12	07-nov	pond	-	-	0.0	0.0	0.0	-
KJE12	21-nov	rain	-	-	-2.0	2.0	1.7	-1.1
KJE12	06-dec	pond	4.0	0.2	0.0	3.4	0.8	-0.6
KJE12	13-dec	pond	3.7	-0.1	-0.2	4.3	-0.6	-2.3
KJE07	08-nov	pond	-	-	1.2	0.0	0.0	-
KJE07	22-nov	rain	-	-	0.9	-1.6	2.5	-1.1
KJE07	06-dec	borehole/pond	0.5	-2.0	-0.5	3.0	0.3	0.0
KJE07	13-dec	other pond	-	-	-0.1	3.1	-0.3	0.0
KJE01	08-nov	borehole	-	-	0.0	-0.6	0.6	-
KJE01	22-nov	borehole	-	-	0.9	1.4	0.0	-1.3
KJE01	06-dec	borehole	0.5	-2.4	1.9	1.3	0.0	0.0
KJE01	13-dec	borehole	-	-	-0.6	2.3	0.0	0.0
AVERAGE LRV				0.1	-0.3	1.7	0.1	-0.7

Detection limit -0.3 – 4.6 Log cfu/100 ml sample water

WS – Water source MT – Membrane tank HH cup – Household cup
ST – Storage tank Perm - Permeate

APPENDIX D. LOG REDUCTION VALUES *continued*

Table D2. Log reduction values of Total Coliforms between different sample locations. ***TOTAL COLIFORMS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Original detection at WS	WS vs. ST	ST vs. MT	MT vs. Perm	Perm vs. Tap	Tap vs. HH cup
THR24	02-nov	river	4.6	0	0.8	4.1	-2.9	-2.1
THR24	15-nov	river	4.6	0	0.4	3.1	-1.2	-2.1
THR24	29-nov	rain	2.8	-0.2	-1.3	2.2	-0.5	-0.1
THR24	14-dec	river	4.3	0.1	0.1	3.8	0.3	-1.6
THR25	02-nov	river	4.6	0.2	-0.2	4.0	0.9	-2.8
THR25	15-nov	rain	-	-	-0.4	2.1	-0.3	-0.5
THR25	29-nov	rain	-	-	-2.4	3.1	-0.6	-1.6
THR25	14-dec	river	4.3	-0.2	0.0	4.2	0.6	0.0
KJE14	07-nov	well	-	-	0.3	0.4	-1.0	-0.3
KJE14	21-nov	rain	-	-	-0.7	2.4	-1.1	-1.7
KJE14	05-dec	rain	2.3	0.0	-1.1	1.2	2.3	-2.2
KJE14	13-dec	well	1.6	-2.7	-0.4	1.3	-0.4	-0.4
KJE12	07-nov	pond	-	-	-0.9	2.6	-0.4	
KJE12	21-nov	rain	-	-	-1.5	2.3	2.3	-2.0
KJE12	06-dec	pond	2.6	-1.7	-0.3	2.6	-0.5	-0.6
KJE12	13-dec	pond	4.1	0.1	-0.6	2.4	-2.2	0.1
KJE07	08-nov	pond	-	-	-0.5	2.1	-0.7	
KJE07	22-nov	rain	-	-	-1.6	1.3	-0.3	-0.5
KJE07	06-dec	borehole/pond	-0.3	-3.9	-1.0	3.2	-1.7	0.5
KJE07	13-dec	other pond	-	-	-0.3	2.6	-0.3	-1.6
KJE01	08-nov	borehole	-	-	0.3	2.0	-0.9	
KJE01	22-nov	borehole	-	-	-1.2	3.8	-0.3	-0.8
KJE01	06-dec	borehole	-0.3	-3.3	0.0	2.6	-0.3	-0.2
KJE01	13-dec	borehole	-	-	0.8	1.6	1.1	-0.5
AVERAGE LRV				-1.0	-0.5	2.5	-0.3	-1.0

Detection limit -0.3 – 4.6 Log cfu/100 ml sample water

WS – Water source MT – Membrane tank HH cup – Household cup
ST – Storage tank Perm - Permeate

APPENDIX D. LOG REDUCTION VALUES *continued*

Table D3. Log reduction values of Enterococci between different sample locations. ***ENTEROCOCCI***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Original detection at WS	WS vs. ST	ST vs. MT	MT vs. Perm	Perm vs. Tap	Tap vs. HH cup
THR24	02-nov	river	3.7	0.8	0.1	3.1	-0.6	-1.6
THR24	15-nov	river	4.1	0.4	0.8	3.0	-1.5	-0.6
THR24	29-nov	rain	2.6	0.3	-0.7	0.3	1.1	-1.6
THR24	14-dec	river	-	-	-	-	-	-
THR25	02-nov	river	3.7	4.0	-3.3	3.3	-0.9	-0.1
THR25	15-nov	rain	-	-	-0.4	2.8	-1.3	1.3
THR25	29-nov	rain	-	-	-0.6	2.3	-1.8	0.6
THR25	14-dec	river	-	-	-	-	-	-
KJE14	07-nov	well	-	-	0.5	-0.6	-	-
KJE14	21-nov	rain	-	-	0.1	2.6	0.0	-2.7
KJE14	05-dec	rain	-	-	-	-	-	-
KJE14	13-dec	well	-	-	-	-	-	-
KJE12	07-nov	pond	-	-	0.0	-1.8	-0.1	-
KJE12	21-nov	rain	-	-	-0.9	2.9	1.7	-1.5
KJE12	06-dec	pond	-	-	-	-	-	-
KJE12	13-dec	pond	-	-	-	-	-	-
KJE07	08-nov	pond	-	-	-	-	-	-
KJE07	22-nov	rain	-	-	0.3	2.4	-0.5	-0.1
KJE07	06-dec	borehole/pond	-	-	-	-	-	-
KJE07	13-dec	other pond	-	-	-	-	-	-
KJE01	08-nov	borehole	-	-	-	-	-	-
KJE01	22-nov	borehole	-	-	-0.4	3.0	-2.3	1.3
KJE01	06-dec	borehole	-	-	-	-	-	-
KJE01	13-dec	borehole	-	-	-	-	-	-
AVERAGE LRV				1,4	-0.4	1.9	-0.6	-0.5

Detection limit -0.3 – 4.6 Log cfu/100 ml sample water

WS – Water source MT – Membrane tank HH cup – Household cup
ST – Storage tank Perm - Permeate

APPENDIX D. LOG REDUCTION VALUES *continued*

Table D4. Log reduction values of Total Viable Counts between different sample locations. ***TOTAL VIABLE COUNTS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	Original detection at WS	WS vs. ST	ST vs. MT	MT vs. Perm	Perm vs. Tap	Tap vs. HH cup
THR24	02-nov	river	-	-	0.4	-	-	-
THR24	15-nov	river	-	-	-	0.3	-0.2	-0.2
THR24	29-nov	rain	1.6	-0.1	-0.3	0.7	-0.1	-0.1
THR24	14-dec	river	2.6	0.0	0.0	0.8	-0.3	-0.3
THR25	02-nov	river	-	-	-	-	-	-
THR25	15-nov	rain	-	-	-0.1	0.5	-0.1	-0.1
THR25	29-nov	rain	-	-	-0.2	0.3	0.3	0.3
THR25	14-dec	river	2.6	-	0.0	1.9	-0.4	-0.4
KJE14	07-nov	well	-	-	-	-	-	-
KJE14	21-nov	rain	-	-	-0.2	0.0	0.9	0.9
KJE14	05-dec	rain	1.5	0.2	-1.4	1.1	-1.1	-1.1
KJE14	13-dec	well	0.3	-1.8	0.8	-0.9	0.2	0.2
KJE12	07-nov	pond	-	-	-	-	-	-
KJE12	21-nov	rain	-	-	-	-	0.2	0.2
KJE12	06-dec	pond	2.2	0.1	-	-	0.6	0.6
KJE12	13-dec	pond	2.1	-0.1	-0.4	0.7	-	-
KJE07	08-nov	pond	-	-	-	-	-	-
KJE07	22-nov	rain	-	-	-1.1	0.0	-	-
KJE07	06-dec	borehole/pond	2.5	0.2	-0.3	0.7	-0.3	-0.3
KJE07	13-dec	other pond	-	-	0.1	-0.2	0.0	0.0
KJE01	08-nov	borehole	-	-	-	-	-	-
KJE01	22-nov	borehole	-	-	-0.3	0.1	0.1	0.1
KJE01	06-dec	borehole	1.6	-0.4	-	-	-0.1	-0.1
KJE01	13-dec	borehole	-	-	0.4	1.3	-0.3	-0.3
AVERAGE LRV				-0.2	-0.2	0.5	0.0	0.0

Detection limit -0.3 – 4.6 Log cfu/100 ml sample water

WS – Water source MT – Membrane tank HH cup – Household cup
ST – Storage tank Perm - Permeate

APPENDIX E. BIOFILM DETECTIONS

Table E1. *E. coli* detections at different sample locations. ***E COLI***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	walls of membrane tank (cfu/1 ml)	Membrane surface (cfu/1 ml)	Permeate tube (cfu/1 ml)	Walls of clean water tank (cfu/1 ml)	Inside tap (cfu/1 ml)
THR24	02-nov	river	0	40	0	0	20
THR24	15-nov	river	0	100	0	0	152
THR24	29-nov	rain	0	29	0	0	0
THR24	14-dec	river	0	24	0	0	0
THR25	02-nov	river	10	40	0	0	0
THR25	15-nov	rain	0	2	0	0	0
THR25	29-nov	rain	0	5	0	0	0
THR25	14-dec	river	7	19	0	0	0
KJE14	07-nov	well	0	0	0	0	0
KJE14	21-nov	rain	400	9	0	0	0
KJE14	05-dec	rain	400	0	0	0	0
KJE14	13-dec	well	0	0	0	0	0
KJE12	07-nov	pond	0	0	0	0	0
KJE12	21-nov	rain	0	11	-	0	0
KJE12	06-dec	pond	0	106	0	0	0
KJE12	13-dec	pond	0	50	0	0	0
KJE07	08-nov	pond	0	0	-	0	0
KJE07	22-nov	rain	0	0	-	0	0
KJE07	06-dec	borehole/pond	0	400	-	0	0
KJE07	13-dec	other pond	0	-	-	0	0
KJE01	08-nov	borehole	0	0	0	0	0
KJE01	22-nov	borehole	0	0	0	0	14
KJE01	06-dec	borehole	0	0	0	0	0
KJE01	13-dec	borehole	0	0	0	0	0

Detection limit: 0.5 - 400 cfu/1ml

APPENDIX E. BIOFILM DETECTIONS *continued*

Table E2. Detections of Total Coliforms at different sample locations. ***TOTAL COLIFORMS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	walls of membrane tank (cfu/1 ml)	Membrane surface (cfu/1 ml)	Permeate tube (cfu/1 ml)	Walls of clean water tank (cfu/1 ml)	Inside tap (cfu/1 ml)
THR24	02-nov	river	0	400	0	20	400
THR24	15-nov	river	180	400	72	21	400
THR24	29-nov	rain	212	400	108	0	400
THR24	14-dec	river	200	200	0	0	9
THR25	02-nov	river	-	400	0	0	0
THR25	15-nov	rain	1	400	0	0	2
THR25	29-nov	rain	2	232	0	0	0
THR25	14-dec	river	32	400	0	0	0
KJE14	07-nov	well	0	0	0	0	0
KJE14	21-nov	rain	400	62	0	0	400
KJE14	05-dec	rain	400	400	0	400	17
KJE14	13-dec	well	6	3	400	400	400
KJE12	07-nov	pond	0	0	0	0	0
KJE12	21-nov	rain	400	400	-	2	166
KJE12	06-dec	pond	400	400	0	0	400
KJE12	13-dec	pond	60	400	0	400	400
KJE07	08-nov	pond	0	0	0	0	0
KJE07	22-nov	rain	2	8	-	0	0
KJE07	06-dec	borehole/pond	27	400	-	0	0
KJE07	13-dec	other pond	400	400	-	0	400
KJE01	08-nov	borehole	0	0	0	0	0
KJE01	22-nov	borehole	400	69	0	0	87
KJE01	06-dec	borehole	0	0	0	0	128
KJE01	13-dec	borehole	400	400	0	0	0

Detection limit: 0.5 - 400 cfu/1ml

APPENDIX E. BIOFILM DETECTIONS *continued*

Table E3. Detections of Total Viable Counts at different sample locations. ***TOTAL VIABLE COUNTS***

FILTER UNIT	**Date of sampling**	**Source used at monitoring**	walls of membrane tank (cfu/1 ml)	Membrane surface (cfu/1 ml)	Permeate tube (cfu/1 ml)	Walls of clean water tank (cfu/1 ml)	Inside tap (cfu/1 ml)
THR24	02-nov	river	-	-	-	-	-
THR24	15-nov	river	400	400	109	18	400
THR24	29-nov	rain	4000*	4000*	0	174	60
THR24	14-dec	river	4000*	4000*	195	23	42
THR25	02-nov	river	-	-	-	-	-
THR25	15-nov	rain	400	400	26	22	66
THR25	29-nov	rain	3000*	4000*	99	400	78
THR25	14-dec	river	208	63	62	28	105
KJE14	07-nov	well	0	0	0	0	0
KJE14	21-nov	rain	400	400	0	64	2
KJE14	05-dec	rain	400	400	400	17	21
KJE14	13-dec	well	1900*	930*	0	0	0
KJE12	07-nov	pond	0	0	0	0	0
KJE12	21-nov	rain	23	17	328	118	88
KJE12	06-dec	pond	400	5	400	1	400
KJE12	13-dec	pond	0	400	6	0	0
KJE07	08-nov	pond	0	0	0	0	0
KJE07	22-nov	rain	134	400	-	82	400
KJE07	06-dec	borehole/pond	57	4000*	-	400	400
KJE07	13-dec	other pond	4000*	2	-	0	0
KJE01	08-nov	borehole	0	0	0	0	0
KJE01	22-nov	borehole	43	400	42	63	11
KJE01	06-dec	borehole	4000*	940*	400	40	1
KJE01	13-dec	borehole	1000*	760*	105	400	-

Detection limit: 0.5 - 400 cfu/1ml standard sample, 0.5 - 4000 cfu/ml diluted sample

* Diluted samples

APPENDIX F1. STATISTICAL ANALYSES

Microbial detection vs biofilm formation.
YES/NO – diagrams

EC in biofilm, permeate tube × EC in permeate

	N	y
n	15	5
y	0	0

TC in biofilm, perm tube × TC in permeate

	n	y
n	0	16
y	0	3

TVC in biofilm, permeate tube × TVC in permeate

	n	y
n	1	1
y	7	12

EC in biofilm, tap × EC in Tap

	N	y
n	16	5
y	3	0

TC in biofilm, tap × TC in Tap

	n	y
n	2	8
y	0	14

TVC in biofilm, tap × TVC in tap

	n	y
n	0	2
y	1	13

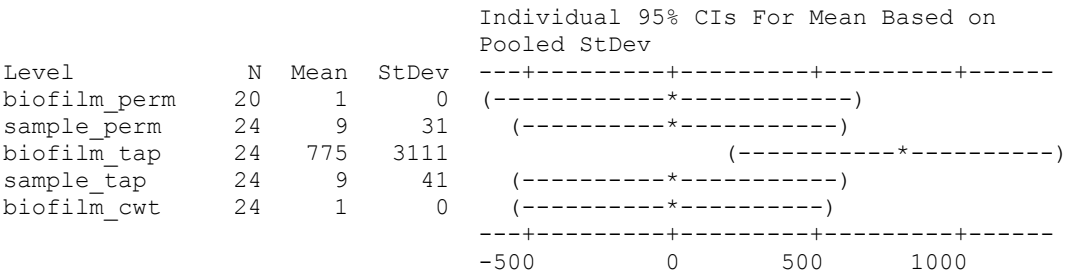
EC – *E. coli*
TC – Total Coliforms
TVC – Total Viable Counts

APPENDIX F2. STATISTICAL ANALYSES

Microbial detection vs biofilm formation.
One way ANOVA

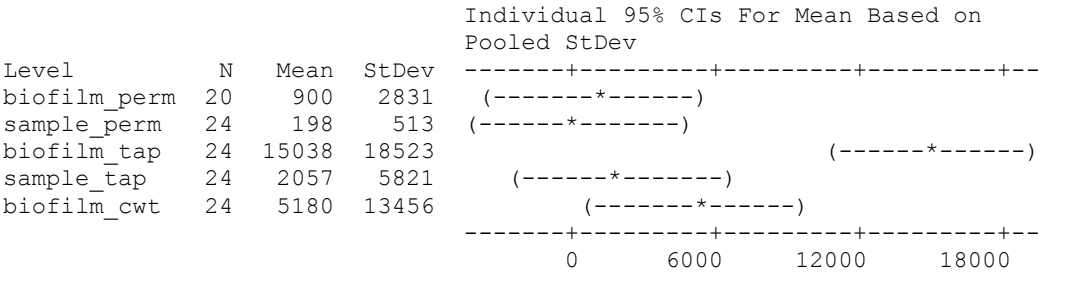
E coli detections

```
Source   DF         SS       MS     F      P
Factor    4   11304590  2826148  1,41  0,236
Error   111  222629084  2005667
Total   115  233933674

S = 1416   R-Sq = 4,83%   R-Sq(adj) = 1,40%
```



Detections of Total Coliforms

```
Source   DF           SS         MS     F      P
Factor    4   3511871002  877967751  7,50  0,000
Error   111  12993999169  117063056
Total   115  16505870171

S = 10820   R-Sq = 21,28%   R-Sq(adj) = 18,44%
```



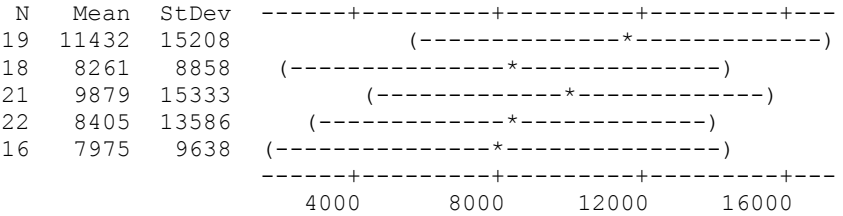
Detections of Total Viable Counts

Source	DF	SS	MS	F	P
Factor	4	158025866	39506466	0,23	0,919
Error	91	15468649708	169985162		
Total	95	15626675573			

S = 13038 R-Sq = 1,01% R-Sq(adj) = 0,00%

Level	N	Mean	StDev
biof_perm	19	11432	15208
sample_perm	18	8261	8858
biofi-Tap	21	9879	15333
biofilm_cwt	22	8405	13586
sample_tap	16	7975	9638

Individual 95% CIs For Mean Based on Pooled StDev



APPENDIX F3. STATISTICAL ANALYSES

Microbial regrowth vs. water source.
One way ANOVA

Permeate level

E coli detections

```
Source  DF     SS     MS     F      P
Factor   2  1,007  0,503  2,17  0,139
Error   21  4,868  0,232
Total   23  5,875

S = 0,4815   R-Sq = 17,14%   R-Sq(adj) = 9,25%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
SW     11  0,3171  0,2895    (--------*--------)
GW      6  0,3266  0,2519  (----------*-----------)
RAIN    7  0,7710  0,7866              (----------*----------)
                          --+---------+---------+---------+-------
                          0,00      0,35      0,70      1,05
```

Detections of Total Coliforms

```
Source  DF     SS    MS     F      P
Factor   2   1,17  0,58  0,49  0,620
Error   21  25,06  1,19
Total   23  26,23

S = 1,092   R-Sq = 4,45%   R-Sq(adj) = 0,00%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N   Mean  StDev  ---+---------+---------+---------+------
SW     11  1,164  1,039   (----------*----------)
GW      6  1,348  1,538  (--------------*---------------)
RAIN    7  1,686  0,638         (-------------*-------------)
                         ---+---------+---------+---------+------
                          0,60      1,20      1,80      2,40
```

Detections of Total Viable Counts

```
Source  DF     SS     MS     F      P
Factor   2  0,420  0,210  0,82  0,459
Error   16  4,111  0,257
Total   18  4,531

S = 0,5069   R-Sq = 9,27%   R-Sq(adj) = 0,00%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -------+---------+---------+---------+--
SW     8  3,4558  0,5343  (-----------*------------)
```

```
GW     4  3,6628  0,5135   (-----------------*-----------------)
RAIN   7  3,7878  0,4694            (------------*-------------)
                           -------+---------+---------+---------+--
                                3,30      3,60      3,90      4,20
```

Tap level

E coli detections

```
Source  DF     SS     MS     F      P
Factor   2  0,248  0,124  0,32  0,733
Error   21  8,243  0,393
Total   23  8,491

S = 0,6265   R-Sq = 2,92%   R-Sq(adj) = 0,00%

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level    N    Mean   StDev  -------+---------+---------+---------+--
SW      11  0,4356  0,6451          (----------*----------)
GW       6  0,5306  0,8684         (--------------*--------------)
RAIN     7  0,2621  0,2276  (-------------*--------------)
                            -------+---------+---------+---------+--
                                 0,00      0,35      0,70      1,05
```

Detections of Total Coliforms

```
Source  DF     SS    MS     F      P
Factor   2   0,20  0,10  0,04  0,956
Error   21  46,59  2,22
Total   23  46,79

S = 1,489   R-Sq = 0,43%   R-Sq(adj) = 0,00%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  ------+---------+---------+---------+---
SW      11  1,472  1,503      (------------*------------)
GW       6  1,656  1,839    (-----------------*-----------------)
RAIN     7  1,420  1,088  (---------------*----------------)
                          ------+---------+---------+---------+---
```

Detections of Total Viable Counts

```
Source  DF     SS     MS     F      P
Factor   2  0,027  0,013  0,05  0,950
Error   15  3,892  0,259
Total   17  3,919

S = 0,5094   R-Sq = 0,68%   R-Sq(adj) = 0,00%
```

```
                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level   N    Mean    StDev  -----+---------+---------+---------+----
SW      8  3,6005  0,5840    (------------*------------)
GW      4  3,6949  0,2983  (-----------------*-----------------)
RAIN    6  3,6587  0,4976    (--------------*--------------)
                           -----+---------+---------+---------+----
                              3,30      3,60      3,90      4,20
```

APPENDIX G. ANALYSING EQUIPMENT

Compact Dry Plates

Compact Dry is a ready to use method for counting of microorganisms provided by HyServe. The method consists of pretreated plates containing selective substrates and redox indicators in order to detect different types of microorganisms. Sample water is plated directly onto the plates. Different plates are used to detect different microorganism. In this study, following Compact Dry plates were used:

Compact Dry TC (Total Counts) – detects all viable bacteria by using a nutrient standard agar solution. Redox indicator is tetrazolium salt and grown colonies are colored red.

Compact Dry EC (E. coli and Total Coliforms) – detections are made by a medium containing two kinds of chromogenic enzyme substrates, Magenta-Gal and X-Gluc. Resulting *E. coli* colonies are colored blue whilst Total Coliform colonies are colored purple.

Compact Dry ETC (Enterococci) – Detects enterococci by using the selective agent X-glucoside along with antibiotics. Colonies are colored blue to blue-green.

Compact Dry Swabs

Compact Dry Swabs are used in combination with Compact Dry plates in order to perform microbial detections of surface areas. After whipping over a targeted area, the swab is placed in a cover containing 1 ml of peptone Buffered Saline. The sample is then plated onto a selected Compact Dry plate.

ATP pens

ATP measurements were made with LuciPac Pens and Lumitester PD20 (Figure G1), both products delivered by HyServe.

The procedure is based on the measurement of biolumiscence, a resulting product from enzymatic decomposition of adenosine triphosphate (ATP) and adenosine monophosphate (ATM), both substances present in all living cells. Samples are taken with a sterile LuciPac Pen whereon a detergent solution releases the measured substances. Resulting biolumi-scence is then analysed in the Lumitester and a value is reported in Relative Luminescence Units (RLU).

Figure G1. LuciPac Pen and Lumitester PD20