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Household drinking-water quality in the Kenyan Rift Valley

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April 17, 2012

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Foreword and Acknowledgments

The master thesis which I was working at for nearly 5 month in 2011 as a part of the master of environmental engineering at ETH Zurich is reported on the following pages. It was carried out in cooperation with EAWAG in Dübendorf, Switzerland, and the water quality program of CDN in Nakuru, Kenya. The first 2 weeks were spent at EAWAG to get familiar with the equipment and for first experiments in collaboration with Nina Küng who was doing a similar thesis about the household drinking-water quality in Ethiopia. The biggest part of time was spent in Kenya on research and field visits (March, April and May). The last weeks were again spent at EAWAG to do the writing. challenges!!

I would like to thank Nina Küng for the collaboration during the first weeks at EAWAG and the exchange of experiences. Several people at EAWAG helped us with instruction and assistance in the laboratory, information about the project, many explanations and a lot of other things. Thanks a lot to Marina Peter, Frederik Hammes, Hansueli Weilenmann, Caterina Dalla Torre, Lars Osterwalder, Annette Johnson, Christoph Häberli and Hermann Mönch. A special thank is for Richard Johnston for the supervision and encouragement during the whole period. He and my supervisor, Prof. Dr. Eberhard Morgenroth, also gave some new inputs and helpful suggestions during the intermediate presentations. For which I'm very thankful. I would also like to thank the assistants of urban water management at ETH Zurich, René Lüscher and Angela Birrer, for the administration work related to the thesis.

In Kenya I had to face unknown working and living conditions but I could always count on the CDN WQ team. They gave me working space in the office and the laboratory and helped me to find my way. Further they supported me in organizing and carrying out the field visits where someone had to drive, translate and explain. I'm very grateful to all of them - Peter Maina Mutheki, Elizabeth Wambui, Carolyne Faith Wanyonyi, Esther Wanja, Daniel Mbandu, Nancy Wanjiku, Julius Waweru, Josua Kubai and the whole CDN WQ staff and technicians. I would also like to thank everybody who allowed me to test his or her drinking- water and patently answered all my questions even when they were strange in their eyes. Asante sana!

Abstract

Naturally high levels of fluoride occur in the drinking-water sources of the African rift valley. Thus defluoridation filters for household and community level were developed by the water quality program of the catholic diocese of Nakuru (CDN WQ), Kenya, to prevent fluorosis which is a severe disease caused by high fluoride consumption. However, large numbers of water borne diseases result form microbial contamination of drinking-water. The microbial water quality has not yet been a big issue for CDN WQ although an extension of the household filters with ceramic candles was implemented a few years ago.

The purpose of this thesis is to measure and document the influence of the defluoridation technique on the microbial drinking-water quality in the Kenyan rift valley. A similar master thesis looking at the defluoridation filter in Ethiopia was carried out at the same time by Nina Küng.

The collected water samples were analyzed for the three indicator bacteria *E.coli*, total coliform and enterococci with Compact Dry plates (enzyme based plating method) usually in combination with membrane filtration. For the community based filters samples were taken from the raw water, the treated water and from the point of use of some households depending on them. The household filters were additionally sampled just after the ceramic candle to get an impression of their reduction efficiency. Copper is said to have an inactivating effect on microorganisms and a few experiments to its implementation in water treatment were carried out in the lab and in household filters.

The remote area filters which are fed with surface water were able to reduce the microbial contamination significantly by more than 1 log unit for each indicator. On average the standard community filters didn't influence the drinking-water quality but some filters showed an enormous contamination through the filter. For the household filters neither the different filter media nor the addition of copper wires had a significant impact on the water quality. The average reduction achieved through the ceramic candles in the laboratory and in the households didn't exceed 0.9 log units compared to the 2 log units promised from the manufacturer. The bacteria levels at the point of use, especially the counts of total coliform, were significantly higher for households depending on a community based collection point such as a water kiosk than for households with a tap nearby. A comparison between the quality at the kiosk and in the households showed a clear increase of the bacteria level especially for total coliform and enterococci.

On average the defluoridation filters didn't influence the drinking- water quality neither positive nor negative except for the remote area filters which were designed to treat surface water and achieved a clear reduction of the bacteria level. The high numbers of total coliform in the water of household relying on kiosks can be explained by their usage of sand to clean the containers and by the fact that total coliform occur in soil.

Further experiments to the inactivating effect of copper and the efficiency of ceramic candles are advisable. Another recommendation is to consider possible intervention measures e.g. shock chlorination to treat filters when the contamination level increased due to filtering and try them out in the laboratory. The Compact Dry plates and the portable filtration stand were suitable the application in Kenya.

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1 Introduction

Access to safe drinking-water is a basic human right and essential to life. Nevertheless, a large number of people in developing countries lack safe drinking-water and therefore one target of the Millennium Development Goals of the United Nations is to halve the proportion of the population without sustainable access to safe drinking-water by 2015. Safe drinking-water includes both quantity and quality.

A large number of people in the Rift Valley, East Africa, suffer from fluorosis because of the naturally high fluoride concentration in their drinking-water. For this reason the chemical water quality especially the fluoride content was the major issue of the collaboration between the Water Quality Program from the Catholic Diocese of Nakuru (CDN WQ). Kenya, and EAWAG so far. In order to reduce the fluoride level to an acceptable level different types of defluoridation filters have been developed and installed. These are described in chapter 2.3.

However, a large number of water borne diseases are related to microbial contamination of drinking-water. According to the WHO unsafe drinking-water, together with inadequate sanitation and hygiene, contributes a majority of the 1.8 million annual deaths caused by diarrhoeal disease. The microbial contamination of household drinking-water in the Kenyan Rift Valley is suspected to be high, but few data are available. For that reason an extension of the household filters with a ceramic candle was developed by CDN WQ a few years ago. But the impact of these defluoridation filters and ceramic candles has not been rigorously examined. The aim of this thesis is to measure and document these influences. Field research for the thesis was done in Nakuru and Baringo districts in the rift valley province of Kenya and can be seen on the map of Kenya below.

Figure 1.1: Left: The East African Rift valley crosses the East African countries Tanzania, Uganda, Kenya and Ethiopia (source: USGS, 2011). Right: The project area in the Kenyan Rift Valley includes the Lakes Baringo, Bogoria, Elementaita, Naivasha and Nakuru which are all in Nakuru and Baringo district (source: world travel, 2011).

A similar Master thesis about the drinking-water quality in Ethiopia was carried out parallel by Nina Küng. The laboratory experiments at EAWAG and the literature review on the indicator bacteria were therefore done in collaboration with her.

2 Background

2.1 Fluoride

High levels of naturally occurring fluoride contaminate drinking-water resources throughout the African Rift Valley. In Kenya, millions of people consume drinking-water containing fluoride levels well over the national drinking-water standard of 1.5 mg/l (CCEFW 2010 and Chibole 1987). Many shallow wells contain more than 10 or even 20 mg/l fluoride and consumption of such high levels of fluoride has led to high levels of crippling skeletal fluorosis. In general surface water has lower levels of fluoride which still cause widespread dental mottling. The 2 mentioned diseases (illustrated in Figure 2.1) are merged to fluorosis. Depending on the diet the intake via food may play an important role besides the consumption by drinking. Once affected to fluorosis there is no real cure to it. Neither the browning and chipping of the teeth nor the deformed skeleton will recover.

Figure 2.1: Dental fluorosis (left) and skeletal fluorosis (right) (source: CDN brochure, 2011)

As a consequence of droughts and increasing water need a large number of new boreholes have been drilled for the last 30 years. More than 50% of the boreholes in Nakuru and Baringo district show high fluoride levels (CCEFW 2010) and alternative water sources with lower levels of fluoride are scarce in the region. As the fluoride concentration in the water is not affected by conventional water treatment processes like boiling or chlorination and the known treatment with alum is expensive, defluoridation filters were developed by Peter Jacobsen and the CDN WQ.

2.2 Water quality program of the Catholic Diocese of Nakuru

The water quality section of the Catholic Diocese of Nakuru (CDN WQ) has developed several different defluoridation filters and has been run as a company called Nakuru Defluoridation Company Ltd. for a short time. The Program has installed about 100 community filters and 1000 household filters since the start of the project in 1998. At the same time they continuously optimized the filter media composition and the design of the filters. EAWAG has been involved in developing and optimizing household and community defluoridation units since 2006 (CDN reports 2007).

However, the project to date has examined only chemical water quality. It is suspected that microbial contamination of household drinking-water in project area is high but it is not known if defluoridation treatment has any impact (positive or negative) on microbial water quality. At this point this master thesis was initiated to open the point of view to the microbial drinking-water quality.

2.3 The different types of filters in the project area

The defluoridation process in the filters is based either on bone char (BC) or on contact precipitation (CP). In contact precipitation filters, calcium phosphate pellets are mixed with bone char and as they dissolve new solids are precipitated in the filter, prolonging their lifetime. When the filter material is saturated, fluoride will break through and the filter media should be replaced or regenerated to retain the defluoridation capability. The descriptions of the different types of filter on the following pages refer to the CDN reports from 2007.

A **household filter** unit is serving a family with water containing low fluoride concentrations for drinking and cooking. Two different designs have been developed: a simple defluoridation bucket or a combined filter system with a ceramic candle unit on top to remove microbial contamination as well. Both of them are either filled with bone char or a mixture of bone char and pellets.

The simplest defluoridation units consist of a 20 L bucket filled with 12 L of filter material. In total around 10 L of water can be placed in the bucket. The filter material must be prevented from drying out otherwise preferable flow paths would develop and thus the lifespan would be shorter.

In 2005 combined filter units were introduced by CDN WQ. They consist of a normal defluoridation unit with a second bucket on top of it. The second one is transparent and contains the ceramic candle which has silver nitrate and activated carbon in it. The microorganisms are held back by the filtering process and remaining ones are killed by the toxic silver nitrate. The activated carbon adsorbs organic compounds and removes residual disinfectants such as chlorine by a catalytic reaction from the water. The candles are imported from Brazil where they are produced by Stefani Ceramics. The candles are said to reduce bacteria concentration by 2 log units. The defluoridation bucket is constructed in a way that the filter material (mostly CP) is prevented from drying out (see Figure 2.2). The upper part controls the flow rate of the water which is decreasing in time and is lower with higher turbidity. The maintenance of the combined filters is more complicated since the ceramic candles need to be cleaned regularly and they are likely to break if they're not treated with care. However most of the people go for a combined filter and for that reason defluoridation buckets are only rarely found in the project area and therefore wasn't part of the survey.

Some nice looking filters have been sold for a while. These filter units are made out of stainless steel (SS) and exist only as combined filters. They don't contain an inner bucket like the plastic combined filters and are always filled with bone char only.

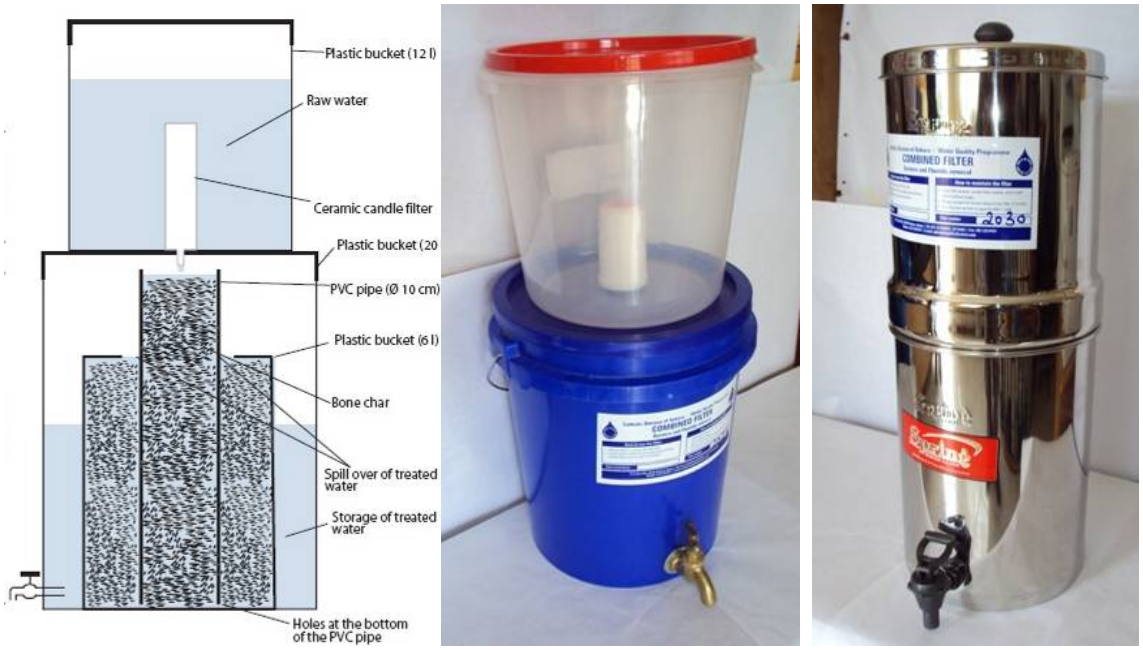

Figure 2.2: Combined filters for Bacteria and Fluoride removal - scheme and picture of the plastic one on the left and a stainless steel unit on the right (source: NDC 2011)

Since the introduction of combined filters, it was observed that most of the people who buy a filter go for the combined ones rather than the defluoridation buckets. As a consequence defluoridation buckets are hardly found in the project area.

Community based filters exist in different designs and sizes which range from 50 L up to 200 m^3. Some are connected to a water supply system and some are fed discontinuously. Three types are differentiated by CDN: institutional filters, community filters and filters for water works. They are all set up in a way that the filter material can not dry out.

Institutional filters are the smallest community based filters and treat around 50 to 500 L per day. They are designed for larger kitchen or institution and are normally connected to a water supply system. The water inflow is controlled by a ball valve which keeps a constant water level in the filter and prevents the filter media from drying out. This kind of filter was not taken into account for the survey.

Community filters (CF) are serving 1000 to 5000 people in communities where the water is collected at a central water point. Standard community filters consist of a 4 - 20 m^3 PVC tank filled with bone char of different sizes and pellets. Some of them are operated as water kiosks where defluoridated water is sold for 2 - 5 KES (Kenya Shilling) per jerry can of around 20 L (Currently 100 KES = 1.1 US dollar or 0.92 CHF; exchange rates (2011)). Others are connected to a supply system which serves the households with treated water or belong to a large institution like a school. These filters are connected to a piped water source which is normally an own borehole. The design of a standard community filter can be seen below.

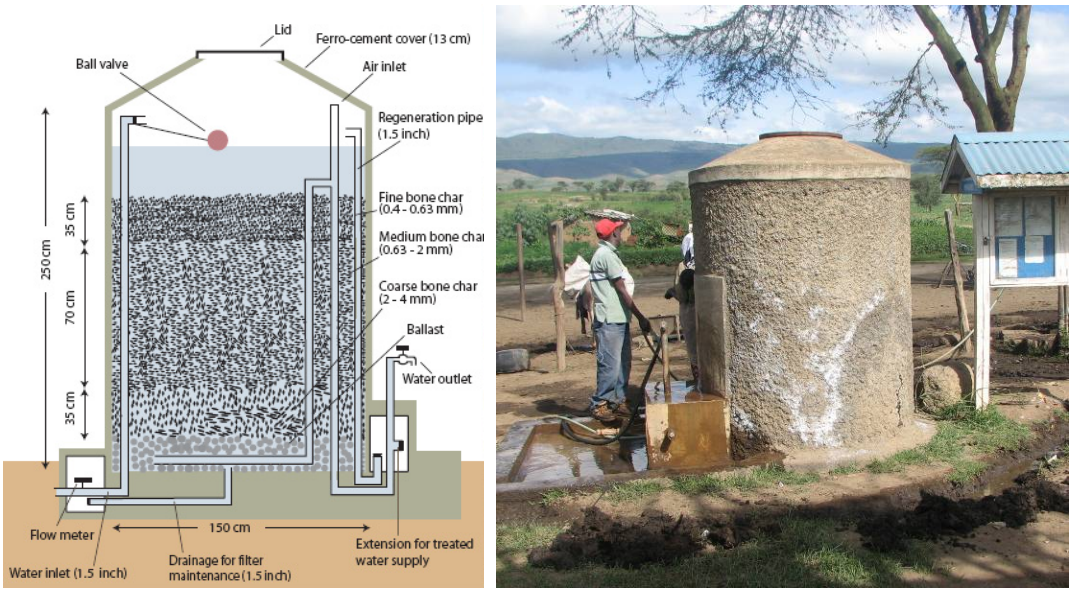

Figure 2.3: Standard community filter scheme (source: NDC, 2011) and a picture of the Moindabi 1 CF in Naivasha

Remote area filters (RF) are a special type of community filters which are not connected to a water supply system but are fed with surface water or with manually pumped groundwater. Most of them were installed in Baringo district where the raw water taken from rivers and lakes is highly turbid, colored and contaminated. Therefore a special design was set up (see Figure 2.4) which allows reducing the turbidity, color and microorganisms. The reduction is estimated to be 95% for turbidity and faecal coliforms. The filters can be used discontinuously and whenever water is added, almost the same amount can be withdrawn immediately.

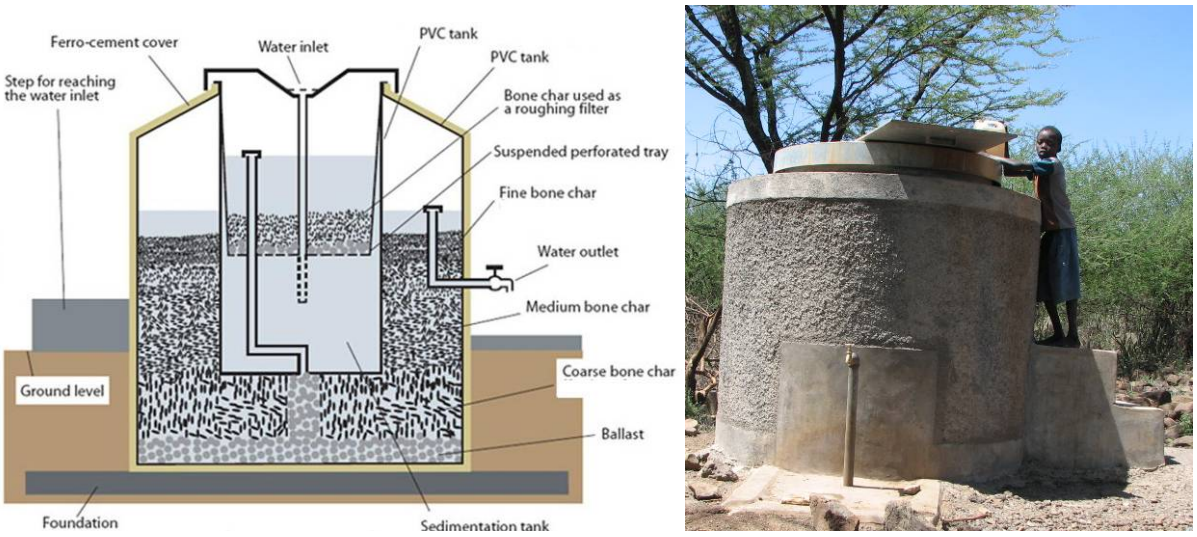

Figure 2.4: Scheme of a remote area filter (source: CDN WQ) and picture of RF Longicharo on an island in Lake Baringo

Filters for water works consist of several large community filters coupled in series. They are slightly modified to the higher working load and need to be regenerated in intervals of a few weeks. No such filter was sampled in the survey as the number of different filter types is already large without them.

The lifespan of all described filters is estimated based on the fluoride concentration of the raw water, the water consumption and the adsorption capacity of the filter media. Since the relevant factors vary highly there are household filters where an exchange of the filter media got necessary after one year only. Others are operated without change since more than 5 years and the fluoride level has not yet exceeded the requirement. Several community based filters are even older and still achieve acceptable levels of fluoride. The age of the sampled filters is listed in Table 4.1 and Table A 3 for the household filters and the community based filters respectively. When the calculated lifespan is reached the water quality needs to be tested regularly as the filter media should be replaced as soon as a fluoride breakthrough is observed. The prizes for the different types are listed in the appendix A3.3.

2.4 Microbial water quality

2.4.1 Indicator organisms

Disease-causing organisms like *Vibrio cholerae* or Salmonella pose a human health risk when they are present in drinking-water- even in small numbers. Testing of microbial drinking-water quality is usually limited to that of indicator organisms since testing for pathogens is complex and expensive. The concept of using indicator organisms as indexes of faecal pollution is a well established practice. Faecal pollution always points out a potentially dangerous contamination since pathogens are found in the faeces of infected people. The most common indicators are total coliform bacteria, faecal (or thermotolerant) coliform bacteria and *Escherichia coli* (*E.coli*).

According to the World Health Organization (WHO) drinking-water guideline (2008), bacterial indicator of faecal pollution should fulfill the following criteria:

- be associated with disease-causing organisms, but not be pathogen themselves
- be universally present in faeces of humans and animals in large numbers
- not multiply in natural waters
- persist in water in a similar manner to faecal pathogens
- respond to treatment processes in a similar fashion as faecal pathogens
- be easily, reliably and cheaply detectable

These criteria are based on the assumption that the same organism can be used as an index of faecal pollution and as an indicator of treatment and process efficiency.

For this survey the microbial water quality was tested by using total coliforms, *E.coli* and enterococci as indicator organisms. The 3 bacteria groups and their suitability as an indicator organism are described below.

Total coliform bacteria include a wide range of aerobic and facultatively anaerobic, Gram-negative, non-spore-forming bacilli. They are present in faeces where they are found in large numbers and were therefore initially chosen as the indicator organisms for drinking-water safety. But total coliforms are also naturally present in the environment, especially in tropical countries. Therefore they are not a good index of faecal contamination, but they can be used as an indicator for the effectiveness of treatment processes, to assess the potential presence of biofilms and for risk assessment in lower-risk waters when *E.coli* is not present. As total coliform bacteria are more sensitive to disinfection than other bacteria, protozoa and viruses, better indicator for this purpose exist. A variety of relatively simple procedures are available based on the production of acid from lactose or the production of the enzyme β-galactosidase.

E.coli is a subgroup of the total coliform bacteria which is capable of fermenting lactose at higher temperatures. *E.coli* are universally present in high numbers in human and animal faeces and are rarely found in the absence of faecal pollution. For that reason *E.coli* is considered to be the most suitable index for faecal contamination. Some strains of *E.coli* are pathogenic, but most of them are harmless. Several simple methods for its detection exist. They are mostly based on the production of acid and gas from lactose or the production of the enzyme β-glucuronidase. Like the total coliforms *E.coli* are more sensitive on some disinfection processes than protozoa and viruses nevertheless it is sometimes used as an indicator of treatment efficiency.

The WHO guideline value is that *E.coli* 'must not be detectable in any 100 mL-sample' of drinking-water and if any are detected 'immediate actions must be taken' as the presence of *E.coli* always indicates potentially dangerous contamination. Developing Countries which have problems to meet the standards should set 'medium-term targets for progressive improvement' for example by using a risk classification system like the following:

0 CFU/100 mL	meet the WHO guideline
1-10 CFU/100 mL	low risk
11-100 CFU/100 mL	intermediate risk
101-1000 CFU/100 mL	high risk
>1000 CFU/100 mL	very high risk

The Kenyan Environmental Management and Co-ordination (Water Quality) Regulations from 2006 sets nil *E.coli* per 100 mL as quality standard for sources of domestic water. At the moment this is the only guideline regarding the microbial drinking-water quality.

Enterococci are relatively specific for faecal contamination. The number of them in human faeces is generally an order of magnitude lower than for *E.coli*. However, some occasionally originate from other habitats like soil. Enterococci are able to survive in environments which would kill lots of other bacteria. They are facultative anaerobes and are more resistant to drying and chlorination than *E.coli*. The presence of Enterococci in drinking-

water indicates recent faecal contamination and therefore further actions should be considered in case of their detection. Simple, inexpensive cultural methods exist for the detection of these organisms.

Recent faecal contamination can be recognized by the presence of *E.coli* and/ or Enterococci. Faecal contamination doesn't necessary mean that pathogens are present too, as pathogens other than the 2 indicator organisms only occur in faeces of infected people. A statement about the efficiency of the process is possible for each indicator organism by comparing the colony forming units (CFU) before and after. Neither of the chosen indicator organisms is a good indicator for the occurrence or removal of protozoa and viruses as they respond different to treatment processes and don't persist in a similar manner.

2.4.2 Enzyme based detection

Enzyme based detection methods generally work with colored or fluorescent markers that change color after an enzyme reaction which is specific for a certain indicator organism. Colorless colonies might grow on the media but as they don't perform the detected reaction they don't belong to the indicator. Besides, most of the medias contain substances to inhibit the growth of other bacteria.

The following subchapter emphasizes on the enzyme based detection of total coliforms and *E.coli*. The detection of enterococci on the contrary is covered in the master thesis of Nina Küng.

β-galactosidase is an enzyme which is particular for total coliforms. Several markers for the detection of the enzymatic activity exist: XGAL (5-bromo-4-chloro-3-indol-β-galactopyranoside), ONPG (O-nitrophenyl-β-D-galactopyranoside), Magenta GAL (5-Bromo-6-chloro-3-indolyl-β-D-galactopyranoside) and MUGAL (4-methylumbelliferyl-β-D-galactopyranoside), respectively. False positives might occur in the presence of Aeromonas or Vibrio cholerae in the water because they have galactosidase although they are not coliform. In particular environments such as estuaries the total coliform count can be overestimated due to UV-stimulated enzymatic activity in certain bacteria.

The activity of β-D-glucuronidase is used as a marker for faecal coliforms in environmental polluted water and specific for *E.coli*. Apart from most *E.coli* strains some strains of Salmonella, Clostridium, Streptococcus and Shigella strains show this enzymatic activity as well and can therefore lead to false positive colonies (Cabral, 2010). However, Köster et al (2003) state that the influence is not significant. Markers such as XGLUC (5-bromo-4-chloro-3-indoxyl-β-D-glucuronide), IBDG (indoxil-β-glucuronide), and MUGLU (4-methylumbelliferyl-β-D-glucuronide), respectively, change color after the enzymatic reaction takes place.

2.5 Copper as a simple intervention for inactivation

Thousands of years ago the sanitizing effect of copper was discovered by the ancient Greeks and it has been used all over the world to disinfect liquids, solids and tissues. There are a lot of opportunities to benefit from the ability of copper to inactivate microorganisms and recent research (e.g.: Michels et. al (2005), Sudha et. al (2009) and Borkow & Gabbay (2004)) was carried out about its implication in the food industry and in healthcare.

Today copper is also used as a water purifier. As copper is an essential trace element in the human diet it is safe for humans at low levels but can lead to acute gastrointestinal effects. Other impacts occur at different levels of copper: staining of laundry and sanitary at concentrations above 1 mg/liter, undesirable bitter taste to water above 2.5 mg/l and impacting the color of the water at higher levels. The WHO drinking-water guideline suggests a guideline value of 2 mg Cu/l. According to Sudha (2009) inactivation of microorganisms takes place for copper storage vessels which are traditionally used in India and for copper devices in storage containers as well. Putting a copper wire into storage containers or filters would be a simple intervention to prevent regrowth on household level. Therefore some experiments were carried out about the inactivating effect of copper.

The inactivating mechanisms of copper are not yet fully understood. Borkow and Gabbay (2005) describe the following mechanisms of the inactivation effect on bacteria: copper mediated cell membrane damage, copper interaction with nucleic acids, copper mediated protein damage and mechanisms of copper antiviral, antifungal and anti-algae activities. But there are as well some bacteria (e.g. some Pseudomonas species) found who demonstrate to be resistant against copper. The 6 known resistance mechanisms against heavy metals can be applied to copper as well: (1) metal exclusion by permeability barrier, (2) active transport of the metal away from the microorganism, (3) intracellular sequestration of metals by protein binding, (4) extracellular sequestration, (5) enzymatic detoxification of a metal to a less toxic form and (6) decrease in metal sensitivity of cellular targets. They are described in more detail by Borkow and Gabbay (2005). The mentioned inactivation mechanisms for bacteria are relevant for viruses as well and since they don't have resistance or repair mechanisms, they are even more sensitive to high copper concentration than bacteria. Protozoas are not generally inactivated by copper and their inactivation depends on the copper concentration and on the ratio to other metal ions. For example: copper in combination with silver is able to inactivate protozoas but only if the ratio is high enough. So it was found out that concentrations within the guideline values don't have an impact on the protozoas.

3 Objectives

The major question of the thesis which was already mentioned above is:

“What is the effect of the defluoridation filters on the microbial water quality in Kenya?”

Since different filter types are used in Kenya, several research questions were formulated:

- Are there significant differences between microbial water-quality at the point of use (POU) for filter-using households and non-filter using ones?
- Are there significant differences between microbial removal efficiencies of the different filter media: bone char only and a mixture with pellets (=Contact precipitation)?
- Are the pellets influencing the inhibition with copper? Are pellets linked with differences in the microbial contamination and / or the copper concentration? (Phosphate is expected to form complexes with copper, which could affect its microbial activity)
- Are there significant differences in the microbial removal efficiency for stainless steel filters compared to plastic ones?
- Is the water quality (raw and filtered water) changing over time? In which magnitude?
- Is the used equipment suitable for the application in Kenya?

The following hypotheses were developed:

- Household water becomes contaminated through transport and storage when collected from community and remote filters.
- Remote filters have a microbial removal efficiency of 95%.
- The combined household filters (i.e. with ceramic candles) have higher microbial removal efficiency than the defluoridation buckets.
- The defluoridation process itself doesn’t have a large impact on the microbial water quality.
- Raw water: The surface water is more contaminated than the water from boreholes and wells. Piped water might be in the range of the boreholes and wells or a bit more contaminated depending on the standard of the water work and the condition of the system.
- Copper contact is inhibiting further growth of microorganisms or even killing them.

4 Methods

4.1 Compact Dry Plates

Compact Dry plates are products for microbial testing which were initially developed for the food industry. The plates contain chromogenic substrates and redox indicators to select specific microorganisms. Several types of Compact Dry plates exist to test for different microorganisms. The EC and the ETC plates were used in this study. The ETC plates are specific for enterococci and EC plates for total coliforms and *E.coli*. So both types of plates are able to detect bacteria which are used as indicator organism in water quality monitoring (compare chapter 2.4.1).

Both plates consist of a shallow plastic dish with pre-poured dehydrated growth media and substrates which react with specific enzymes. The EC plates use Magenta GAL for the detection of total coliforms and X-Gluc for the detection of *E.coli*. Therefore total coliform bacteria appear purple and *E.coli* blue. This type of plate is AOAC approved and was certified to be equivalent to the norms ISO 16649-2 (2001) for *E.coli* and ISO 4832 (2006) for total coliforms. These standards refer to microbial testing of food and a comparison to the equivalent standards for drinking-water testing has not yet been carried out. Nevertheless the results of the Compact Dry plates should be comparable to results from traditional plating methods.

The detection of enterococci with the ETC plates is based on the use of X-Gluc and antibiotics. They will grow with blue to blue-green color (see Figure 4.1).

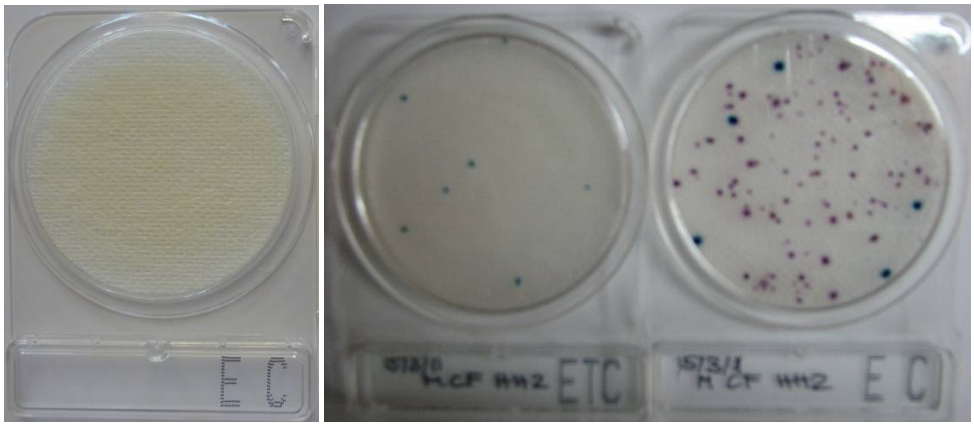

Figure 4.1: Dry Compact plates- before using (left) and after incubation (right): EC plates with total coliforms (purple) and *E.coli* (blue) and ETC plates with Enterococci (blue)

The procedure to use the plates is quite simple and straightforward: after labeling the plate, 1mL of the sample is placed onto the dry plate, and diffuses into the media. Plates can be used in combination with membrane filtration (see chapter 4.2) by rehydrating the media with 1mL of sterile water and placing the filter on top of it. One of the most challenging parts of the research project was to decide on the appropriate water volume to get a reasonable amount of colonies. The number of colony forming units (CFU) should ideally lie between 20 and 200 CFU per plate. For counts outside this range the uncertainty gets much bigger. The manufacturer recommend to incubate for 24 hours at a temperature of 35°C ±2°C.

As it is a plating method the detected organisms are the ones which are able to multiply. Therefore this method will not detect organisms around which are present but incapable of growth. As pathogens can only cause harm when they are able to multiply the colony forming unit is still a good parameter. Nevertheless it is important to keep in mind that some organisms might recover and grow again.

4.2 Membrane Filtration

Whenever it is required to sample a larger volume than 1 mL, membrane filtration is necessary. A portable filtration stand from Millipore, the Microfil system, was used for that. So it was possible to process samples either on site or in the laboratory by using Whirlpak bags or sterilized bottles. Whirlpak bags are sterile sample collection bags with a volume of 100 mL containing a thiosulfate tablet to inactivate any chlorine present (Figure 4.2)

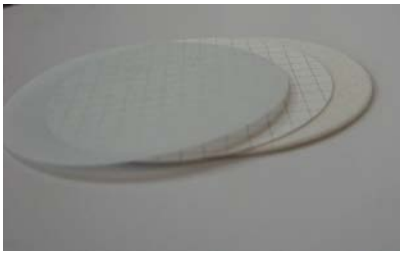

Figure 4.2: Whirlpak bag for sample collection (left; source: hatch 2011) and filter membrane (gridded paper in the middle) for membrane filtration

A sterile filter membrane is placed on top of the stand. The used membranes had a diameter of 47 mm, a pore size of 0.45 µm and were gridded. Three different brands were used which consisted of slightly different material: Millipore (mixed cellulose esters), Pall (mixed cellulose esters; Figure 4.2) and Sartorius (cellulose nitrate). A comparison between the 3 types showed that they can be used interchangeable. Then a sterile 100 mL cup which tightly seals to the manifold is positioned. Afterward a certain volume of water (20, 50 or 100 mL) is poured into it. The volumes can be measured with the marks on the cup for 20, 50 and 100 mL. The water is manually sucked off with a syringe (see Figure 4.3).

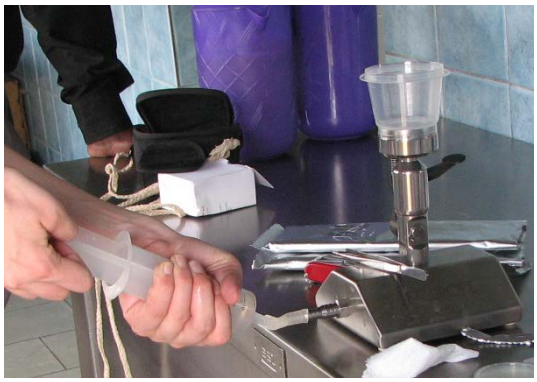

Figure 4.3: Filtration stand with a 100 mL cup on top

The filter is removed from the stand using sterile tweezers, and placed on the Compact Dry plate which has already been rehydrated with 1 mL sterile water (boiled water). Volumes of 1 mL were measured with a VWR fixed volume pipette. Sample cups were reused after sterilization in the oven of the laboratory at approximately 80°C for at least 6 hours. The stand and the tweezers were flamed or wiped with methanol to sterilize them before each filtration. Periodically they were sterilized in the oven at around 80°C.

4.3 Data Analysis

The reduction and the difference between 2 data oints were calculated in log units as follows:

Log reduction value: $LRV = \log(CFU_{before}/CFU_{after})$ resp. log difference between A-B: $LD_{A-B} = \log(CFU_A/CFU_B)$

For the calculations a maximum of 400 CFU were put in whenever this number was exceeded. After counting 100 colonies one could estimate visually if the total number is above or below 400. If the former is the case the counts were declared to be > 400 otherwise the remaining colonies would be counted as well. It's common to use half the detection limit for calculation. As the detection limit of the plates is one colony, 0.5 CFU were inserted for calculation. The maximum log difference is therefore 2.9 and -2.9 respectively, when the same volume is measured before and after treatment.

4.4 Laboratory Experiments at EAWAG

4.4.1 Incubation at different temperatures

The majority of the dissertation research was planned to take place in Kenya. It was expected that the electricity would not always be available and therefore that an incubator could not always be used, especially during visits to remote rural areas. For this reason experiments were made at EAWAG to investigate the impact of different incubation temperatures on the number of CFU. Preliminary experiments were conducted with different combinations of Chriesbach water and effluent of the primary clarifier to identify a mixture with a suitable contamina-

tion level for both the EC and the ETC plates. The following temperatures were chosen: 11°C, 20°C, 25°C, 30°C, 37°C, 42°C and 45°C. Additionally one set of plates was stored at variable temperatures. Firstly it was incubated at 37°C for 7.5 hours which imitated the body temperature of a human ('pocket incubation'). Over night it was stored at 11°C for 13 hours which corresponds to the minimum temperature for the months of March to May in Kenya. For the next 7 hours the plates were incubated at 37°C again. Afterwards they were stored at 11°C constantly. The CFU were counted after 24, 48, 96 and 120 hours of incubation to investigate temporal effects.

4.4.2 Exposure to Copper and Steel

A short first experiment with copper which was carried out in the laboratory at EAWAG is described here: 6 tubes of 50 mL were filled with the same combination of Chriesbach water and primary clarifier effluent which was used for the temperature experiment (described in the previous chapter). A piece of copper wire (6 cm long and 0.4 mm thick) was added to 2 of them and a similar piece of iron florist's wire to 2 others. The 2 remaining tubes were stored as a control without any supplement. The tubes were incubated at 30°C in a shaking incubator. At the start of the experiment 2 samples for EC plates were taken. After 24 hours of exposure one of every type of tube was sampled to EC-plates. After 96 hours of exposure to copper and florist's wire all the tubes were sampled for ETC and EC plates with several dilutions (1, 1:100 and 1:1000) and duplicates. All the samples were incubated at 30°C.

4.5 Laboratory Experiments at CDN WQ

The plates were kept at around 35°C for 24 hours with an incubator of the model Cultura M from Selectech which was also used for the incubation of the plates from the field.

4.5.1 Comparison of different copper wires

The aim of this experiment was to compare the inactivation capability of copper wires locally available in Kenya, and the one which was used in Switzerland. For that reason three 300 mL bottles of water were stored for 24 hours in the laboratory (26 - 30°C). One contained a local available copper wire with a length of 9.5 cm and a diameter of 1 mm. The second one contained the Swiss copper with a similar surface area (length: 24 cm and diameter: 0.4 mm). The third one served as a control and didn't contain any copper. Treated water from the St. Mary's community filter served as a water source and 100 mL samples were plated at the start of the experiment. After an exposure to copper of 24 hours 100 mL samples were taken from each bottle. The samples were carried as duplicates with EC-plates and counted after incubation at around 35°C for 24 hours.

4.5.2 Combined plastic filters

Three combined plastic filters were installed in the laboratory of CDN to conduct experiments under controlled conditions. Filters 1 and 2 contained contact precipitation media while Filter 3 contained bone char only. A copper wire from Switzerland (length: approx. 18 m and diameter: 0.4 mm) was placed inside the lower compartment of Filter 1. The amount and time of filling was recorded every time. The same water source was used for all 3 filters and consisted of tap water which was contaminated with bacteria from a previous plate or/ and some pond water.

Samples (in most cases 100 mL) were taken from the raw water, directly after the ceramic candle and from the filter tap and were analyzed as duplicates with EC plates.

This set up served 3 purposes: comparison of the 2 different filter medias, impact of the copper wire and an assessment of the efficiency of ceramic candles. In addition the uncertainty of the used plating method could be quantified due to the duplicates.

4.5.3 Quality control

Every 10 - 20 samples a blank sample was carried out to make sure that there was no contamination through the boiled water used whenever membrane filtration was necessary. Duplicates were carried out for all the samples taken in the laboratory at CDN.

4.6 Field visits

Whenever possible the plates were incubated in the incubator at around 35°C for 24 hours what was not possible for the samplings in remote areas. Therefore the plates were carried in the pockets during the day and put into the incubator over night. All plates from a filter were handled in the same way so that at least the ratio should be consistent.

4.6.1 Household filters

Almost all the owners of household filters live in an area where a water distribution system is established. As there isn't running water all the time most of them store water in storage containers for the rest of the time. Preliminary studies showed that the microbial quality of tap water in Nakuru town is quite good and 100 mL samples are adequate. The sampling procedure for the household filters included the following sampling points:

- Source: either tap water when running water at the day of the visit or from a storage container
- Between the ceramic candle and the defluoridation process for the combined filters: for the stainless steel the sample could be taken from the standing water on top of the bone char, for the plastic combined filters the upper part with the ceramic candle was placed on another container
- Sterilized tap of the filter: the tap was sterilized with a lighter and flushing after that and the water was collected with whirlpaks
- Point of use (POU): from a glass or cup

The samples were usually filtered through membranes and inoculated onto Compact Dry plates at the household. This did not pose a large time burden, as one had to wait anyway for the water to filter through the ceramic candle. In addition the required sample volume was large and therefore the wastage of whirlpaks would have been enormous.

10 combined filters (5 stainless steel and 5 plastic ones) were sampled 5 times in irregular intervals over a period of 2.5 months (Mid March to end of May). The monitored filters are summarized in the table below and the location can be seen on the map in the appendix (Figure A 1). Copper wires were put in eight of them at different points in time (last column of Table 4.1). The used wires had a surface area of 74 cm^2 and were either locally available ones or from Switzerland. According to Sudha (2009) a ratio of around 15 cm^2 copper per liter of water should be sufficient to achieve a reduction i.e. the used wires should be able to treat around 5 liters of water. For the plastic filters the wires were placed at the bottom of the lower filter part outside the inner bucket and for the stainless steel filters they were simply put on top of the bone char. The aims of the monitoring were first to see the variability in the drinking-water quality, second to gain some data about the inactivation through copper and third to see possible differences between the filter types in the microbial contamination, the copper inactivation mechanism, the copper and phosphate concentration in the treated water. Samples for copper and phosphate measurement at EAWAG were taken in the end of the observation period for the following filters: SS 2, SS 4, Pl 2, Pl 3 and two laboratory filters (CP with and without copper) for comparison purposes. These measurements were carried out with an inductively coupled plasma mass spectrometry (ICP-MS) from Agilent Technologies.

Table 4.1: Overview of the monitored combined household filters in Nakuru: The owner of SS 1 have a defluoridation bucket which they use for cooking only, SS 4 and Pl 2 are owned by the same family who use the water from the plastic filter for cooking and the one from the stainless steel for drinking (SS = stainless steel, BC = bone char and CP = contact precipitation)

ID	User	material	media	age of media	age of candles	Source	# sampling	Copper
SS 1	5	SS	BC	summer 2009	Nov 10	tap / container	5	7.Apr
SS 2	5	SS	BC	Feb 11	Feb 11	tap / container	5	7.Apr
SS 3	7	SS	BC	spring 2009	spring 2009	container (tap)	5	21.Apr
SS 4	5	SS	BC	2009	2009	container (vendor)	5	21.Apr
SS 5	5	SS	BC	Apr 10	Apr 10	tap	4	
Pl 1	5	Plastic	CP	2010	Jun 05	Tap	5	7.Apr
Pl 2	5	Plastic	CP	Nov 10	Nov 10	container (vendor)	5	7.Apr
Pl 3	4	Plastic	CP	19.03.2010	19.03.2010	tap / container	5	21.Apr
Pl 4	5	Plastic	CP	12.08.2008	12.08.2008	tap / container	5	21.Apr
Pl 5	4	Plastic	CP	06.07.2009	06.07.2009	tap / container	5	

4.6.2 Community filters and remote area filters

In general a sample was taken from the raw water and one from the tap of the filter. The treated water was taken after sterilization of the filter tap for the remote area filters, St. Theresa, Longiwan and the second sampling at Greensteds. For the WSUP kiosks in Karagite, Moindabi 1 and Moindabi 2 sterilization was not possible because of plastic pipes fixed to the taps. Additionally households which use the water from the filters were sampled at the point of use whenever and as many as possible. When the community filters were set up for a school, a sample from the point of use was taken as well. For standard community filters with a borehole or piped water

source 100 mL samples were filtered. Since the source water for remote filters was expected to be of poor microbial quality, 1 and 20 mL samples for the source and the 50 mL samples for the tap were taken from these filters. For the households of standard community filters and remote area filters a sample volume of 1 or 20mL was convenient. The filtration was carried out either on site (especially for large sampling volumes), in a hotel room or in the laboratory. If the samples had to be transported, they were carried in whirlpaks and filtered within less than 8 hours.

A short description to the sampled filters can be found in the appendix (Table A 3) and their locations are displayed in Figure A 2 - 4. The 7 WSUP (Water and Sanitation for Urban poor) kiosks in Karagite, Naivasha, are identical community filters which were set up at the same date and have the same water source. Therefore one gets a good comparison possibility.

4.6.3 Quality control

The following principles of quality assurance and control according to Lantagne (2010) were obeyed for all field visits to ensure that the data generated are reliable: approximately 10% of all samples were duplicated and one blank sample was taken every 10-20 sample. As the number of available ETC plates was much smaller than the available EC plates, the blank samples were restricted to EC plates with the idea that a possible contamination of the boiled water would be visible on both types of plate. The duplicates have the purpose to give a better understanding of the precision of the method and the blank samples are a control of the sterility of the boiled water.

5 Results

5.1 Laboratory Experiments at EAWAG

5.1.1 Incubation at different temperatures

For an incubation temperature of 30°C, 37°C and 42°C the CFU of ***E.coli*** were constant over time and laid within the range of 15 - 18 CFU/mL (see Figure 5.1) over five replicates. This could be observed for the variable temperature set up as well. At temperatures of 11°C and 45°C almost no CFU developed no matter how long the plates where incubated. For the incubation temperature of 20°C the counts changed significantly between 24 and 48 hours of incubation (p-value: 0.0004). After 48 hours no significant change of the amount of CFU appears. At 25°C the number of colonies didn't change significantly over time (p-values >0.1) however the counts are significantly lower than the ones at 30, 37 and 42°C (p-values: 0.0039, 0.0022 and <0.0001 respectively).

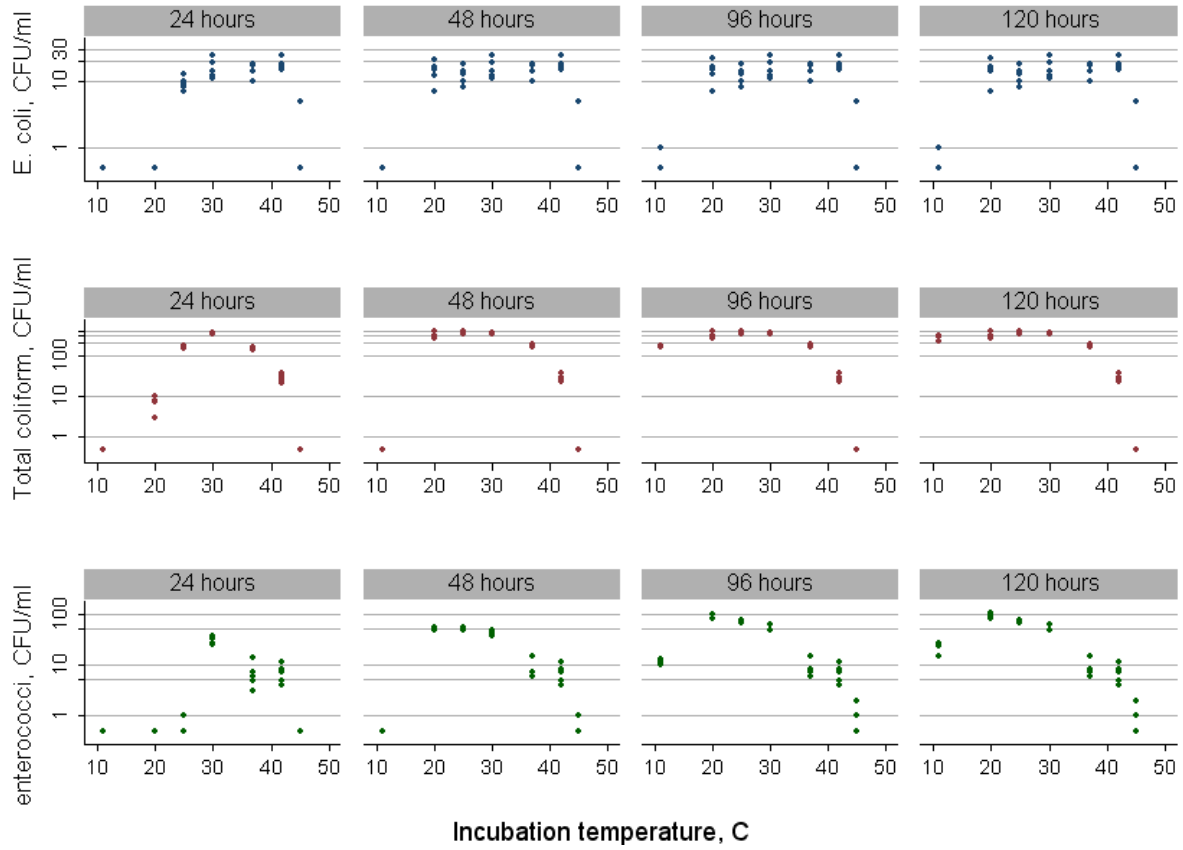

Figure 5.1: Development of the bacteria counts per mL over time at different incubation temperatures (11, 20, 25, 30, 37, 42 and 45°C)

The CFU of **total coliforms** showed a different sensitivity to incubation temperature and time. (see Figure 5.1). At a temperature of 11°C counts increased immensely between 48 and 96 hours and reached the same level as incubation at 37°C after 3 days but kept on growing significantly afterwards. At incubation temperatures of 20, 25 and 37°C, counts increased significantly between 24 and 48 hours of incubation (p-values <0.001). For 30°C the counts stayed constant at 340 CFU/mL. For 20°C and 25°C the counts reached the same level as at 30°C after 48 hours. The CFU which were counted at an incubation temperature of 37°C were significantly below these counts at around 180 CFU/mL. The counts for an incubation temperature of 42°C and 45°C were much lower compared to the others for all incubation periods. For the variable temperature setting the average counts were around 50 counts lower than at the steady incubation temperature of 37°C, which is within the uncertainty of duplicates (compare with chapter 5.4 and 6.4).

For the **ETC** Compact Dry plates the incubation temperatures of 37°C and 42°C were almost the same (7 - 8 CFU/mL) and no further growth was observed after 24 hours of incubation. The counts for the variable temperature set up were in the same range but changed with time. At 45°C no enterococci were growing which was also the case at 11°C in the first 48 hours. After that the counts increased and reached more than 20 CFU/mL after 120 hours of incubation when the observation stopped. For 20°C, 25°C and 30°C the counts changed significant-

ly in each incubation period and more than 50 colonies/mL developed. All p-values are summarized in Table A 7 ID 35- 52)

5.1.2 Exposure to Copper and Steel

The water which was exposed to copper didn't show any change in color but the florist's wire released stain. Therefore the water got a reddish color and contained small rust particles.

The EC plates which were inoculated after 24 hours of exposure showed uncountable numbers of total coliforms for all three plates (one for each type of tube). The control sample and the one with florist's wire had around the same amount of *E.coli*, namely 370 CFU/mL. For the sample with copper only 58 CFU/mL were growing.

The same tendency was observed after 96 hours of exposure (see Figure 5.2). The results of the undiluted samples are described here as the amount of colonies lied within the optimal range per plate and the ones for the dilutions 1:100 and 1:1'000 showed <4 CFU per plate. The concentration of total coliforms was too high to count for the control and the florist's wire sample. Therefore they are displayed as 400 CFU in the graph below. For the exposure to copper 52 and 27 CFU per mL were detected. This means that the counts of total coliforms were decreasing by more than 1 log units due to the copper exposure. The average concentrations of *E.coli* in the samples were at 1, 2 and 20 CFU per mL for the exposure to copper, the control and the exposure to florist's wire, respectively. The control sample showed 13 CFU per mL and the florist's wire 70 CFU per 100 mL. For the copper exposure only one colony was growing. This corresponds to a reduction of 1.1 log units due to the exposure to copper. The calculated p-value of the t-test between the copper and the control samples after 96 hours showed 0.13 for EC and <0.001 for both TC and ETC (see also Table A 7).

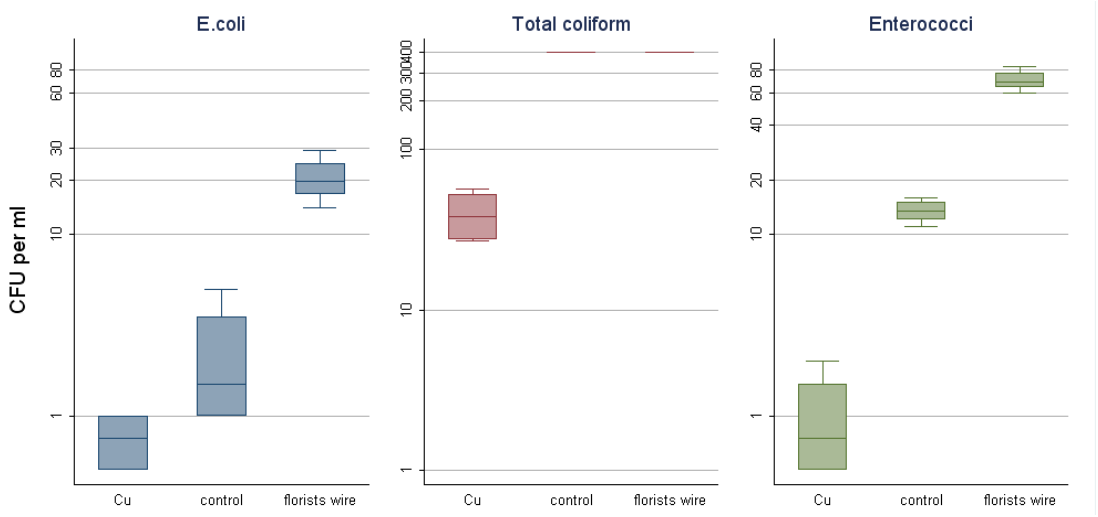

Figure 5.2: Amount of colony forming units for the different set ups with exposure to copper , exposure to florist wire and a control sample after 96 hours of storage at 30°C (four data points for each box)

5.2 Laboratory Experiments at NDC

5.2.1 Comparison of different copper wires

The bacteria concentrations didn't change substantial from the raw water to the control after 24 hours. The impact of the two copper wires was similar and the water quality of the samples wasn't significantly different from each other (compare Table A 7 ID 31-34). The observed reduction compared to the control sample was in the range of 0.5 to 1.1 log units

5.2.2 Combined Plastic filters

The contamination of the raw water was at around 400 CFU total coliform and 10 CFU *E.coli* per 100 mL. After the ceramic candle filtration the levels were lower. The concentration of *E.coli* was mostly zero and the one for total coliform varied from zero to 400 CFU per 100 mL. The same contamination levels were observed in the water from the filter tap. The effect of the defluoridation process (i.e. log reduction values (LRV; chapter 4.3) between the water after the filtration through the ceramic candle and the treated water) in the 3 set ups are displayed with the box plot in Figure 5.3 where a positive LRV refers to a decrease of the bacteria counts. T-tests were carried out to compare the results for CP with both other data series bone char only and CP with copper. T-tests showed that there were no significant differences of the LRV between BC and CP, nor between CP with and without copper (compare Table A 7 ID 28 and 29).

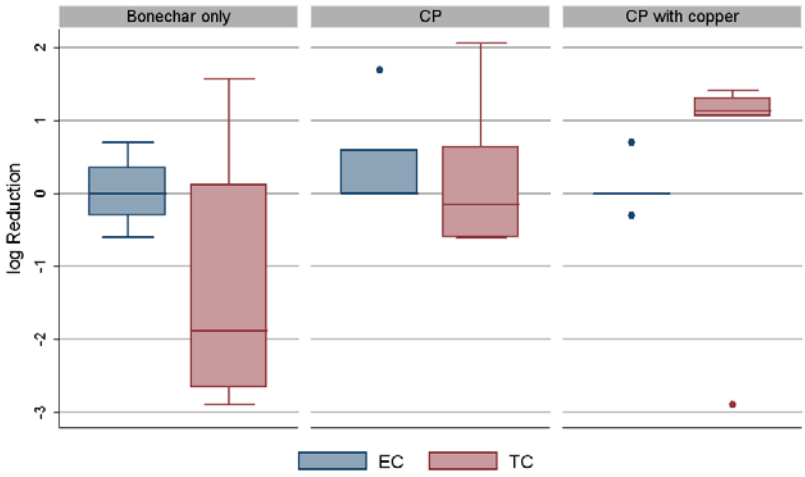

Figure 5.3: Effect of the filtering process as log reduction for bone char only (n = 4), Contact Precipitation (CP) (n=7) and CP with exposure to copper (n=5)

The reduction values through the ceramic candles are presented in Figure 5.6 chapter 5.3.2. In 50% of the measurements log reduction values were positive (i.e. microbial counts were lower after ceramic candle filtration). The t-test between the bacteria concentrations in the raw water and after the ceramic candle showed no significant difference neither for *E.coli* nor total coliform.

5.3 Field visits

5.3.1 Drinking-water sources

A detailed summary of all sampled drinking-water sources in the project area can be found in the appendix Table A 1. Every Standard community filter and the remote area filter in Biretwonin have an own borehole whereas the other three remote area filters depend on surface water as a source. Almost all the owners of a household filter live in areas where a municipal water distribution system is established. The others bought the water from vendors. It's common to harvest rain water on household level in addition to any of the listed water sources. A few samples were mixtures of the mentioned water source with rainwater but pure rain water wasn't analyzed. The water of all sources has been consumed without any treatment from a part of the communities. Samples were taken without sterilizing taps or sampling devices. The levels for the boreholes of community filters and the municipal distribution systems in Nakuru are in the same range (see Figure 5.4). The bacteria concentrations detected in the surface water are a multiple of the counts in the 3 other sources and even the concentrations in the water provided by vendors are significantly higher than in boreholes and the distribution system (p-values in the appendix Table A 7 ID 14-17). However the contamination levels for water from vendors are lower estimates since a large fraction of samples were above the detection limit of 400 CFU per plate. The levels displayed in the graph below base on different sample sizes: 44 samples for the distribution systems, 11 from boreholes, 10 from vendors and only 5 from surface water sources.

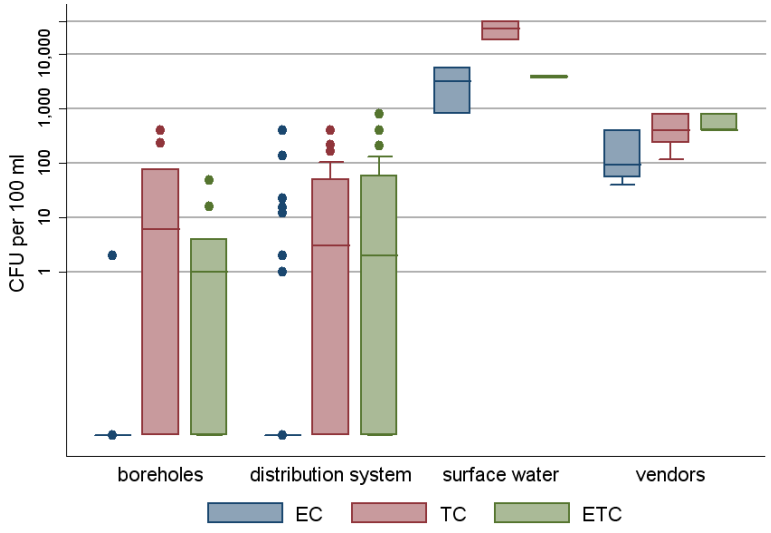

Figure 5.4: Concentration of the indicator bacteria for the 4 different drinking-water sources

5.3.2 Household filters

The bacteria levels at the different measurement points of the household filters are plotted in Figure 5.5. One can notice that the *E.coli* concentrations are the lowest and that total coliform counts are mostly the highest. All 3 indicators show the lowest concentrations in the sample from the sterilized tap. The height of the boxes indicates that the counts vary heavily especially for the total coliforms.

For the last sampling round at the 10 monitored filters no colonies developed on the majority of the EC-plates even for the normally highly contaminated water sources (compare Figure A 7). For that reason the results appeared to be unreliable and were not taken into account for the analysis. The following amount of data points was included in the analysis of the household filter measurements: 46 for the raw water, 33 after the ceramic candle, 38 from the sterilized filter tap and 29 at the POU. Whereas the ratio of samplings at stainless steel filters to plastic filters was around 1:1. The differences between the numbers of samplings occur because the sampling points after the ceramic candle and the one from the sterilized filter tap were not included in the beginning. After sampling the household filters more than once, no sample from the point of use was taken as it wasn't representative any longer due to the sterilizing of the filter tap.

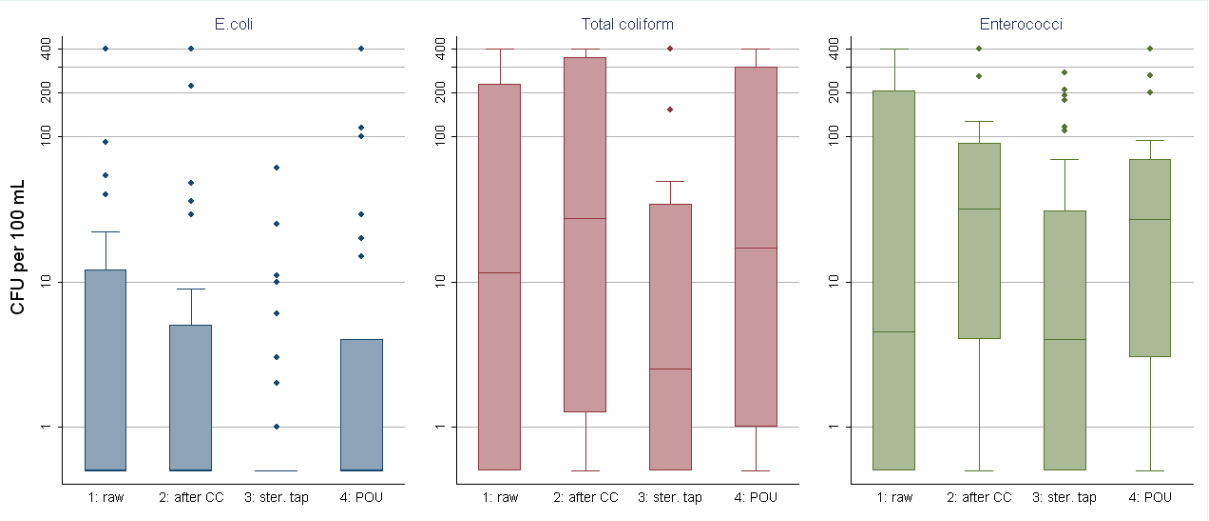

Figure 5.5: Overview of all the samplings at household filters for different locations (CC= Ceramic Candle, ster. tap = sterilized tap of the filter unit).

The figure below shows the reduction through ceramic candles in household filters on the left. It stands out that the mean is negative for ETC and 0 for EC and TC. The variation of the reached reduction is large for all the indicators and ranges from the minimum of -2.9 to the maximum of 2.9 for TC.

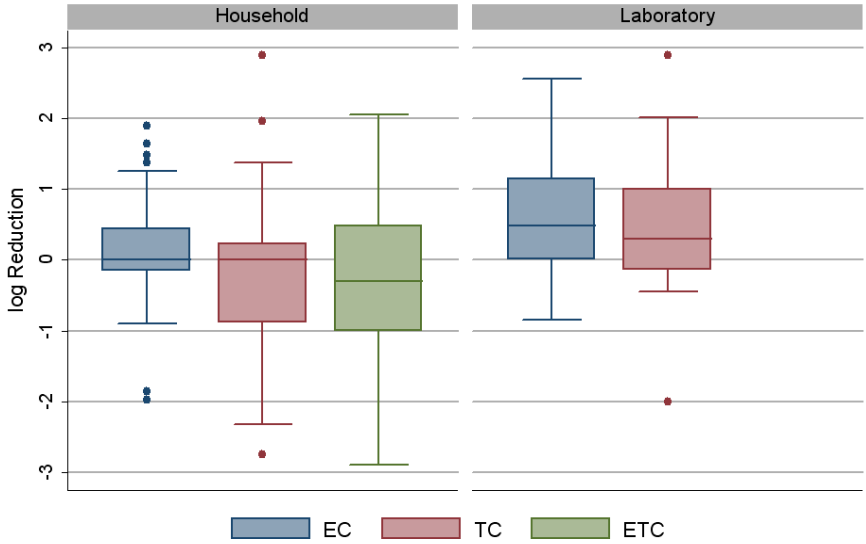

Figure 5.6: Effect of the ceramic candles as log reduction values of the indicator bacteria *E.coli* (EC), total coliforms (TC) and enterococci (ETC). On the left household filters (n=33) and on the right in the laboratory (n=19)

The comparison of the plastic and stainless steel filters (see Figure 5.7) shows similar ranges for bacteria concentrations. Visually there seem to be important differences for the *E.coli*. However the t-tests showed that all p-values for the comparisons between plastic and stainless steel filters were above 0.18 at each point of measurement (see Table A 7 ID 9-12).

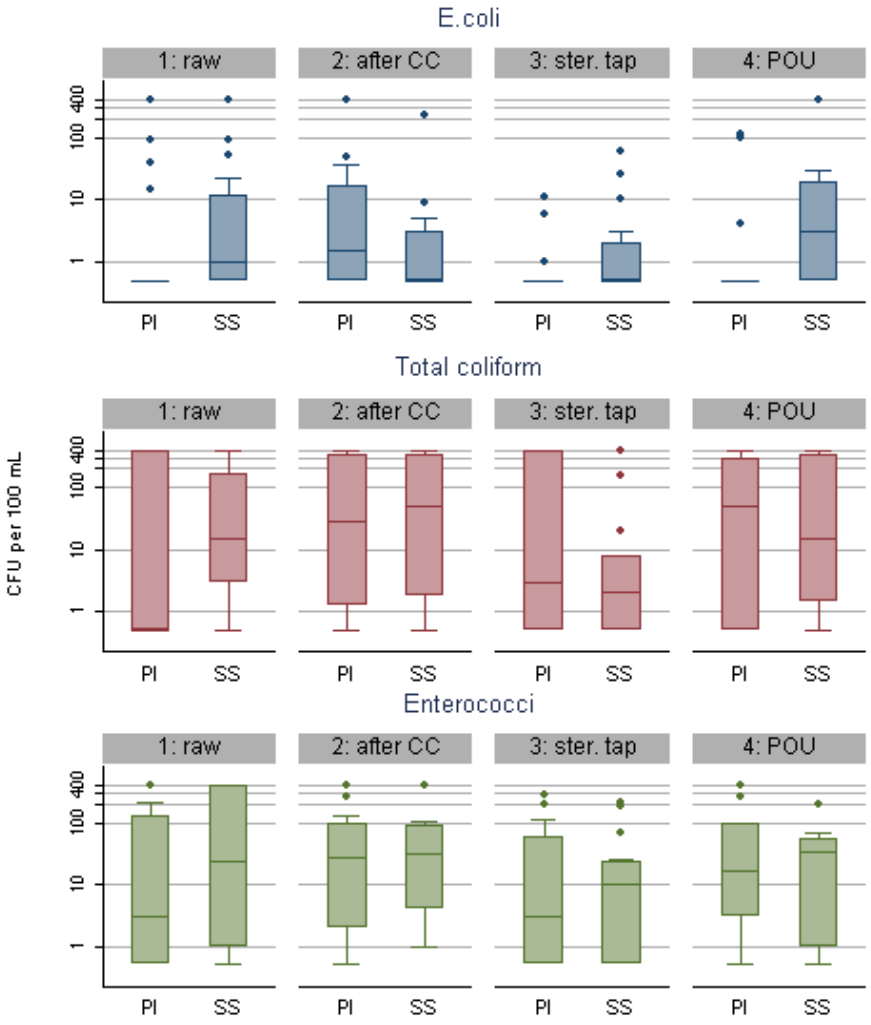

Figure 5.7: Counts of the indicator bacteria at the different sampling points for the plastic and the stainless steel combined household filters

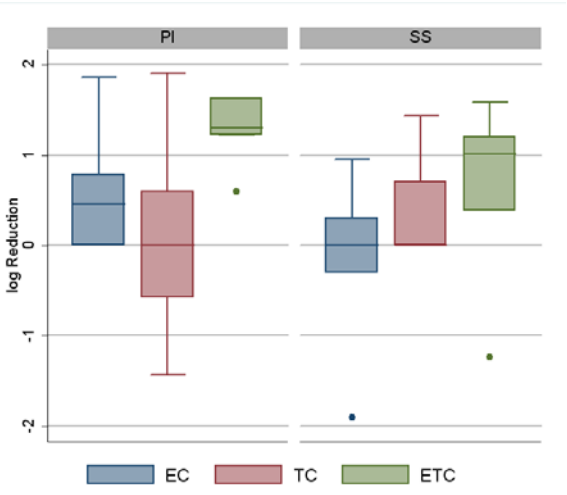

Figure 5.8: Reduction of the bacteria counts through the filtering process in plastic and in stainless steel filters - CP and BC respectively

Figure 5.8 and Figure 5.9 illustrate the reduction of bacteria counts through the defluoridation process (i.e. the log reduction between the measurement after the ceramic candle and the one from the sterilized filter tap) in household filters. The figure above compares the reduction through stainless steel and plastic filters and the one below focus on the effect of copper on the defluoridation process. According to the t-tests no significant differences could be seen for both comparisons (see Table A 7 ID 12 and 13).

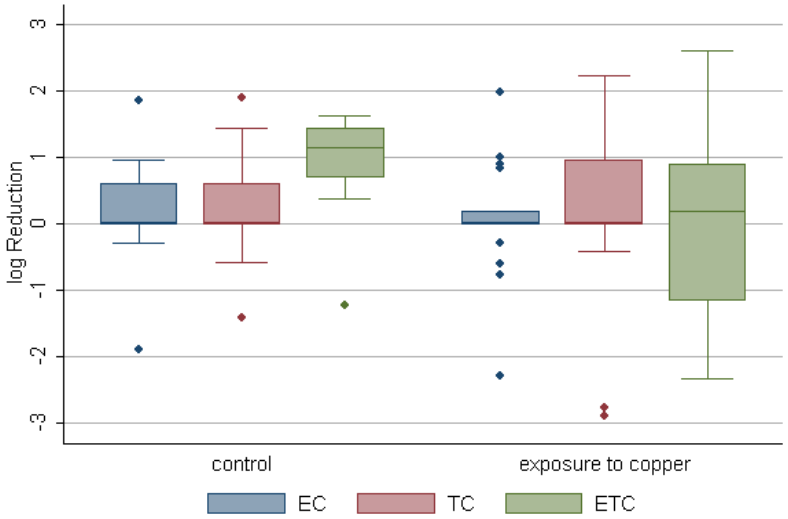

Figure 5.9: Impact of the defluoridation process in household filters on the bacteria counts with (n=20) and without (n=13) exposure to copper expressed in log reduction between the measurement after the ceramic candle and the one from the sterilized tap

5.3.3 Community filters

In total 15 of the existing 23 remote area filters were visited during the study. Unfortunately 8 of them were not used anymore because of some sort of damage. 3 of the remaining 7 filters were not in use at the moment of the visit because they either belong to schools which were closed or were operated with pond and rainwater which was not available at this time. On that account 4 filters were sampled. 3 of them are operated with water from Lake Baringo and the one in Biretwonin is connected to a hand pump to get water from the borehole.

Through the RF the turbidity of the water was reduced visibly by 0.51 - 1.76 log units which is equal to 70 - 98% reduction (see appendix Table A 4).

At 2 of the 16 visited standard community filters the pump was broken and not yet repaired. Another filter was not in use because the rainwater was used instead. Therefore 13 filters were sampled in the end.

The results of the 7 WSUP kiosks and the borehole which serves them are summarized in Table 5.1.

Table 5.1: Results for the 7 sampled WSUP kiosks in Karagite, Naivasha

			Borehole	K 1	K 2	K 3	K 5	K 6	K 7	K8
Meter filter		[m^3]	-	792	411	180	144	175	382	390
Raw	EC	[CFU/	0	0	0	0	2	0	0	15
	TC	100	0	1	0	>400	118	>400	>400	3
	ETC	mL]	1	4	0	15	64	85	79	3
Treated	EC	[CFU/		0	0	0	2	0	0	0
	TC	100	-	0	43	300	0	39	13	0
	ETC	mL]		3	21	20	4	1	1	0
Fluoride		[mg/L]	9.5	2.34	0.25	0.32	0.10	0.16	0.13	0.47

Table 5.2 gives an overview of the water quality of the raw and the treated water of all sampled community filters. The average log reduction through the Standard Community Filters is negative or 0 whereas the reduction is significantly higher for the remote area filters. However the counts for remote area filters are higher than for Standard Community filters, for both the raw and the filtered water. Figure 5.10 illustrates that the differences in the treated water are not as high as for the raw water.

Table 5.2: Water quality of the community filters for the raw and the treated water in CFU per 100 mL and the calculated log reduction values. Samples were taken from the sterilized filter tap for all RF, Longiwan, St. Theresa and the second sampling at Greensteds.

	name	EC			TC			ETC		
		raw	treated	log red	raw	treated	log red	raw	treated	log red
standard community filters	St. Mary	<1	41	-1.9	1	279	-2.5	1	2	-0.3
	Muririchua	<1	<1	0	400	334	0.1	<1	2	-0.6
	Greensteds 1	<1	>400	<-2.9	22	>400	<-1.3	4	154	-1.6
	Greensteds 2	<1	<1	0	<1	19	-1.6	2	<1	0.6
	St. Theresa	<1	>400	<-2.9	<1	>400	<-2.9	<1	>400	<-2.9
	Longiwan *	20	2	1.0	>400	20	>1.3	>400	9	>1.7
	WSUP K1	<1	<1	0	1	<1	0.3	4	3	0.1
	WSUP K2	<1	<1	0	<1	43	-1.9	<1	21	-1.6
	WSUP K3	<1	<1	0	>400	300	0.1	15	20	-0.1
	WSUP K5	1	2	-0.3	118	<1	2.4	64	4	1.2
	WSUP K6	<1	<1	0	>400	39	>1.0	85	1	1.9
	WSUP K7	<1	<1	0	>400	13	>1.5	79	1	1.9
	WSUP K8	15	<1	1.5	3	<1	0.8	3	<1	0.8
	Moindabi 1	2	1	0.3	77	61	0.1	<1	3	-0.8
	Moindabi 2	<1	<1	0	230	37	0.8	16	8	0.3
	average	**2.5**	**56.4**	**<-0.8**	**163.5**	**129.7**	**-0.1**	**44.9**	**41.9**	**0.0**
remote area filters	Kokwa Island	>700	14	>1.7	5'400	800	0.8	>4'000	800	>0.7
	Longicharo	>700	600	>0.1	15'000	800	1.3	>4'000	800	>0.7
	Ng'enyin	>700	6	>2.1	30'000	16	3.3	>4'000	800	>0.7
	Biretwonin **	76	1	1.9	348	62	0.8	170	2	1.9
	average	**544**	**155.3**	**>1.4**	**12'687**	**419.5**	**1.5**	**3'043**	**600.5**	**>1.0**

* The tap water was piped over more than 1km from the filter to the point of sampling!

** This RF is operated with the water of a borehole pumped by hand. The others are fed with water of Lake Baringo

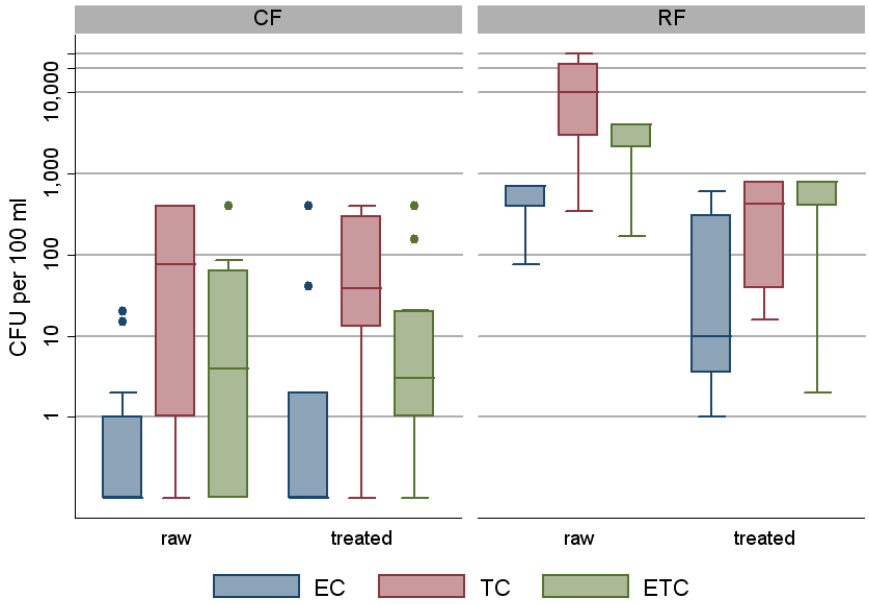

Figure 5.10: Bacteria level of the community filters - the standard community filters (CF) and the remote area filters (RF)

The drinking-water of 17 households which use the treated water from a community filter was analyzed. 6 of the households belonged to a remote area filter (Kokwa Island and Ng'enyin) and 11 to a standard community filter (Muririchua, WSUP kiosks, Moindabi 1 and 2). Non filtered water was sampled in 3 households in Karagite where a lot of people buy the untreated water from the WSUP kiosks because it is cheaper. On Figure 5.11 the

impact of transport and storage is shown. The log reduction was calculated from the bacteria concentration at the source and the one from a glass or a cup in the households (= point of use). The mean impact was negative for all the indicators. But for a few samples the quality improved through storage and transport.

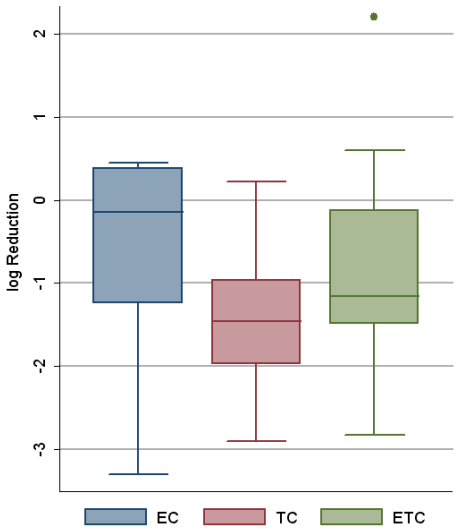

Figure 5.11: Log reduction from the source (= tap of a water kiosk) to the point of use in 20 households using the defluoridated water from a community filter

An overview of the microbial water quality at the point of use is given in Table 5.3. This means that the water was analyzed from a cup or a glass in the household used for drinking. The label "untreated tap" refers to the municipal water distribution systems in Nakuru which was sampled in connection with the household filter measurements. Parts of the households told that they were drinking this water without treatment before they had the filter. Its quality therefore reflects the drinking-water quality of many households in Nakuru. In addition the bacteria concentration at the point of use for households with an own filter and for the ones using the water from community filters is shown.

Table 5.3: Geometric mean (minimum - maximum value) of the counts at household level in CFU/100mL whereas the sample volumes were 1 or 20mL for the households of a CF and the untreated water

source	sample volume	# meas-urements	Households Point of use in CFU per 100 mL		
			EC	TC	ETC
untreated kiosk	20 mL	3	31.1 (<1 - >2'000)	1'339 (600 - >2'000)	379.4 (35 - >2000)
untreated tap	100 mL	46	2.1 (<1 - >400)	60.4 (<1 - >400)	39.5 (<1 - >400)
treated CF and RF	1/ 20 mL	17	2.5 (<1 - 500)	1'054 (160 - 11'700)	59.5 (<1 - >2000)
treated HHF	100 mL	27	1.8 (<1 - >400)	14.6 (<1 - >400)	15.3 (<1 - >400)

The level of *E.coli* in the treated water and in the untreated water tap is the same and the one in treated water of CF and RF as well. Only the variation and the geometric mean for the households using untreated water from a kiosk are higher. In contrast the total coliform concentration in households relying on central water collection points (i.e. kiosk, CF or RF) is a multiple of the one which are connected to a distribution system whether using a filter or not. Regarding the enterococci concentration the quality is best for the HH using a filter and worst for the untreated water from households. It's visible for all indicators that the mean concentrations are slightly higher for the untreated water compared to the treated one.

5.4 Quality control

All the blank samples which were carried out in Kenya (20 plates) were negative i.e. no EC or TC developed. For some samples colorless colonies grew, especially for larger volumes when membrane filtration was used.

The difference between two duplicates of the same sample in Kenya was observed to be up to 1.34 log units for Enterococci, 0.90 log units for *E. coli*, and 0.60 log units for total coliforms. From Figure 5.12 it can be seen that the average differences were in a similar range of 0.1-0.2 log units for both the analysis in Kenya and the one at EAWAG. However the maximum differences were higher in Kenya and were significantly lower for duplicates in the optimal range of 20-200 CFU per plate. The average log differences between duplicates for *E.coli* and total coliform are even larger in the optimal range of counts than for all plates.

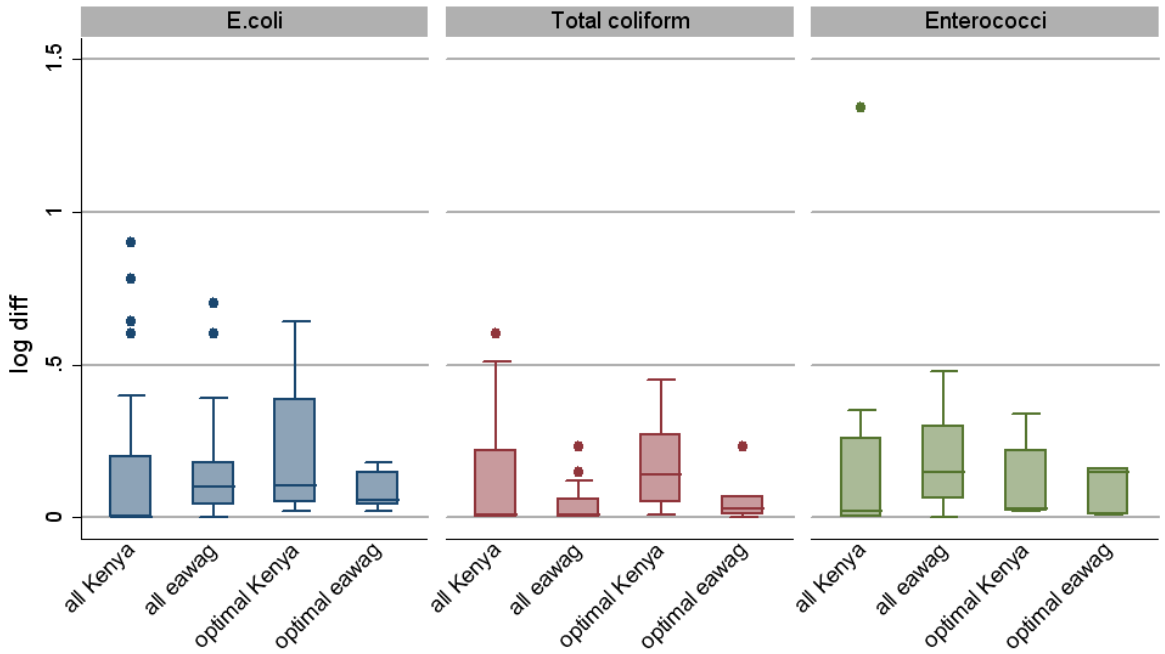

Figure 5.12: Summary of the log differences from the duplicates carried out within the study

In the figure above 16 data points were plotted for the measurements at EAWAG whereas only few were within the optimal range of counts (6, 7 and 3 for EC, TC and ETC respectively). In Kenya 79 duplicates were carried out with EC plates and 20 with ETC plates. For total coliform 18 plates were in the optimal range of 20 - 200 colonies per plate but only 4 and 5 for *E.coli* and enterococci respectively.

Some experiments at EAWAG were carried out with 5 replicates and were not taken into account in the figure above. The average standard deviations (4 series of 5 replicates) were 0.1 log units for *E.coli* and 0.3 for enterococci. For total coliforms only one series could be analyzed as the others showed more than 400 CFU per plate. A standard deviation of 0.03 resulted for this one sample.

6 Discussion

6.1 Laboratory Experiments at EAWAG

6.1.1 Incubation at different temperatures

The *E.coli* are the most replicable organisms for incubation, as similar counts were observed in the range of 30°C to 42°C and for the variable temperature set up as well. The full number developed after 48 hours or longer at 20 and 25°C were in the same range too. For the total coliforms and the enterococci the different incubation temperatures greatly influenced counts, sometimes in unexpected ways. One would expect that the highest counts are reached for the recommended incubation temperature, but that was not the case for these indicator organisms. So for comparison purposes they rely more on a temperature around the recommendation. Fortunately the variable temperature set up resulted in similar results as the incubation at 37°C for the total coliforms and the enterococci, although it takes much longer until the same level of CFU is reached. Therefore 'pocket incubation' is expected to result in the same range of CFU as an incubation at 37°C which is within the recommended temperature of the producer. During the stay in Kenya it was observed that the temperatures in the night mostly exceeded 11°C which was the incubation temperature in the laboratory simulating the night. The lowest temperature measured was around 13°C in Nakuru whereas in Baringo region it didn't cool down in the night and the minimum temperature was approximately 22°C. The counts at 20°C hypothesize that this might have a large influence on the number of growing colonies. A constant temperature of 35°C ± 2°C should therefore be chosen whenever possible in order to make sure that the results of different plates can be compared. Pocket incubation was only the second choice. In the field pocket incubation during the day was combined with the incubator in the night what resulted in a more or less constant temperature for the plates.

It was observed that the temperature of the incubator which was used in Kenya varied between 34 and 37°C what should lead to appropriate results. The electricity went off from time to time but mostly only for a few minutes which should not have effected the temperature more than opening the incubator. Therefore the impact of power breakout can be neglected.

6.1.2 Exposure to Copper and Steel

It was expected that copper would have an inhibitory effect on microorganism growth (compare chapter 2.5) what was confirmed by this experiment. 24 as well as 96 hours of exposure showed a reduction of bacteria due to copper exposure what is illustrated in Figure 5.2 and in Figure A 8. A comparison between the counts for the control and the copper exposed water after an exposure period of 96 hours showed that the concentration of total coliform and enterococci was significantly lower after the exposure to copper. However the p-value for *E.coli* indicated that this was not the case for this bacteria group. A reason for that could be that *E.coli* are more resistant to the inactivation through copper than the other indicator, or to the fact that *E. coli* levels were relatively low in all samples. Significantly more CFU developed for the water which was exposed to the florist's wire. The released iron might be the cause for it.

6.2 Laboratory Experiments at NDC

6.2.1 Comparison of different copper wires

Although the ratio of copper surface to water was only 2/3 of the one in the experiment at EAWAG, a reduction of indicator bacteria was observed as well. The effect of the locally available copper was the same as for the one from Switzerland for an exposure of 24 hours. It might be that the long term effect is different which would need to be identified by further experiments.

6.2.2 Combined Plastic filters

Figure 5.3 shows a trend that bone char has a more negative impact on the microbial water quality (considering total coliforms, though not *E. coli*) than contact precipitation and that through the exposure to copper the impact is more positive than without. However the calculated p-values are all above 0.05 and therefore the differences are not significant. Further experiments with larger sample sizes would be necessary to confirm the observed trends.

The results to the ceramic candles are discussed in chapter 6.3.2 together with the candles in household filters.

6.3 Field visits

6.3.1 Drinking-water sources

The expectation that the water quality of boreholes is better than the one of surface water and piped water is verified by the results of the measurements. 7 of 8 boreholes met the drinking-water quality standard of nil *E.coli* per 100 mL. Considering the measurement uncertainty of the plates all of them fulfill the criteria. Most municipal water distribution systems showed a good quality of the water too. The variations for the indicator bacteria are the same as for the boreholes. The differences are higher especially for total coliforms where the variation is maximal from 0 to more than 400 CFU/100 mL. This is unremarkable as total coliform exist in the soil. Both *E.coli* and enterococci were detected in this two water sources what indicates faecal contamination which can either originate from the source itself or from a leak in the distribution system. The concentrations of enterococci are higher than the one for *E.coli* although it is the other way round in faeces. Reasons for the observation might be that first the enterococci survive longer in the environment and the faecal contamination lies some time back so that the *E.coli* already died what would point at a contamination of the source water. Second the enterococci are more resistant to chlorination and could therefore survive this treatment step in a higher number than the *E.coli*.

Some households have to buy the water from vendors because they are not connected to a distribution system or there is some problem with it. The quality of the water was generally worse than the one directly from a distribution system or a borehole. Especially the enterococci levels are alarmingly high with an average of more than 350 CFU/100 mL. The contamination most likely originates from the transport and storage containers or directly from the source.

In contrary to the above sources the Perkerra River and Lake Baringo are highly contaminated with several thousand CFU/100 mL from each indicator bacteria. High concentrations can already be expected when one looks at the conditions of the water bodies (used for washing, animals are walking through it etc. - see Figure A 6). Large variations of the water quality over the year are expected. So it is likely that rainfalls flush some excreta from human and animals into the water. Despite this the sampled surface water are used for drinking without treatment from a part of the population.

6.3.2 Household filters

Comparing the counts before and after the ceramic candles didn't show a significant impact on the water quality with p-values above 0.05 for both the household filters and the ones in the laboratory. On average the reduction through the ceramic candles in the laboratory was larger than for the ones of household filters. As the quality of the raw water mixed for the laboratory experiments was much more contaminated than the raw water used in the households the potential for a reduction was much higher in the laboratory. The good water quality from most of the water sources makes it impossible to observe a reduction of 2 log units as it is promised by the producer. Often there were not many indicator bacteria in the raw water and in the water after the ceramic candle. This appears as a log reduction of 0 and influences the mean log reduction heavily. Still, even if only the samples with > 20 CFU per 100 mL in the raw water are taken into account , the average log reductions are 0.89 (EC), 0.36 (TC) and 0.62 (ETC), indicating that the ceramic candles are not as effective as expected.

Each measurement point of the filters was analyzed if there are significant differences between the 2 filter types SS and Plastic or bone char only and CP respectively (see Appendix Table A 7). All the p-values were above 0.05 and so no significant difference between the 2 filter types was observed. These findings correspond with the ones from the laboratory (see chapter 6.2.2). Therefore the remaining comparisons were carried out without differentiating between the 2 types.

The exposure to copper didn't change the microbial water quality significantly as the p-values in Table A 7 show. The bacteria concentration between 2 samplings of the same household filter varied highly without changing anything in the operation. Therefore the influence of copper wasn't significant. It might be that either it wasn't enough copper in the filters or the contact time was too short to inactivate the organisms or that the inactivation was not durable.

If one looks at the overall impact of the household filters it gets visible that the quality of the raw water and at the point of use doesn't differ substantially on average. However sometimes the treated water had a better quality as the raw water and sometimes it was the other way around. At least the quality of the water from the sterilized filter tap contains significantly less *E.coli* and enterococci than the raw water (p-values: 0.03 and 0.02 respectively). The reduction must result from the ceramic candle and the filtering together as there is no essential difference for raw versus after the ceramic candle and after the ceramic candle versus sterilized tap respectively (compare Table A 7). After all the improvement is lost at the POU as no significant difference between the raw water and at the POU was observed (p- values even > 0.2)

As the sampling procedure of the last sampling round was the same as for the previous ones an explanation for the failure couldn't be found. One thought was that it was just too hot in the car where the plates were 'incubating' while sampling the other filters. From the incubation temperature experiment at EAWAG it got obvious that all 3 bacteria group aren't growing at a temperature of 45°C. So if it really got that hot, it would have prevented the enterococci from growing too and not only the colonies on the EC- plates.

6.3.3 Community filters

On Table 5.2 it stands out that some standard community filters like St. Theresa, St. Mary and the first sampling at Greensteds show an extremely high contamination after the filter. An explanation for the large difference in the bacteria concentration for the first and second sampling at Greensteds is that the first time the tap of the filter was not sterilized and flushed like it was done for the second sampling. Further sampling of the St. Mary's filter wasn't possible because the filter was taken out of operation and reconstruction started shortly after the sampling since the filter media was saturated. Unfortunately it had not been finished within the sampling period in Kenya. As the tap was not sterilized it might be that the contamination resulted from a contamination at the tap and not from the filter media. The filter of St. Theresa was around 2 weeks old when it was sampled and showed a maximal contamination from 0 before the filter to more than 400 CFU/100 mL from the sterilized tap for all indicator bacteria. There is almost no other explanation than a contamination through the filter media (Bone char and Pellets). The media could get contaminated during storage and transport of the bags or during the construction of the filter.

Longiwan is one of the standard community filters where the contamination decreased significantly. The raw water had to be sampled around one kilometer away from the filter as there was no tap at the borehole site. It's possible that the water got contaminated in the pipes from the borehole and filter site to the sampling site and that the water which got into the filter didn't show the same contamination level. Therefore one should regard this reduction values with suspicion.

The *E.coli* counts for both the untreated and the treated water of the 7 sampled WSUP kiosks lay within the range of uncertainty. The differences in the enterococci are a bit larger but still more or less in this range. The differences in total coliforms are enormous (0 to more than 400) and smaller for the treated water than for the untreated one. A look on the map (Figure A 4) shows that the filters with the significantly higher contamination of the untreated water (kiosks 3, 5, 6 and 7) are also the ones with the longest distance from the borehole. Therefore it seems more likely that the water gets contaminated in the contribution system than in the kiosks themselves. The filters 5 to 8 appear to have a significant reduction effect on the bacteria in the water whereas the effect of 2 other filters is within the measurement uncertainty and kiosk 2 even showed a negative impact on the bacteria level in the water. This contamination might result from the tap of the filter or from the filter media as the plastic tube at the filter could not be sterilized with the lighter. After all that was the case for the other WSUP- kiosks as well. Hence no connection of the contamination level to the meter reading of the treated water is visible.

An overall impact of the defluoridation process in standard community filters could not be observed. Each filter seemed to influence the water quality different. A reason could be that some components in the water or the temperature in the filter have an effect on the water quality. Still, even the identical filters on the WSUP- kiosks which also use the same raw water and are built in the same area showed significant differences which can not be fully explained.

The remote area filters were specially constructed to reduce turbidity and microorganisms from the water. The 4 sampled filters show that both the turbidity and the bacteria level were reduced through the remote area filters (compare Table 5.2 and Table A 4). However the promised reduction of 95% (equivalent to 1.3 log units; CDN brochure 2011) for both turbidity and faecal coliforms is not fulfilled for all measurements. The remote area filters in Ng'enyin and Kokwa Island didn't fulfill the turbidity efficiency and the filter in Longicharo didn't remove 95% of *E.coli* but didn't change the concentration at all. The only filter which fulfilled both criteria was therefore the one in Biretwonin which is the only sampled remote area filter which is operated with borehole water.

The users of the remote area filters reported that one needs to add more water to the filter than you can withdraw. This is not a problem if the filter is near the water source but can be if the distance is far. This was sometimes also one of the reasons why a remote area filter is not in use anymore. The challenge of the remote area filters is the organization of the community to pay the operating and maintenance costs of the filter for it's not possible to operate the filters as kiosks like the standard community filters.

People using the untreated water from a water kiosk for drinking were exposed to higher bacteria levels than the others. As these results are based on 3 measurements, they cannot be generalized and give only a first trend. Two of the three measurements were actually in similar ranges than the treated water from CF and RF. For the 3 other categories (treated water from CF or RF, treated water from household filters and untreated water in the city of

Nakuru) the health risk according to the *E.coli* concentration was very low (classification see chapter 2.4.1). The high level of total coliform found in the drinking-water of households depending on kiosks can be explained through the fact that a large portion of the people specify that they use sand for cleaning the storage and transport containers. As total coliforms appear in soil the high numbers are not surprising. The high enterococci concentration in the water of these households might originate from a previous faecal contamination of the soil where these bacteria can survive longer than *E.coli* because they are more resistant to drying.

6.4 Quality control

The blank samples were working as desired. The colorless colonies which developed for the larger sample volumes might originate from a contamination of the boiled water during storage or from the membrane filtering. In case the later was the case it could influence the samplings. Contamination was constricted by preventive measurements. One of them was careful handling and sterilizing of all the supplies involved like the cups and the filter stand. In addition the boiled water was exchanged regularly to minimize the contamination of the plates with potentially contaminated water even though it wasn't used up.

The average log differences between duplicates appeared to be larger for the optimal range of 20 to 200 CFU per plate. It might be explained by the plates with 0 CFU which are included in the overall calculation. They made up a large part of the samples especially for *E.coli* on the field visits in Kenya and therefore have a large influence on the average values. The duplicates illustrate that an uncertainty of around 0.2 log units must be expected what means for example that the 'real' number might be 30 colonies when 20 are counted and that a log difference of 0.2 between 2 samples should be considered as statistically insignificant.

7 Conclusion and Outlook

As expected the surface water was more contaminated than the water from boreholes and the piped water sources which were not significantly more contaminated than the boreholes. However the actual levels of bacteria were not expected to be that high for the surface waters. The quality of the surface water is most probably strongly depending on the season. The good quality of the water from boreholes and particularly the one form the distribution system was surprising. Although a majority fulfills the national regulation of nil *E.coli* per 100 mL, most of the Kenyans don't trust these sources and boil the water if they have enough money to do so. The bacteria levels of water bought from vendors is between the 2 mentioned levels and significantly different from both the concentration of surface water and from boreholes and piped systems, respectively. Therefore the vendors most likely didn't sell surface water but it might be that additionally the source water is already more contaminated than borehole water. Measurements showed that the water quality got worse due to transport and storage for the water of community based water collection (compare chapter 6.3.1) what can be applied to the vendors as well.

The elimination effect of the ceramic candles was alarmingly low. The average log reduction value for the households didn't exceed 0.9 even if excluding candles with low counts in the raw water and the 2 log units reduction promised from the manufacturer is only reached a few times. The experiments in the laboratory showed similar results. Therefore more measurements in the laboratory and for the households should be considered in the future. It might be good to include a comparison of different brands to see if it really makes sense to import ceramic candles from Brazil.

Both the differences between BC and CP in the laboratory and the one between Pl CP and SS BC in the households were not significant. There was only one standard community filter with bone char (Moindabi 2) which didn't show differences to the other filters either. In general the impact of the defluoridation process wasn't significant neither for household filters nor for community filters. However there was the standard community filter of St. Theresa where a maximal contamination from 0 CFU per 100 mL raw water to >400 CFU per 100 mL treated water was detected. Based on this observation and other standard community filter which showed an increase of indicator bacteria a microbial test is suggested to be carried out before handling a standard community filter over to the community members. If a significant contamination is detected, an action should to reduce the contamination through the filter be taken immediately. A possible intervention could be some sort of chemical treatment of the filter media e.g. through shock chlorination.

Although the remote area filter didn't reach the promised reduction of 95%, the reduction was significantly higher than observed for standard community filters. The modified design of the filters proved oneself also for removing turbidity. The difference in turbidity was impressive to see.

An inactivation due to copper was visible for the experiments in the laboratory where the water was stored at room temperature for 24 hours. Unfortunately its impact on the bacteria counts wasn't significant for the household filters. Therefore a statement about the influence of pellets on the inhibition is not possible. The copper wires showed signs of oxidation. The copper concentration in the treated water was higher compared to the raw water for filter with a copper wire what indicates a release of copper to the water. However a significant difference between the filters with BC and the ones with CP is not visible. Further experiments with copper addition to the filters are necessary to find out more about its inactivating impact and the long term development. Approaches could be to increase the amount of copper, to place it at another part of the filter or to add the copper in a different form e.g. as plates and not as wires.

A significant difference between households using defluoridated water was not visible. The source of the drinking-water i.e. whether having a tap nearby (households in Nakuru) or depending on a community based collection point like a kiosk (different community filters) mattered a lot. The drinking-water quality from households relying on water collection points such as a remote area filter or a water kiosk was usually much worse than for the other source especially regarding total coliform.

The measured bacteria concentrations from one sampling date to another showed in average a log differences of approximately 1 log unit which is a multiple of the difference between duplicates. These differences occur both for the raw and the treated water of household filters. The variation in the raw water might be explained by the rainy season when some people do rainwater harvesting and the rains also influence the quality of other water sources used for the municipal water systems. Considering the whole year the fluctuations might even be higher and one should be careful with statements to the water quality if the results depend on one sampling only.

It was sometimes observed that the filter media in stainless steel filters was drying out unnoticed by the owner. This should be avoided because it is reducing the accessible adsorption capacity for fluoride due to the development of preferable flow paths. The other sampled filter types (plastic combined, standard community filter and remote area filter) were constructed in a way that the filter media could not dry out. The design with an inner bucket as it exists for the combined plastic filter might be a good option.

The equipment used in Kenya was suitable for the purpose of the survey. A drawback is that the Dry Compact plates require constant temperatures if the results of different measurement rounds need to be compared. To achieve this an incubator which can be used at least in the night is required. That also means that one needs electricity to operate it. A big advantage is that no media needs to be prepared before sampling but the plates are ready to use. First steps to compare the results to the agar method which was used at CDN WQ so far were not successful because of inappropriate bacteria concentrations. Therefore some more experiments on that would be helpful, if CDN is going to use both methods in the future. Another unresolved question is the behavior of the EC-plates in the last sampling round where no colonies were growing although the procedure was the same as usual. The portable filtration stand which was used in combination with the plates to sample larger volumes was easy to use and due to the syringe no electricity was required. It could also be applied in the field. A disadvantage are the cups which are not durable. But if a system for sterilization is available, they can be reused. During the stay in Kenya some cups were sterilized in the oven about 10 times and it was still possible to use them.

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Appendix

Table of Figures

List of Tables

A1 Maps

A1.1 Household filters

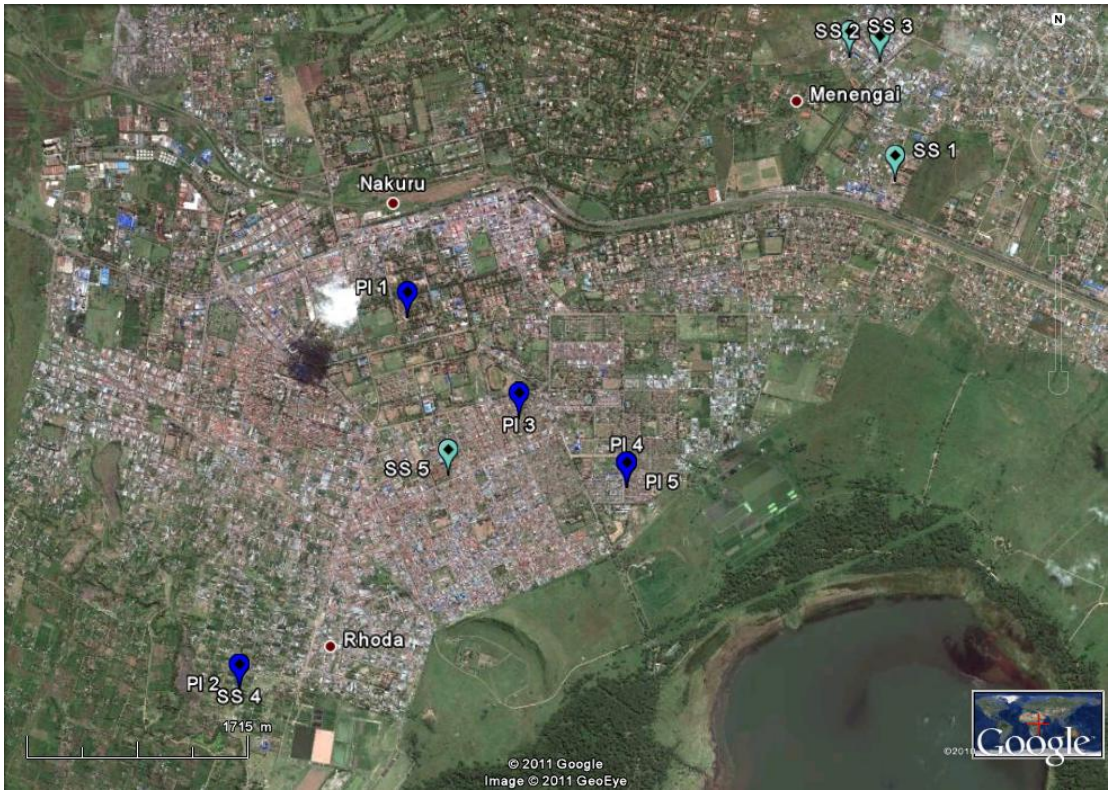

Figure A 1: Monitored household filters in the city of Nakuru

A1.2 Community filters

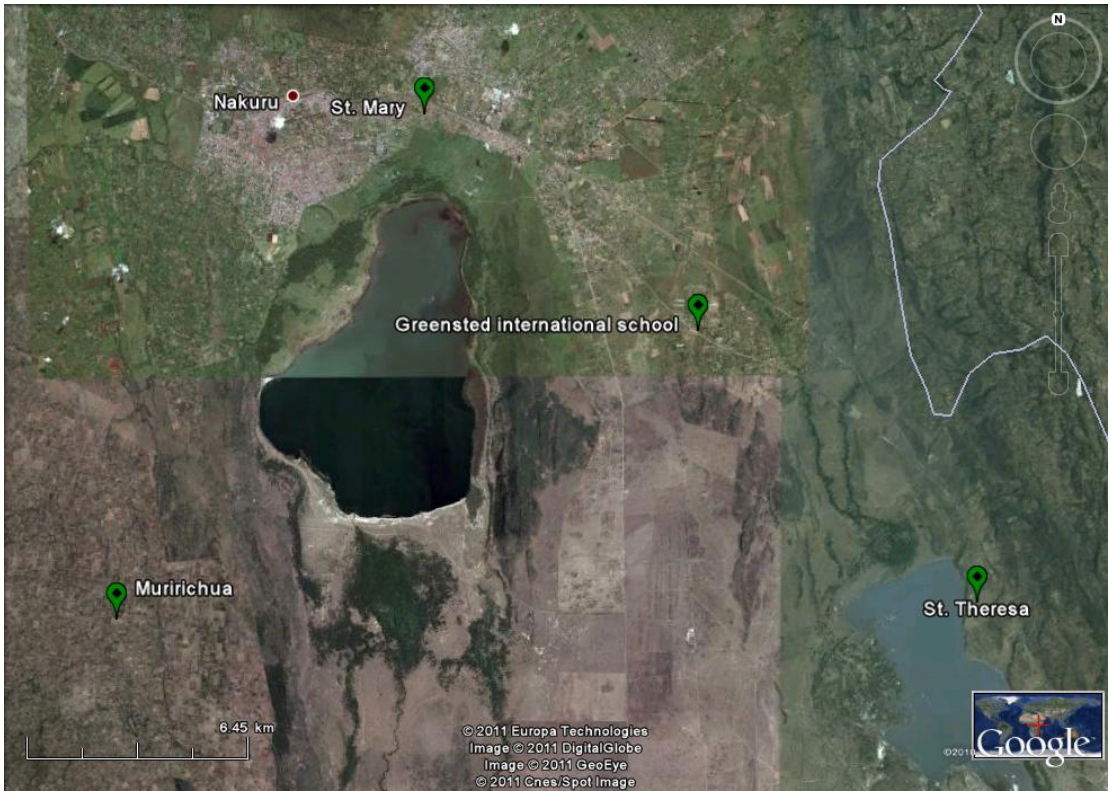

Figure A 2: Sampled standard community filters around Lake Nakuru

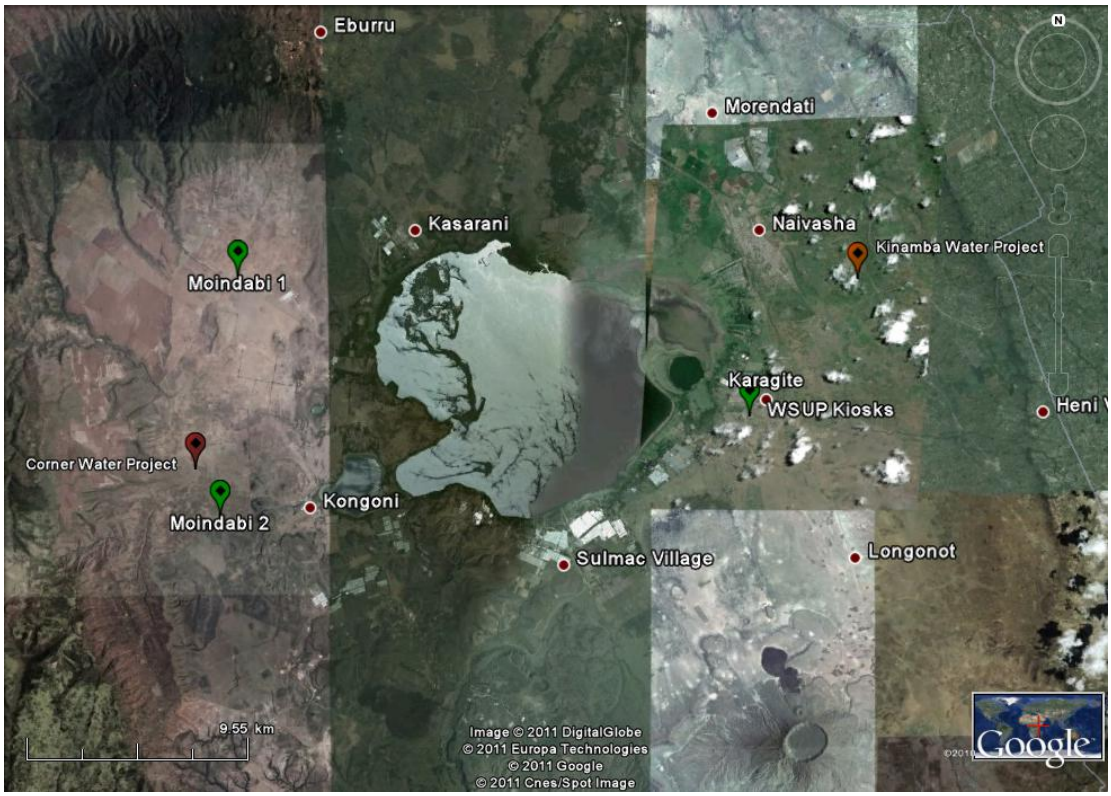

Figure A 3: Standard community Filters in Naivasha- green: sampled kiosks and red/ orange: broken or not used filters

Figure A 4: Locations of the sampled WSUP kiosks in Karagite, Naivasha

Figure A 5: Visited remote area filter in Baringo district - red: not in use, orange: in use but no sample and green: in use and sample

A2 Drinking-water sources

Table A 1: Overview of the sampled drinking-water sources structured after the different types of sources If a source was sampled more than once the geometric mean is showed (instead of 0 0.5 CFU were applied what corresponds to half of the detection limit of 1 CFU per plate). All values are in CFU per 100 mL.

		# samples	sample volume [mL]	EC	TC	ETC
municipal piped water systems of Nakuru	SS 3	4	100	<1	2.4	2.0
	SS 2	4	100	1.3	3.5	3.2
	Pl 6	3	100	14.4	400.0	219.9
	SS 1	3	100	2.3	144.7	9.5
	SS 1 new	3	100	2.9	46.8	198.0
	SS 6	1	100	<1	104.0	28.0
	SS 7	1	100	<1	14.0	3.0
	Pl 4 and Pl 5	10	100	<1	<1	2.3
	SS 5	4	100	<1	5.0	3.6
	Pl 3	5	100	<1	3.4	4.3
	Pl 1	5	100	<1	4.2	<1
	Pl 7	1	100	<1	<1	3.0
average piped water				2.1	60.8	39.8
standard deviation				4.0	116.7	79.5
vendors Nakuru	SS 4 and Pl 2	9	50 / 100	52.3	96.1	359.0
	SS 2 vendors	1	100	1	> 400	> 400
average vendors				26.6	248.1	379.5
Boreholes of CF	St. Teresa	1	100	< 1	< 1	< 1
	Greensteds	2	100	< 1	3.3	2.8
	CDN	3	100	< 1	3.8	4.6
	Ndonyosas	1	100	< 1	6.0	< 1
	WSUP	1	100	< 1	< 1	1
	Moindabi 1	1	100	2	77	< 1
	Moindabi 2	1	100	< 1	230	16
	Muririchua	1	100	< 1	> 400	< 1
average boreholes CF				0.7	90.1	3.3
standard deviation				0.5	148.3	5.3
surface water	L. Baringo	4	1 / 20	750	17'500	4'000
	Perkerra R.	1	1 / 20	5'500	40'000	3'500
average surface water				3'125	28'750	3'750

Figure A 6: Perkerra River (left) and Lake Baringo (right) are both located in Baringo district

A3 Filters

A3.1 Household filters

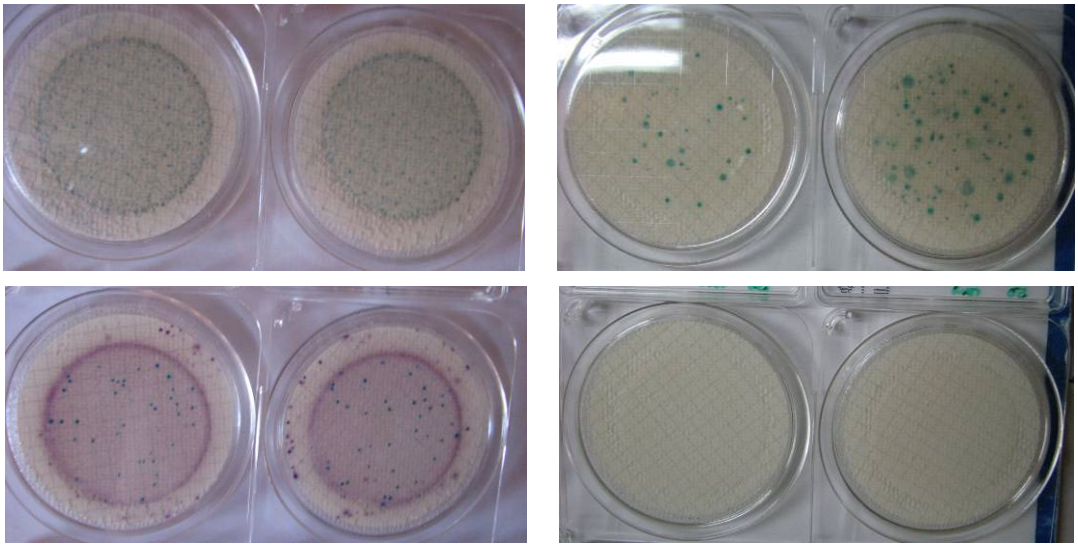

Figure A 7: EC (bottom) and ETC (top) plates for the same water source on may 12 on the left and for the last sampling round on may 25 (right) when the detection with the EC-plates didn't work

Table A 2 illustrates the measured copper concentration for some household filters with copper addition. Both concentrations increase from the raw water to the treated one. except the copper concentration of the filter without a copper wire. The detected concentrations vary highly for the different sources.

Table A 2: Copper and phosphate measurements (<DL: below the detection limit of 0.2 mg/l whereas for the calculation 0.1 mg/l was applied)

	Phosphate		Copper	
	[mg/l]	log diff	[µg/l]	log diff
SS 2 raw	<DL	1.61	16.4	0.42
SS 2 treated	5.6		43.7	
SS 4 raw	<DL	0.00	2.5	1.32
SS 4 treated	<DL		51.5	
Pl 2 raw	<DL	0.32	2.5	1.20
Pl 2 treated	0.2		39.3	
Pl 4 raw	<DL	1.74	1.2	1.93
Pl 4 treated	5.4		102.7	
laboratory raw	9.1		30.6	
lab Pl CP Cu treated	12.9	0.15	95.9	0.50
lab Pl CP treated	16.1	0.25	14.4	-0.33

The ICP-MS measurements showed increased copper concentrations in the treated water what indicate that copper was released to the water. The resulted copper concentration were still far below the guideline value of 2 mg/l. One couldn't guess from the concentration or the log reduction that the copper wires in SS 2 and Pl 2 were added before the ones in SS 4 and Pl 3. Due to the calcium phosphate pellets in the plastic filter one would suggest that the resulting log difference is higher for them than for the stainless steel filters but this was not the case.

A3.2 Community filters

Table A 3: Overview of the sampled community filters: the CDN water kiosk was renewed and therefore no in operation for the month of April and May and the WSUP kiosks are all connected to the same borehole (CF = standard community filter, RF = remote area filter)

ID	Type	location	media	Size [l]	last addition	purpose	source	date of sampling
CDN kiosk	CF	Nakuru	CP	~10000		kiosk	borehole	10.03.2011
Greensteds school	CF	Nakuru	CP	5000	16.08.2008	school	borehole	15.03.2011 05.04.2011
Muririchua	CF	Nakuru	CP	5000	21.03.2007	kiosk	borehole	15.03.2011
St. Theresa	CF	Nakuru	CP	6000	18.03.2011	school	borehole	05.04.2011
Longiwan	CF	Baringo	CP	2*4000	Dez. 09	school & kiosk	borehole	12.04.2011
WSUP K1	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
WSUP K2	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	19.05.2011
WSUP K3	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
WSUP K5	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
WSUP K6	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
WSUP K7	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
WSUP K8	CF	Naivasha	CP	4000	30.09.2009	kiosk	borehole	18.05.2011
Moindabi 1	CF	Naivasha	CP	5000	20.06.2008	kiosk	borehole	19.05.2011
Moindabi 2	CF	Naivasha	BC	5000	01.03.2000	kiosk	borehole	19.05.2011
Kokwa Island	RF	Baringo	CP	4000	17.05.2006	school & community	Lake B.	12.04.2011
Longicharo	RF	Baringo	CP	4000	11.04.2008	community	Lake B.	12.04.2011
Ng'enyin	RF	Baringo	CP	5000	30.03.2007	community	Lake B.	12.04.2011
Biretwonin	RF	Baringo	CP	4000	01.05.2006	school & community	borehole	27.04.2011

Table A 4: Turbidity measurements for remote Area Filters in Baringo district

Turbidity in NTU	source	Raw	filtered	log Reduction
Kokwa Island		54	16	0.53
Longicharo	Lake Baringo	58	1	1.76
Ng'enyin		84	26	0.51
Biretwonin	borehole	44	1	1.64

A3.3 Costs

Table A 5: Costs for the different defluoridation filters described in chapter 2.3

Type of filter	costs in KES	costs in USD
Defluoridation bucket 20 L	2’500	30
Defluoridation bucket 80 L	14’000	155
Combined plastic filter	3’700	41
Stainless steel filter 24 L	7’400	82
Stainless steel filter 34 L	9’600	107
Standard community filter	80’000 - 3 millions	887 - 33’250
Remote area filter	480’000 - 700’000	5’320 - 7’760

Fluoride testing of a water sample is around 100 KES. Such a test is required before buying the filter to estimate the lifespan and when reached it to detect break through. Replacing the filter media costs 70 to 100 KES per L depending on the ratio of bone char and pellets (compare Table A 6).

Table A 6: Prizes for replacement of different filter elements

element	costs in KES	costs in USD
Bone char per L	70	0.77
Pellets	110	1.21
Ceramic candle	700	7.72

A4 Laboratory experiments

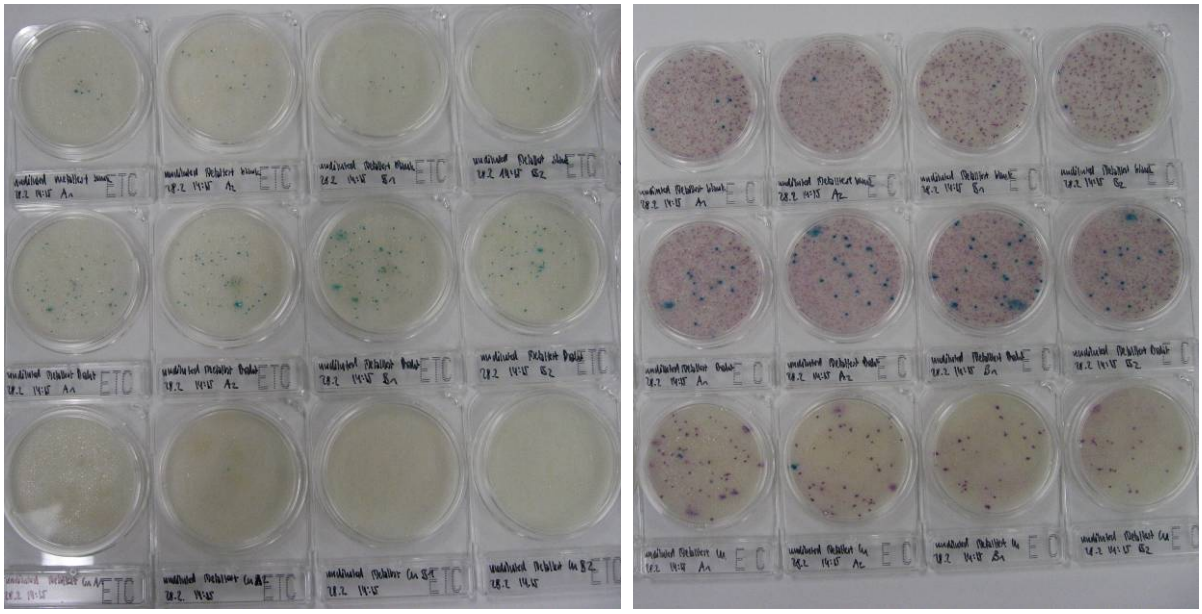

Figure A 8: ETC (left) and EC (right) plates after incubation of 1mL samples of water which was exposed to copper (lowest line) and florist's wire (middle row) respectively for 96 hours and the control in the upper line

A5 Analysis and illustration with Stata

Stata SE v.11.0 is a software package for data management, data analysis and graphics. It was used to carry out statistical analysis and to illustrate the data graphically.

Most results are plotted as **box and whisker plots** (e.g.: Figure 5.5) which display much different information. The mean of the data series (corresponds to the 50% percentile) is indicated as the middle line in the box. This marks the 25% and 75% percentile of the distribution. The whiskers are the 2 vertical lines below and above the box. They mark the lowest and the highest value within 1.5 times the interquartile range (= height of the box) from the borders of the box. The values outside this range are regarded as outliers and displayed as dots.

With the help of **t-tests** one can evaluate if the means of two data sets are statistically different or not. The t-value is computed as the ratio between the difference of the means and its standard error. The different probability values (abbr.: p-values; see last row in Figure A 9) result from the t-value and the degrees of freedom (= total # observations -2). P-values below the chosen level of significance indicate a statistical difference between the 2 data groups. For the present analysis all tests were two-tailed comparisons of the equality of means expressed by the probability value in the centre. P-values stated in the text and listed in Table A 7 refer to this value. It indicates the probability that there is no significant difference between the means of the 2 data sets. If the value is below the level of significance of 0.05 the 2 data groups can be characterized to be statistically different.

```
. ttest tc if media=="raw"|media=="CC", by(media)

Two-sample t test with equal variances

   Group |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
      CC |      19    111.4211    33.93512    147.9197    40.12602    182.7161
     raw |       7    168.2143    65.90269    174.3621    6.956205    329.4724
---------+--------------------------------------------------------------------
combined |      26    126.7115    30.19824    153.9814      64.5171     188.906
---------+--------------------------------------------------------------------
    diff |           -56.79323    68.5115                -198.194    84.60756
------------------------------------------------------------------------------
    diff = mean(CC) - mean(raw)                                   t =  -0.8290
Ho: diff = 0                     degrees of freedom =       24

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.2076         Pr(|T| > |t|) = 0.4153          Pr(T > t) = 0.7924
```

Figure A 9: T-test output in Stata- first row = command to test whether the 2 data sets (total coliform concentration in the raw water and the one after the ceramic candles) are statistically different from each other, the most relevant p-value is the one in the middle 0.4153

Table A 7: Overview of the results from the two tailed t-tests in Stata

ID		compared	variable	EC	TC	ETC
1	CC	HH vs. lab	log Red	0.0579	0.0439	-
2	filtering Cu	HH vs. lab	log Red	0.9342	0.7789	-
3	HH	raw vs. ster tap	CFU	0.0262	0.4219	0.0166
4	HH	raw vs. POU	CFU	0.3517	0.7117	0.2722
5	HH	ster tap vs. POU	CFU	0.1043	0.2859	0.1793
6	HH	raw vs. after CC	CFU	0.2910	0.5266	0.3729
7	HH	after CC vs. ster	CFU	0.1260	0.1802	0.0994
8	HH	after CC vs. POU	CFU	0.9440	0.8273	0.7897
9	HH after CC	Pl vs. SS	CFU	0.5411	0.7817	0.8809
10	HH POU	Pl vs. SS	CFU	0.3653	0.8262	0.3056
11	HH ster	Pl vs. SS	CFU	0.1781	0.3403	0.7301
12	HH filtering	Pl vs. SS	log Red	0.1301	0.6262	0.2136
13	HH filtering	Cu vs. no Cu	log Red	0.6213	0.9768	0.0649
14	sources	distribution vs. vendors	CFU	<0.0001	<0.0001	<0.0001
15	sources	distribution vs. boreholes	CFU	0.4988	0.8739	0.1517
16	sources	vendors vs. surface water	CFU	0.0180	<0.0001	0.0001
17	sources	vendors vs. boreholes	CFU	0.0010	0.0008	<0.0001
18	treated CF	CF vs. RF	CFU	0.3374	0.0424	0.0001
19	treated POU	CF&RF vs. HH	CFU	0.6778	0.0012	0.0160
20	treated POU	CF vs. RF	CFU	0.3377	0.6546	0.8748
21	filter tap to POU	CF vs. RF	log Red	0.0501	0.5197	0.0010
22	CF defluoridation	CF vs. RF	log Red	0.0220	0.0670	0.1995
23	CF defluoridation	raw vs.. Treated	CFU	0.5897	0.1372	0.1452
24	CF- HH	filter tap vs. POU	CFU	0.2012	0.0030	0.0398
25	lab EAWAG	Cu vs. control	CFU	0.1274	<0.0001	<0.0001
26	lab EAWAG	Cu vs. florists wire	CFU	0.0007	<0.0001	<0.0001
27	lab EAWAG	control vs. florists wire	CFU	0.0014	-	<0.0001
28	lab defluoridation	Cu vs. no Cu	log Red	0.4091	0.7609	-
29	lab defluoridation	CP vs. BC	log Red	0.4049	0.1399	-
30	lab CC	raw vs. after CC	CFU	0.1167	0.4153	-
31	lab CDN	Cu vs. control	CFU	0.0017	0.0043	-
32	lab CDN	local vs. Swiss	CFU	0.1982	no calc	-
33	lab CDN	raw vs. copper	CFU	0.0025	0.0020	-
34	lab CDN	raw vs. control	CFU	1.0000	0.1705	-
35	lab EAWAG	temp 11 24h vs. 48 h	CFU	no calc	no calc	no calc
36	lab EAWAG	temp 11 48h vs. 96 h	CFU	0.1411	<0.0001	<0.0001
37	lab EAWAG	temp 11 96h vs. 120 h	CFU	0.5796	0.0002	0.0009
38	lab EAWAG	temp 20 24h vs. 48 h	CFU	0.0004	<0.0001	<0.0001
39	lab EAWAG	temp 20 48h vs. 96 h	CFU	0.9078	1.0000	0.0001
40	lab EAWAG	temp 25 24h vs. 48 h	CFU	0.1492	<0.0001	<0.0001
41	lab EAWAG	temp 30 24h vs. 48 h	CFU	1.0000	1.0000	0.0106
42	lab EAWAG	temp 37 24h vs. 48 h	CFU	1.0000	0.0008	0.6489
43	lab EAWAG	temp 42 24h vs. 48 h	CFU	1.0000	0.6536	1.0000
44	lab EAWAG	temp 45 24h vs. 48 h	CFU	1.0000	no calc	0.0400
45	lab EAWAG	25° vs. 30°C	CFU	0.0039	0.1443	0.4344
46	lab EAWAG	25° vs. 37°C	CFU	0.0022	<0.0001	<0.0001
47	lab EAWAG	25° vs. 42°C	CFU	<0.0001	<0.0001	<0.0001
48	lab EAWAG	30° vs. 37°C	CFU	0.5423	<0.0001	<0.0001
49	lab EAWAG	37° vs. 42°C	CFU	0.0135	<0.0001	0.3173
50	lab EAWAG	37°C vs. variable temp	CFU	0.0004	<0.0001	0.1467
51	lab EAWAG	37°C 24h vs. var. temp 48h	CFU	0.1151	0.0305	0.3558
52	lab EAWAG	37°C 24h vs. var. temp 96h	CFU	0.1151	0.3102	0.7093