Trier University of Applied Sciences

Department of Civil Engineering

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Master-Thesis

Mobile drinking water purification for developing countries

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Safe drinking water is one of the main problems in developing countries. Worldwide about 780 million people have no access to clean drinking water and suffer from poor sanitation facilities.

One of this is the African country Uganda, where 22 children die every day from diseases caused by unsafe water. Recent advances in technology and Ugandan ingenuity have led to opportunities to change things for the better. Related ideas range from

- chlorine production by a simple car battery for water disinfection to
- “high tech” mobile facilities for water purification.

Within the scope of this thesis technical and management as well as social aspects of the drinking water problem in developing countries will be summarized, particularly in Uganda. During a field visit to rural Uganda, existing facilities and organizational structures should be explored and different mitigation strategies and technical solutions investigated. This should include one state-of-the-art mobile system that will be tested in the field and in laboratory facilities in Trier. Its observed efficiency should be compared with other systems, in particularly with simple methods for water disinfection. For this purpose, results of similar analysis from prior theses are available. Evaluation of results should include the recommended values of the World Health Organization for disinfection.

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Abbreviations and Acronyms

%	percent
°C	degrees Celsius
<	less than
>	greater than
≈	approximately equal
AC	alternate current
Al	aluminium
AOX	absorbable organic halogen compounds
B.Eng.	Bachelor of Engineering
B.Sc.	Bachelor of Science
C_2H_5OH	ethanol
CBM	Community Based Management
cfu	colony forming units
cfu/100 ml	colony forming units per 100 mililiters
cfu/ml	colony forming units per millliliter
chlor.	chlorinated
Cl_2	chlorine gas
cm	centimeter
cm^2	square centimeters
DC	direct current
Dipl.-Ing.	Diplom Ingenieur (graduated engineer)
E.Coli	Escherichia coli
e.g.	*lat.* exempli gratia (for example)
EC	electrical conductivity
et al.	*lat.* et alius (and others)
Fig.	Figure
filtr.	filtrated
g	gramm
GDP	Gross Domestic Product
h	hour
H^+	hydrogen ions

H_2	hydrogen gas
H_2O	water
HClO	hypochlorous acid
HPC	heterotrophic plate counts
IC	ion chromatography
kg	kilogramm
l	liter
l/min	liters per minute
lat.	latin
M.Eng.	Master of Engineering
m^3	cubic meter
MDG	Millenium Development Goal
MFU	Membrane Filter Unit
mg	milligramm
mg/l	milligram per liter
min	minutes
ml	milliliter
MLSB	Membrane Lauryl Sulphate Broth
mm	millimeter
Mn	Manganese
N	Nitrogen
n.v.	no value
NaCl	sodium chlorite
NaClO	sodium hypochloride
NaOH	sodium hydroxite
NH_4	Ammonia
NO_2	Nitirite
NO_3	Nitrate
NPS	nutrition pad sets
NTU	nephelometric turbidity units
O&M	Operation and Management
O_2	Oxygen gas
OH^-	Hydroxid ions
P	Phosphorus
PET	polyethylene terephthalate
pH	*lat.* potentia hydrogenii (power of hydrogen)
PO_4	phosphate
PVC	Polyvinyl chloride
SAME	Society of American Military Engineers
Sew.pl.effl.	Sewage plant effluents
SODIS	Solar disinfection
Rainw.	Rainwater
Tab.	Table
Temp	Temperature
THM	Trihalomethanes
THW	Bundesanstalt technisches Hilfswerk (Federal Agency for Technical Relief)
tntc	too numerous to count

TrinkwV 2001	Trinkwasser Verordnung 2001
UBOS	Ugandan Bureau of Statistics
UNDP	United Nations Development Programm
UNICEF	United Nations Children´s Fund
US$	US dollar
UV	ultraviolete
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WTP	Water Treatment Plant
WUC	Water User Comitee
µm	micrometer
µS	microsiemens
µS/cm	mircosiemens per centimeter

1. Introduction

In 1876 Robert Koch had proven that microorganisms are able to cause infectious diseases within the human body, and succeded in 1893 to drastically reduce the number of cholera outbreaks in Hamburg by filtering drinking water. In 1875 Joseph Bazalgette eradicated the cholera from London through his sewer system. Since these milestones in the disciplines of medicine and civil engineering have revolutionized drinking-water treatment and wastewater management, the spectre of water-borne diseases is banished from industrialized countries. In 2016 water-borne diseases still are bitter reality in many developing countries. Worldwide about one million people, primarily children under five, die because of water- and hygiene-related diseases every year, almost soley in developing countries. Every 90 seconds a child dies due to diseases that directly result from microbially unsafe drinking water, and the lack of proper hygiene and sanitation (WHO/UNICEF, 2015). Today, numbers of people without access to safe drinking-water sorces worldwide range from more than 660 million people (WHO/UNICEF, 2015) to more than 780 million people (WHO/UNICEF, 2012). About 2.4 billion people do not have access to proper sanitation facilities (WHO/UNICEF, 2015).

One of the most affected regions worldwide is sub-Saharan Africa. Despite that Uganda for example has quite large resources of freshwater and reliable rainfall patterns it is one of the countries that is the most encountered by drinking-water problems. Therefore drinking-water problems are not due to water scarcity, they arise primarily from scarcities of safe drinking-water sources and from the absence of proper drinking water and wastewater management, and -treatment. Several other developing countries with comparable attributes and climates such as Ethiopia, Kenya, India or Bangladesh are affected in similar ways. In particulary, problems in drinking-water quality do interact with widespread (complex) problems in developing countries. These problems are related to natural aspects, technical and political status, water –availability, -management, -distribution and -treatment, sanitation and hygiene, politics, education, social- and socioeconomic aspects, medical supply, infrastructure, and many more. Often the problems occur in high enumeration within specific regions, especially in the least developed countries. This thesis does not aim to discuss all or nearly all aspects that affect drinking-water quality in developing countries. The approach of this thesis in this context is to specifically investigate the drinking-water situation in both urban and rural areas in parts of Uganda and to investigate the potential of mobile pressureless microfiltration units, as a high-tech solution and individually produced chlorine with a low-tech approach. The general sanitation situations, as well as some of the most evident social- and socioeconomic aspects, were also taken into consideration, but in limited depth. Many of these points can be seen as an example for widespread general problems relating to drinking water in developing countries, which are similar to Uganda.

In this context, twelve drinking-water sources in Uganda were tested for water-quality parameters to get first impressions of the drinking-water quality within the researched areas. The sources are located in urban and rural areas, all of them are constantly used for drinking-water supply. The raw-water samples were tested on-site for physical-chemical parameters (turbidity, pH, electrical conductivity (EC), metals and minerals) and microbial parameters (total aerobic plate counts and total coliforms). After the process of raw-water testing, four villages were chosen to test the practicability and the disinfection capability of a

low-tech chlorination system, originally designed by Dipl.-Ing.. Michael Ottensmann. Within these thesis, the on-site testing results are furthermore compared to laboratory testing results of a reconstructed prototype, that were executed by B.Eng. Triet-Vu Luu in a prior bachelors thesis (LUU, 2016).

In addition, two of these villages were researched on-site in a similar way, using mobile pressure-less microfiltration units developed by the Foundation Veolia (Aquaforce 5). Some of the researches on-site were also intending to assess the potential of microfiltration with additional chlorination. To verify the on-site results, the Aquaforce 5 filters were also tested in laboratory conditions in Trier. With this intention, five German raw and –waste waters were investigated for important water-quality parameters before and after filtration. The laboratory tests were also used to gain further knowledge of microbial cleaning efficiencies (related to E.Coli, total coliforms and heterotrophic plate counts) of the microfiltration units. Also the effects of microfiltration related to physical-chemical parameters (turbidity, pH, electrical conductivity (EC), magnesium, calcium, sodium and potassium) were researched. Some of the laboratory test procedures should also assess the effects of microfiltration on acceptability parameters: taste, odor and appearance. The laboratory cleaning success of the Aquaforce 5 was compared with the cleaning success of prototype-produced chlorine (LUU, 2016) and similar mobile filter systems in German raw- and waste waters, that were originally researched by M.Eng. Sasha Dany (DANY, 2011) in a prior masters thesis.

As another alternative low-tech drinking-water purification method used in developing-countries, some general aspects, thoughts, and research findings of solar disinfection (also called SODIS) are represented within this thesis.

2. Background, Uganda

2.1 Geography, politics and economy

Uganda, officially “The Republic of Uganda“, is a landlocked country in east sub-Saharan Africa. It borders on Kenya, South Sudan, the Democratic Republic of the Congo, Rwanda and Tanzania. It covers a total area of about 240,000 square kilometers, so it roughly has the same geographical dimension as the United Kingdom. With its population of about 35,000,000 people (UBOS, 2016) Uganda, is beside Namibia, the most populated landlocked country in Africa. The official languages are both Swahili and English. Besides that, numerous other languages are spoken within Uganda, depending on specific regions and tribes.

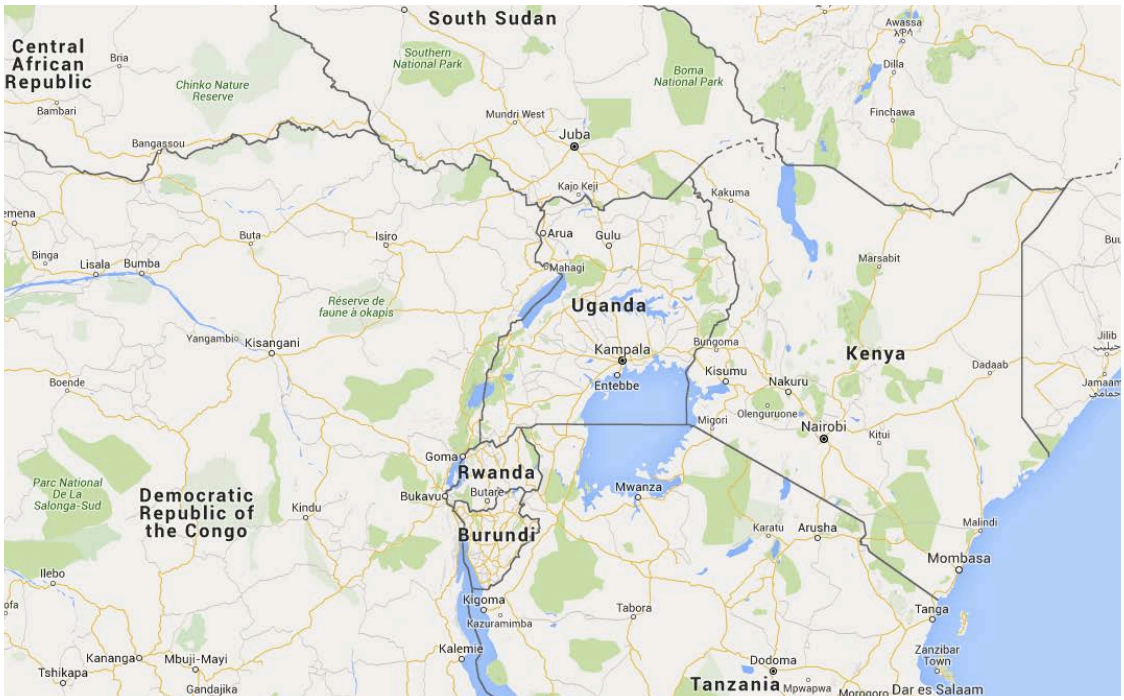


Fig. 1: Geographical position of Uganda in Eastern Africa (Google Maps, 2016)

Economically speaking, Uganda is one of the least developed countries in the world. According to the data of the World Bank in 2015, the nominal Gross Domestic Product (GDP) of Uganda was about 676 US$ per capita. In worldwide comparison, it ranks 167th out of 183 researched countries. With this GDP, it is comparable with countries like Afghanistan, Ethiopia, Rwanda, Sierra Leona or Nepal. In relation to Uganda, for example, Germany has a nominal GDP of about 41,221 US$ per capita (World Bank, 2016). Uganda has, for the most part, fertile soils and regular rainfall, so the majority of the economic income is generated by the export of agricultural products (mainly coffee, tea and tobacco). The country has several natural resources including gold, copper, cobalt and, to this date, untapped mineral oil and natural gas (CIA, 2016). In the last decades, Uganda has gained a stable economical growth, mostly in the single-digit percentage area. Despite that, the country is still considered one of the poorest nations in the world. In 2012, about 33 % of the Ugandan population (about 12 million people) still lived below the global poverty line, meaning less than 1.90 US$ a day (World Bank, 2016).

Similar to many other developing countries, Uganda is plagued by severe problems in regards to corruption. This is often seen to impede positive developments in all sectors of society, the economy (Transparancy International, 2016) but also drinking water and sanitation (IRIN, 2013).

2.2 Climate and water availability

The Ugandan climate is mainly influenced by its geographic position in the tropical zone, its altitudes and its water bodies. The southern, western and the central areas are, for the most part, located on a plateau of about 1,000 meters above sea level or higher. Besides that, the geographical position near Lake Victoria, which is the second largest inland freshwater lake worldwide, influences the climate. The conditions in these areas are slightly cooler than in other, similar tropical areas. The temperatures are relatively constant over the year and

range from about 20 to 25 degrees Celsius during the day and about 17 degrees Celsius at night. The rainfall distribution within Uganda is depicted in Fig. 2.

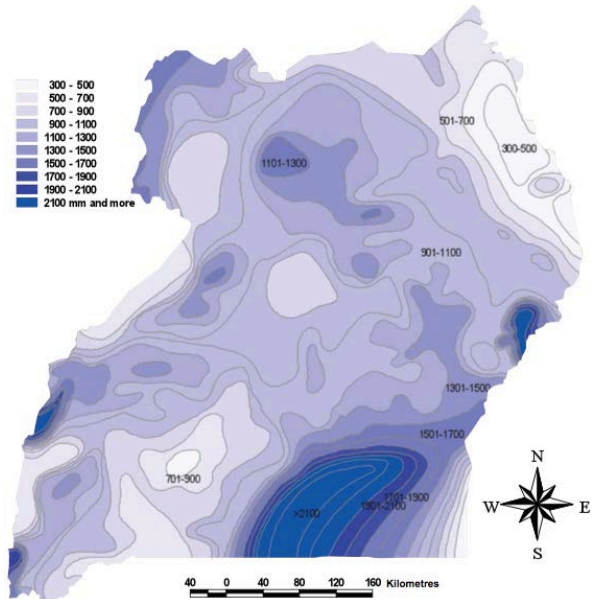


Fig. 2: Rainfall distribution within Uganda (NEMA, 2009)

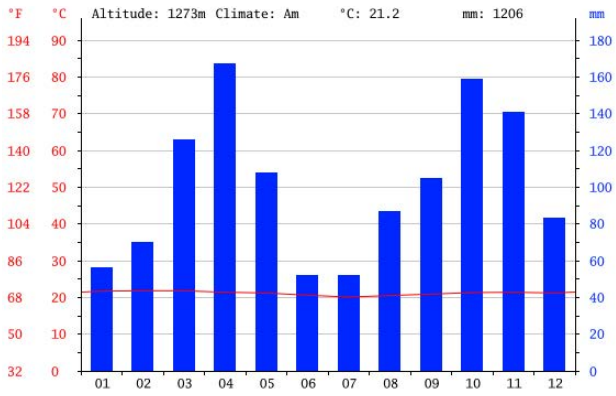


Fig. 3: Precipitation over the year in Mityana (climatedata.org, 2016)

The highest precipitation rates (1,200 to more than 2100 mm a year) are achieved near Lake Victoria or near other big water bodies. In the central, western and southern areas, the precipitation rates are distributed within two (more or less intensive) wet seasons from March to May and September to November, while precipitation rates in the other months are still relatively high (NEMA, 2009). Probably as an early result of climate change, the regions in the north (especially in the northwest) have become a semi-arid and hot climate (unlike the tropical, humid climate in other parts of the country). Here, the precipitation rates are lower; they range from under 800 to about 1000 mm per year, and have merged into one wet period within the year. Some parts in the north are even characterized by droughts in the dry-season (FAO, 1999).

Uganda is located within the so-called “Great Lakes Region”. The majority of its landscape is characterized by the presence of open water bodies (lakes, rivers) and wetlands covering about 17 % of Uganda’s total area. Uganda is not especially rich in groundwater, but the groundwater situation has not been adequately explored (NEMA, 2009). Uganda seems to be blessed with relatively rich amounts of water from numerous sources, as opposed to many other developing countries that are challenged with general water scarcity.

3. Drinking-water situation in developing countries

In many developing countries, especially countries located in tropical zones, drinking-water problems do not arise from raw-water scarcity. These regions suffer primarily from the absence of raw-water in suitable drinking-water quality. Often one of the main problems relates to acute scarcities of functional, improved drinking-water sources, considered to

permanently and reliably deliver clean drinking water. Many people in the least developed countries do not have adequate access to improved drinking-water sources and have to use unimproved drinking-water sources. In many cases, there is no proper raw-water treatment or wastewater management to improve quality of raw-water used as drinking water. Uganda is no exception to this. Water is widely available, but is often gained through so-called unimproved drinking-water sources, especially rural areas.

The WHO (2011) defines an improved drinking-water source as a source that *by the nature of its construction and design adequately protects the source from outside contamination, in particular by faecal matter* (WHO, 2011). Drinking water from these sources should have a high probability of being free of fecal indicator bacteria and, if possible, meeting the WHO guidelines for drinking-water quality. Conversely, unimproved drinking-water sources are vulnerable to permanent or temporary water-quality deterioration and often do not meet the WHO guideline values for safe drinking water.

Improved drinking-water sources are, for example, seen in:

- piped water into dwellings, yards or plots
- public tap water
- tubular wells or boreholes
- protected wells or springs
- rainwater collection

Unimproved drinking-water sources are, for example, seen in:

- unprotected wells or springs
- surface water sources
  (rivers, dams, lakes, ponds, streams, canals, irrigation canals)
- tanker-truck provisions of water
- bottled water

One of the most ambitious goals of humanity within the last decades is to improve the drinking water and sanitation situation worldwide and to reduce inequality and poverty in this context. These goals were taken on to solve by the UNICEF and WHO by defining so-called “Millenium Development Goals” (MDGs) in 1990. To get a general overview about the drinking water and sanitation situation and the achievements of the MDGs from 1990, parts of the WHO/UNICEF paper “Progress on Sanitation and Drinking Water 2015 Update” (WHO/UNICEF, 2015) are summarized under special consideration of data for Uganda.

3.1 Progress on Sanitation and Drinking Water 2015 Update

In terms of drinking water, the MDG was globally reached. In 2015 more than 90 % of the world’s population had access to improved sources of drinking water. Alongside the many remarkable positive developments in drinking-water availability and quality since 1990, however, there are still deficiencies and disparities in many areas, especially between urban and rural areas. In urban areas the percentage of people having safe drinking-water sources (96 %) still exceeds those of rural areas (84 %). So there are more than 660 millions of people worldwide without access to improved drinking-water sources, primarily in rural areas in the least developed countries.

2.1 billion people have gained access to improved sanitation facilities since 1990, but today 2.4 billion people still worldwide lack any access to improved sanitation facilities. This often leads to sanitation facility-sharing among communities or open defecation, both serious evolving issues for human health and the environment.

Uganda has met the targets according to drinking water in general. The total coverage of access to improved drinking-water sources have increased since 1990 from 40 to 79 % (of population) in 2015. 96 % of people living in urban areas have access to improved drinking-water sources, while in rural areas 76 % have in 2015. This means, however, that 21 percent of total population in Uganda, about 7 million people, still lack improved drinking-water sources.

Like many other countries, Uganda could not accomplish significant improvements in terms of the MDG in sanitation. In total the amount of people using improved sanitation facilities has slightly increased from 13 % (of population) in 1990 to about 19 % (of population) today. Urban areas have not achieved significant achievements since 1990. Only 29 % of urban population now has access to improved sanitation facilities. In rural areas, the percentage increased from 11 to 17%. Percentages of people practicing open defecation have decreased in the last 25-year span to 7 % of population (in total). Rural areas showed declining percentages of open defecation from 22 % in 1990 to 8 % in 2015.

3.2 Drinking-water and sanitation situation in Kalangaalo, Uganda

As an example for rural areas in Uganda and for similar regions in developing countries, the drinking water and sanitation situation was researched in Kalangalo (also referred to as Kalangaalo). Kalangalo is a sub-county in the Mityana District and is located in the Central Region of Uganda (see Fig. 4).

Fig. 4: Geographic position of the Mityana District and Kalangalo (Google Maps, 2016), edited

Many of the following numbers are taken directly from the 2014 census, accomplished by the Uganda Bureau of Statistics (UBOS) and published in 2016. The relevant pages of the census are presented in the annexes.

It is estimated that about 330,000 people live in the Mityana District and about 30,000 people live in Kalangaalo itself. The area is rural, with the majority of people (83 %) practicing subsistence farming (UBOS, 2016). Despite that, there appear to be high population densities near main streets. Because of this, the volume of needed drinking water in parts of the area is high, so almost every available water source is used (in some cases extensively) for drinking-water supply.

The numbers of the census also indicate that nearly 5000 of the 6900 households in the area are using “unprotected“ water sources for drinking water supply. These “unprotected“ drinking-water sources are not specificly defined by the UBOS, conversely, “protected“ drinking water sources include: piped water, boreholes, protected well/springs, gravity flow and bottled water. These definitions concur more or less with the classification of the WHO (2011): “protected“ water sources can be compared to “improved drinking water sources“. The “unprotected“ water sources are comparable to “unimproved drinking water sources“. One major disfference is that the WHO does not consider bottled water to be an improved drinking water source; so the UBOS statistics would have probably been worse using WHO standards and classifications. Estimates also say that 1,500 households in the area are using “improved toilet facilities“, therefore only minorities of people living in the area have relatively good standards in terms of sanitation. Improved toilet facilities are seen in flush toilets, VIP (ventilated improved pit) latrines, covered pit latrines or compost toilets. About 5,000 households within the area are using “unimproved toilet facilities“; more than 200 households do not have any access to toilet facilities.

Several villages have been researched within Kalangalo (Kyamagemule, Namukomago, Mayobyo, Kabayiima). It is difficult to determine the number of inhabitants and the number of users of the researched drinking-water sources accurately. To get at least an overall view of these numbers, the author of this thesis had to rely on the estimations of inhabitants. Mostly one village within Kalangalo (at the same time this is the number of potential users of a water source) seems to be about 50 – 200 people. One exception to this is Kyamagamule, which has, in addition, a secondary school with about 150 students.

Statistics and on-site impressions show that the overall drinking water situation in rural Uganda is poor compared to western standards. The inhabitants of these partly very rural areas receive their drinking water supplies for domestic use by filling jerry cans (20 liter PVC) at local water sources and carrying them home. Piped drinking water sources arealmos non-existend. Mostly the users boil the drinking water gained from the sources before they consume it, with the intention to kill as much bacteria as possible. Although this technique is known to kill the majority bacteria and parasites contained in the water (WHO, 2011), this procedure is not seen to be practical in the long term. Because of the high level of energy and time required for the boiling process, it is not applicable for larger volumes of drinking water. In addition, turbid water or water with other (inorganic or organic) components often become unenjoyable in taste and appearance, because some components flocculate while boiling. In addition, especially children often drink the raw-water before it is treated this way,

for example right after they have taken it from the raw-water source. If the water seems extremely turbid/dirty, some of the villagers also filter the water through rags or cloths before boiling.

The majority of the surface water sources within the researched villages are ponds (see Fig. 5 and Fig. 6) that can be seen as mixtures of uprising groundwater, surface- and rainwater collectors. Some of them can be classified as springs resulting from uprising groundwater, collecting in stagnant ponds. In extreme cases, some surface water sources appear to be seasonal, depending on the origin of the water. The size and water quality (at first glance) of these ponds is varying widely; also the ponds seem to be differently affected by external impacts. Several ponds have been researched, each of them characterized by differences in coloration of the water, pollution and external (natural or anthropogenic) impacts.

Fig. 5: Drinking-water source (pond) in Kabayiima

Fig. 6: Drinking-water source (pond) in Namukomago

Fig. 5 and Fig. 6 can be seen as examples of the majority of these ponds: both of the ponds are relatively large, and more or less naturally vegetated by algae and water plants. Other plant/organic matter is frequently affects the water quality. These larger ponds seem to gain the majority of their water from rainwater, surface water and uprising groundwater. Other types of ponds are relatively small, without these amounts of vegetation or plant matter: probably the origin of the water within these smaller ponds can primarily be classified as uprising groundwater, but they are also influenced by rainwater and runoff by nature. Nevertheless almost all of the researched ponds seem to be directly endangered by anthropogenic or natural impacts in terms of water quality. In rural areas like this, anthropogenic impacts essentially mean fecal or other pollution.

Fig. 7: Pit latrine in Mayobyo

This pollution often results from the absence of improved sanitation facilities, proper wastewater management and domestic waste disposal. Sanitation facilities are commonly available among villages/communities, but sewage treatment or disposal is often unavailable or poor. In most cases the facilities consist of pit latrines or shared toilets (flush toilets are also available but more rarely) that dispose their sewage into hand-dug septic tanks or hand-dug/concrete sewage channels leading nowhere. In general, it is not common amongst the villagers to practice open defecation, but some of the villagers do (at least partly) practice open defecation.

Also agricultural practices seem to affect the water quality of the drinking water sources. Most of the areas surrounding the villages and the sources are directly used for agriculture. Agriculture in this context is means cultivation of field crops (maize, tobacco, coffee), fruits (banana, papaya, mango) or wild mixtures respectively. The areas are mostly fertilized with manure. Artificial or industrial fertilizers are not affordable for the farmers. At the same time. some areas near the surface water-sources are constantly used for small-scale livestock farming. Because of this, the animals (cows, goats, more rarely domestic pigs) often drink directly from the water-sources and defecate in the area near the water-source.

Naturally all of these surface water sources (ponds) are located at the bottom of more or less wide valleys, while the villages and parts of the agricultural used areas are located at significantly higher altitudes. This increases the vulnerability of surface water sources to microbial and chemical contamination. This is because the runoff, after heavy rainfall events or long-duration rainfalls within the rainy season, floods amounts of human or animal feces, wastewater, domestic waste, plant matter and other things into the source.

Fig. 8: Drinking-water source (stream) in Mayobyo

Smaller streams (see Fig. 8) are also used by some of the villages, but the most popular drinking water source is generally seen in ponds like the ones mentioned above. Streams are naturally affected by similar dangers like other surface water sources.

The main decision criteria, however, for the use of any specific water source is either the location near the village or the absence of suitable alternative drinking water sources in general.

Some communities are able to use shallow groundwater wells/boreholes. Shallow wells particularly seem to have the most suitable drinking water in the researched, rural areas.

They essentially gain drinking water from groundwater aquifers, which are seen to be one of the most suitable sources for safe drinking water. Groundwater aquifers in general, seem to be well protected from outside contaminations because the overlying layers of soil and sediments filter rainwater (or other entering water) and remove majorities of potential pollutions. Nevertheless, groundwater quality can indeed be negatively affected by several external influences: further studies (HOWARD et al., 2003) have shown, that water quality can, in particular, be deteriorated by inflow of fecal matter into the aquifer after short time rainfall events, especially in very densely populated or very polluted areas. This means that shallow wells using groundwater supplies can be quite vulnerable to contamination related to on-sire pollution on-site and even more to pollution from a wider drainage area. Surprisingly these studies have also indicated that pit-latrines and septic tanks near groundwater sources seem to have considerably less impact on groundwater quality than local surface pollution such as solid waste disposal and fecal matter.

An example of potential on-site contamination of shallow wells can be seen at the researched well in Kyamagamule. At this specific well it could be imagined that contamination arises from poor construction or damage due to extensive everyday usage of the hand-pump. While pumping the water up with the manually enabled pump, the head of the well must withstand severe forces and vibrations, which has resulted in cracks at the base of the pipe (see Fig. 9 and Fig. 10).

Fig. 9: Shallow well in Kalangaalo Kyamagemule

Fig. 10: Cracks at the base of a shallow well in Kalangaalo Kyamagemule

Water from outside the well is able to pass these cracks, rinse down the pipe and contaminate the pipe or the aquifer. Especially in rural areas maintenance and repair of shallow wells is often not available or poor. The repair of these or similar damages is for many communities either not affordable or includes the danger of contaminating the whole water-source for longer periods of time during or because of construction. This specific problem is generally seen to be widespread within extensively used shallow wells with hand-pumps.

External contamination sources also often appear within the immediate surroundings of specific shallow wells**.** In many cases these areas are noticeably dirty/muddy. This pollution is able to intensify the problem of the cracks at the pipe and to negatively impact drinking-water quality. The pollution probably results from high human activity around the wells. Not only do the wells have an essential meaning for the drinking-water supply: to fulfill the need

for drinking water for almost every family of the village who uses the well several times a day. In addition, the wells seem to be one of the most important social meeting places within the villages. This means that, for example, children are almost constantly playing at the well.

In addition to the already listed water-sources and water-distribution, a minority of households/communities in these rural areas actively collects rainwater for domestic use. Rainwater collection, however, is practiced in different dimensions and is used with different intentions. Some households simply collect small amounts of rainwater in containers (trashcans or clay vessels) for domestic use or for small-scale irrigation. Some more developed households (and also schools, in particular) collect rainwater on a larger scale, store it in plastic rainwater tanks (see Fig. 11) and use it primarily to supply part of their non-consumed drinking-water needs (e.g. for toilet flushing, showering, body washing or laundry). Collected rainwater is not generally used for drinking-water consumption in the researched villages, even if other studies have shown that targeted rainwater collection can be particularly seen as a relatively safe drinking-water source (OKOT-OKUMU & OTIM, 2015; NAYEBARE et al., 2014).

Fig. 11: Rainwater collection at a school in Kalangalo Kyamagemule

Uganda, as a country located within the tropical zone, has plenty of reliable rainfall patterns, distributed relatively constantly over the year. An overall impression in Kalangalo, in regards to rainwater collection, is that the potential of targeted rainwater collection, especially in private households or smaller communities, is not adequately utilized.

In principle, bottled drinking water is relatively widely available, but using it to suit the domestic drinking-water need is unpractical and for many families or communities simply not affordable.

3.3 Drinking-water and sanitation situation in Kampala, Uganda

To research drinking-water sources that are quite typical for urban areas in Uganda and similar developing countries, several sources in Kampala have been investigated. These drinking-water sources consist of a public water distribution system (piped drinking-water with public taps) in Kosovo and an unprotected spring in Masajja.

A large majority of the population in this district of Kampala lives in extraordinarily poor, slum-like conditions. It is generally seen that areas with high population densities and extreme poverty are often plagued with extraordinarily bad situations in sanitation, hygiene, wastewater management and domestic waste disposal. These points are seen to directly affect the drinking water situation within the areas. The researched area in Kampala can hereby serve as an example for numerous similar districts within cities in other developing countries, which are more or less challenged with the same problems.

Again data and numbers from the 2014 census by the **Uganda Bureau of Statistics** (UBOS, 2016) were used for the following text. The relevant pages of the census can be seen in the annexes.

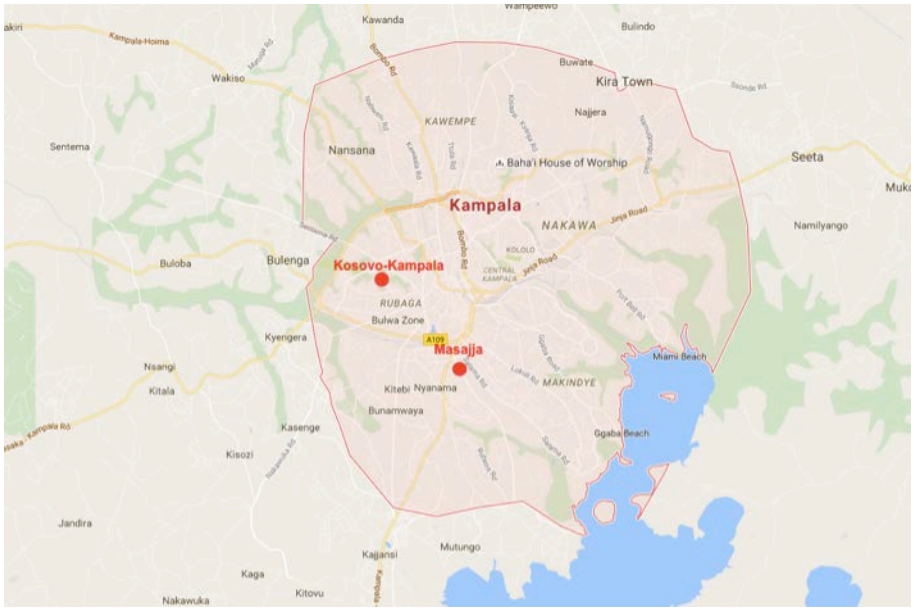


Fig. 12: Geographic position of Kosovo and Massajja within Kampala (Google Maps, 2016), edited

Kampala is the capital of Uganda, at the same time it is the most populated city with an estimated total population of about 1.5 million people. The researched drinking water sources in Kosovo and Masajja are located within the Lubaga District (also called Rubaga District), one of the districts with high population numbers (about 380,000 people) and population densities of more than 10,000 persons per square kilometer.

A difference in comparison to rural areas is that agriculture is most non-existent within the area; only 1 % of the population in these Kampala districts is dependent on subsistence farming. Also, at the first glance, the drinking-water situation seems to be better in general because about 95 % of the households (about 100,000 households) have access to “protected water sources“, including piped water, boreholes, protected wells/springs, gravity flow and bottled water.

The sanitation situation seems to be more difficult, with about 77,000 households lacking access to improved toilet facilities (UBOS, 2016). Most households probably use shared sanitation facilities (with unknown numbers of users), which mostly consist of pit latrines directly disposing the wastewater into septic tanks or leading the sewage away with sewage channels made of concrete. These statistics, furthermore, seem to be quite underwhelming, as other studies have shown that even a relatively widespread availability of improved sanitation facilities does not necessarily lead to better sanitation situations. Even if improved sanitation facilities (which, according to the WHO (2011) are sanitation facilities with a “reasonable“ number of users) are widely available and have the potential to significantly improve sanitation in general, the benefits are often overshadowed by its deficiencies (KWIRINGIRA et al., 2014). These deficiencies relate to construction and maintainance, misuse, absence of proper and regular cleaning, wastewater disposal, emptying costs, lack of privacy, security (especially at night) or abuse. These negative developments may end in

a vicious circle: because of the deficiencies, many sanitation facilities are thereafter abandoned by the users, and the users return back to the use of unimproved sanitation facilities. Eventually they are even forced to return to practicing open defecation or using “flying toilets“. Flying toilets in this context describes the practice of defecation into plastic (or paper) bags that are afterwards disposed of in solid waste dumps. To what extend this problem affects the sanitation situation in Kosovo-Kampala and Massaja cannot be accurately evaluated within this thesis. Although the problem of open defecation and flying toilets is, according to TUMWEBAZE et al. (2012), probably affecting small minorities within the slum dwellers (up to 1%), sanitation and waste management problems like these have potential to significantly deteriorate the quality of drinking-water within the area. If one were to consider the high population density and high population numbers within the Lubaga Division, and pretend that about 1% of the dwellers permanently practice open defecation or use flying toilets, about 3,800 people would be affected. These numbers would seem to be capable of having negative impacts on drinking-water quality, assuming that a majority of affected population are probably accumulated within the poorest areas with the highest population densities.

The majority of the “improved drinking-water sources“ that are mentioned within the statistics of the UBOS consist of piped distribution systems. The Kampala drinking-water distribution system is constructed with the intention of using water from Lake Victora, treating the water using filtration and disinfection (chlorination) in three Water treatment plants (WTPs), storing the water in reservoirs within different parts of the city and transmitting the water to the specific areas through piped systems. The piped system is either directly connected to the households or passes several public “tap stations“ on its way to the end of the distribution system (see Fig. 13).

Fig. 13: Drinking-water source (Piped water distribution) in Kosovo-Kampala

Fig. 14: Drinking-water source (spring) in Masajja

Through the use of this system, contamination from outside the piped systems seems to be excluded for the most part. Nevertheless, one potential problem of the system seems to be that the water quality is able to negatively change along its way from the WTPs to the reservoirs and from the reservoirs to the end of the distribution system. The longer the distance that the water has to pass through the pipes, the higher is the probability that the water quality will deteriorate, according to ECURU et al. (2011). This is due to the increase of contamination sources along the way, for example because of leaks or breakages within the system. Additionally, the chlorine residual in the water is able to decay along the way,

leading to degradation in drinking water quality (especially microbial drinking water quality) at the last of the private or public taps. In case of the public “tap stations“, there is also a general lack of hygiene. The surrounding area of the drinking-water sources and the taps themselves seem to be noticeably dirty, similar to the impressions at the shallow well Kyamagamule.

In addition, the streets within the area are littered with individual dumps and accumulations of domestic waste. This includes flying toilets, organic matter, food leftovers, bits of animal carcasses, plastic waste and other things. Contaminated water from solid or other waste (from local dumps, sewage channels, leaking or poorly constructed septic tanks) is potentially able to percolate into the ground and to contaminate the piped system through leaks. Also there is the known problem of the entrance of fecal matter or other pollution into the system through inflow or sub-surface infiltration after rainfalls. Flooded waste is also able to clog sewage canals and drainage canals leading to impoundation of contaminated water that contains residues of waste, sewage, feces and other things (SATTERTHWAITE, 2003). These impounds of contaminated water can furthermore intensify the problem of contaminated water percolating into the soil (affecting leaky piped systems or groundwater sources). In a greater context, it can lead to other serious problems relating to human health in general. This is seen to increase the danger of water-borne diseases and insect-borne diseases (due to outbreaks of mosquitos, who prefer to breed in moist areas).

Another source that was researched for its drinking-water quality is located in Massaja. This drinking-water source consists of a spring, which arises from under a house, creating a smaller stream next to it (see Fig. 14). At the first glance, the water from this spring appears extraordinarily clean/clear. In addition, the immediate surroundings of the drinking-water source do not appear to be polluted to a similar degree (by domestic waste or wastewaters) as the area around the distribution system in Kosovo-Kampala. This is probably corresponding with the general impression that this area does not seem to have as large of a population density as Kosovo-Kampala. Nevertheless, this drinking-water source is by nature more endangered by fecal or other contamination than the piped system in Kosovo-Kampala.

3.4 Social, socioeconomic and political aspects

The problems mentioned above are well known in general. The drinking water quality and sanitation situation have to be assessed together to develop sustainable solutions for better drinking water within developing countries. In particular, the situation of the borehole in Kyamagamule is a prime example for how a lack of proper sanitation, hygiene and water facility management can potentially worsen drinking-water quality. This affects unimproved and improved drinking-water sources.

These general problems in hygiene also relate to the jerry cans that are used to transport the drinking water from the source to the home of the villagers. These cans are often used for several years, at several different water-sources with (in some cases) specifically different water quality. Often the cans are not well prepared for transport, meaning that they are not properly cleaned and are not properly stored after usage. So in principle, clean and suitable drinking water can be re-contaminated with bacteria, bugs or sediments that may have collected inside the jerry cans.

3.4.1 WASH programm

One famous worldwide program in context of drinking water, sanitation and hygiene is the WASH-programm (WASH = **WA**ter **S**anitation and **H**ygiene). Born from an UNICEF idea, this program is followed and spread by numerous foundations, governments, politicians and executives all over the world. It is intended to improve education and awareness in regards to water resources, treatment, sanitation and hygiene in order to reach the MDG´s of drinking water and sanitation. So it is also meant to improve the drinking water situation in developing countries. One of its main arguments is that first steps into better sanitation/hygiene must begin within the educational system itself.

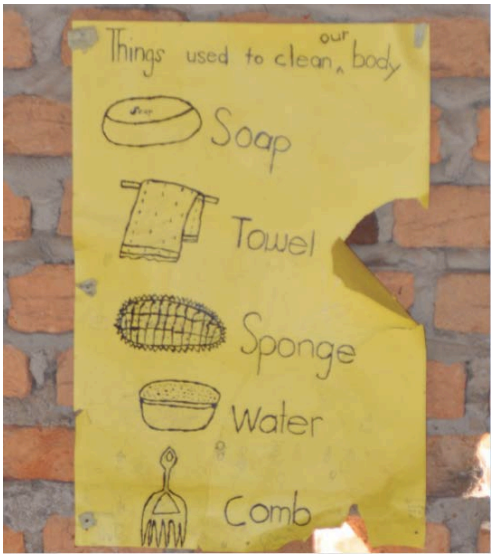


Fig. 15: Educational poster regarding to hygiene in a public school in Kyamagamule

Often the general knowledge in terms of sanitation and hygiene seems to be limited among inhabitants of developing countries such as Uganda. But more important seems to be that people in developing countries seem to underestimate the importance of sanitation and hygiene in many cases. Politics and executives must ensure that education in sanitation and hygiene is improved (see Fig. 15).

Public schools are seen as suitable places to initiate developments that could improve knowledge and awareness relating to water problems, sanitation and hygiene because children are often more likely to be willing to change daily habits and mindsets that affect living practices of their whole family in a sustainable way.

3.4.2 Water management

Problems in drinking-water quality like the ones at the shallow well in Kyamagamule not only depend on extensive use, general quality of the source or sanitation/hygiene, they often relate to the general ownership or management of water sources.

The borehole in Kyamagamule shows that Operation and Management (O&M) is an important factor affecting the quality of drinking water. Proper O&M seems to be essential for reliable drinking-water supplies through improved drinking-water sources (for engineered water sources, like boreholes, piped systems or shallow wells in general). In addition to this point, the drinking-water quantity is linked to O&M. Studies have shown that the widespread presence of improved drinking-water sources does not necessarily guarantee that these sources attain safe drinking water or attain drinking water at all: according to VAN DEN BROEK & BROWN (2015) for example, a third of the hand-pumps in sub-Saharan Africa are not in a functional condition due to problems in O&M. Similar problems are also seen to affect other parts in the world, such as parts of Asia and especially India.

Many water-sources worldwide are managed in Community Based Management (CBM) with Water User Committees (WUC) or comparable management structures. WUC are relatively widespread, for example, in rural areas of sub-Saharan Africa, with varied success: sometimes WUC have emerged as functional water management systems in communities that were willing to work collectively and to collect funds for O&M of their water source. However, CBM has often resulted in conflicts among communities/users, misuse or abuse of drinking-water sources and funds, or general problems in collecting funds for maintenance and repair (VAN DEN BROEK & BROWN, 2015). Problems like these are heavily dependent on the social structures and relationships, ownership structures, cultural values and many more aspects that are of different composition in every region worldwide.

3.5 Water-borne diseases in developing countries

In Uganda and similar developing countries, water-borne diseases, caused by the use of microbial unsafe drinking water, are seen as one of the most common reasons for health issues (WHO, 2011). The most vulnerable population group, among others, is seen in children younger than five years old, often having life-threatening diseases. The most common, and ironically the most dangerous, water-borne disease in developing countries is seen as diarrhoea (WHO, 2011; UNICEF, 2012). In Uganda (and other developing countries), where almost 50 % of the population is younger than 15 years old (UBOS, 2016), child mortality due to water-borne diseases is seen as a serious problem. This especially affects the regions of sub-Saharan Africa, more precisely the so-called “Great Lakes region” in Eastern Africa. According to SCHNABEL (2009), Uganda is one of the most affected countries in this region.

Water-borne diseases are not only seen as an exclusive problem affecting human health, they are furthermore also seen as a huge social and socioeconomic problem. People who are infected by water-borne diseases often have challenging financial problems directly related to water-borne diseases. If medical facilities are available in the specific region, people have to pay immense amounts of money for medical treatment, medication, nutritional supplements and transport. This mostly affects rural areas: medicinal costs are about 20 % higher than in urban areas because the medical facilities are not that widespread and the distance to the nearest facility is longer. This can lead to the so called “Medical poverty trap”, meaning that rural people have to sell parts of their agricultural land or even have to sell their house to keep up with the needed medical treatment, simultaneously losing their livelihood (SCHNABEL, 2009).

Additionally, the absence of work for specific family members is a burden, which affected families have to carry. In rural areas of Uganda, 80 % of the people live directly from their agricultural work (UBOS, 2016). If a family member gets sick and cannot fulfill his or her duties on the field, the work has to be done with the help of other family members (juveniles or children) that are most likely regularly going to school. If the disease becomes chronic because of the absence of medical treatment, the students have to stay at home from school working, losing the opportunity to get a proper education (UNICEF/WHO, 2013). With the loss of education, there is often a loss of perspective about the future, leading to poverty. Ironically, poverty and educational deficiencies are often seen to directly correlate with hygienic and sanitation problems (UNICEF/WHO, 2013), ultimately leading to increased

outbreaks of water-borne diseases. This vicious circle is directly caused by poverty and directly causes poverty, and is able to negatively affect social, socioeconomic and economic conditions of entire states (SCHNABEL, 2009).

Climate change intensifies these problems. It is seen to directly affect outbreaks of water-borne diseases in developing countries (ASHBOLD, 2004): major outbreaks of water-borne diseases typically correlate directly with the more frequent occurrence of heavy rainfall events due to climate change.

4. Drinking-water requirements

National standards for drinking-water may vary widely in worldwide comparison. These requirements depend not only on politics, technical status and living practices of countries, they also depend on natural circumstances like raw- water availability and quality.

In industrialized countries, raw-water quantity, quality and treatment are affected by remarkably different factors than those in developing countries. Livelihood and living practices influence the need and availability of drinking water relating to quantity and quality. The term “drinking-water“ relates not only to the water actually consumed, but also the water supplies needed for domestic food preparation and washing/sanitation.

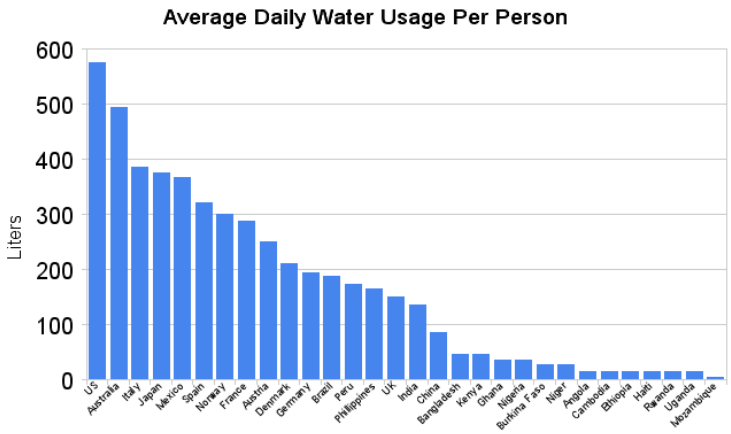


Fig. 16: Average Daily Water Usage Per Person (UNDP, 2006)

According to the United Nations Development Programm (UNDP), the average daily water use per person ranges in industrialized countries from about 600 liters in the United States, to about 200 liters in Germany. The lowest daily water consumption per capita can be found in developing countries (such as Bangladesh, about 50 liters) and in the least-developed countries, especially in sub-Saharian Africa (Rwanda, Uganda, Mozambique, with less than 25 liters).

Despite these differences in the quantity of water needed for drinking water, the most important requirements for drinking water are relatively similar in most countries in the world. Water parameters protective of health are commonly to be found in the recommendations of the World Health Organization (WHO). Therefore, the following definitions and requirements for drinking water evaluation are essentially taken from the fourth edition of the WHO Guidelines for Drinking-water Quality (WHO, 2011). These guidelines serve as worldwide recommendations for politicians, executives and consumers to provide good drinking-water quality: to minimize possible health hazards during consumption, to guarantee a good acceptability and to reduce negative effects in drinking-water distribution, treatment or disinfection (for example because of corrosion). Some of the contents and recommendations below have been adopted from the German drinking-water regulations (Trinkwasser

Verordnung 2001, abbreviated TrinkwV 2001) (BMJV, 2016). Where other sources are used, they are specifically named.

In the following, some of the most important drinking-water evaluation values and recommendations in microbial, physical and chemical terms are listed and defined. The listed values are either seen to be directly or indirectly health harming, to be important for the evaluation of drinking water quality in general or to have a direct influence on the purification methods (chlorination, filtration), which have been researched within this thesis.

Within this thesis, the recommendations and critical values of both the TrinkwV 2001 and the WHO are used as orientation values to assess the drinking-water quality and the cleaning success of the researched treatment systems.

4.1 Microbial requirements

According to the WHO (2011), the great majority of known water-related health problems are the result of microbial (bacterial, viral, protozoan or other biological) contamination.

Microorganisms of several types are widely spread in all aspects of environment. In raw-water, as well as in drinking water, there always are specific amounts of bacteria. Most bacteria do not cause any harm to human health, but some of them have pathogenic effects and can cause serious health issues under specific conditions. Diseases do not arise from the presence of pathogens in drinking water alone. However, the risk of outbreaks of diseases significantly increases with a massive growth of pathogenic bacteria under specific conditions. In particular, mesophile pathogens, which have their maximum colony growth in a temperature range of about 20 to 40 degrees Celsius, are dangerous for human health. Because of the constant body temperature of about 37 degrees Celsius, the pathogenic bacteria find good living conditions in human intestines. They grow in numbers and after some time they reach an infectious concentration, causing disease (FRITSCH et al., 2011). People who already have other health issues or who are generally susceptible to disease are the most endangered by pathogenes. This affects especially young children in developing countries because of either undernourishment or very young age. It also affects older people, people who are already weak because of other diseases, people who are suffering from undernourishment or dehydration or people who are discriminated (because of their gender, ethnicity, religious beliefs or other reasons) and excluded from receiving proper drinking-water or health care (SATTERTHWAITE, 2003). In particular, short-term fluctuations in pathogen concentration are dangerous for human health.

A direct correlation is often seen between the presence of pathogenic bacteria in drinking water and fecal pollution by human or animals (WHO, 2011). For this reason, potential drinking water should be continuously tested for fecal indicator organisms. Two of the most common indicators for fecal and other contaminations in drinking water are Escherichia coli (E.coli) and coliform bacteria.

In addition to the danger of water-borne diseases, which are directly caused by pathogens, there is a strong correlation between other health problems and fecal or other contaminants

in drinking water. This includes, for example, health-harming viruses, parasites and insect-borne diseases in a greater context (WHO, 2011; SATTERTHWAITE, 2003).

4.1.1 Total coliforms

Coliform bacteria are more or less related to bacteria caused by fecal contaminations, but they do not appear exclusively with fecal contamination. Furthermore, the presence of coliform bacteria can also be indicative of overall problematic hygienic conditions in drinking-water sources or distribution systems. Total coliforms represent the whole group of coliform bacteria, including coliform bacteria which multiplies at about 37 °C, thermo-tolerant (fecal) bacteria that can grow at higher temperatures of about 44°C, and E.Coli (OECD/WHO, 2003).

Traditionally total coliforms are used to assess microbial water quality, because total coliforms can easily be detected and enumerated. According to the WHO guidelines (2011) and the TrinkwV, 2001 (BMJV, 2016), no coliforms should be detectable in 100 ml of drinking water.

4.1.2 Escherichia coli (E.coli)

E.coli itself is found in largest numbers in intestinal flora of human and animals. E.Coli is analyzed separately from coliform bacteria. E.Coli appears exclusively with fecal contamination. Because of this, it serves as a direct indicator organism for fecal contaminations in drinking water (OECD/WHO, 2003).

The WHO and the TrinkwV 2001 recommend that there should be no detectable amounts of E.Coli in 100 ml of drinking water (WHO, 2011; BMJV, 2016).

4.1.3 Heterotrophic plate counts

The determination of heterotrophic plate counts (HPC) (often also referred to as total aerobic counts or total viable counts) in drinking water is a traditional way to get an insight into the number of bacteria present in the water. The measurement of this value relates to discoveries of Robert Koch in 1892, who has observed that the probability to fall ill of water-related diseases significantly decreases when bacteria numbers in drinking-water are as low as possible. This value/terminology is quite unspecific: consequently it becomes very complex to register and to determine every type of bacteria within water samples. Therefore researches of drinking water samples generally concentrate (besides on fecal indicator bacteria) on the count of heterotrophic, aerobic bacteria colonies, that are able to grow on a relative nutrient media (BMJV, 2016), after incubation of the samples with 20 °C or 36 °C. More precisely, heterotrophic, aerobic bacteria are organisms that reach their maximum growth under conditions where organic compounds as well as oxygen are available.

The WHO does not use any comparable value in order to assess drinking-water quality in its guidelines (WHO, 2011). HPC are nevertheless used within this thesis, because it is traditionally seen as an important water-quality indicator and it is also seen as useful value to

assess the cleaning success of water treatment systems. Here, the critical value for this parameter is taken from the TrinkwV 2001: these regulations recommend that the HPC in drinking-water should not be higher than 20 cfu/ml immediately after disinfection or treatment in general (BMJV, 2016), meaning that in this context the HPC should not be higher than 2000 cfu/100 ml.

These indicator organisms and microbial values (E.Coli, total coliforms, HPC) however, are able to give temporary insights into the microbial quality of the researched drinking water. Especially drinking water from unimproved sources in developing countries are often temporarily affected by natural or anthropogenic factors. That is why permanent microbial surveillance of drinking-water sources is essential (FRITSCH et al, 2014). In addition, if permanent surveillance is not possible, constant drinking-water purification (e.g. through disinfection, filtration) is needed.

4.2 Physical and chemical requirements

Chemical ingredients or physical parameters in drinking water are generally considered to have less influence on human health than microbial contaminations. Chemical compounds in drinking water are primarily present in very low concentrations and may cause long-term health issues through the continual intake of small dosages. The chemical ingredients and physical parameters of drinking water may fluctuate, as they are dependent on factors affected by natural regional aspects, numerous technical and cultural aspects, such as living, industrial and agricultural practices, water-usage, -management and –treatment.

But chemical and physical parameters are able to directly affect acceptability aspects of drinking water. They can lead to significant changes in appearance, odor and taste; so that the consumers may possibly consider the drinking water as un-enjoyable. Additionally, chemical or physical parameters can drastically influence drinking-water treatment and distribution (WHO, 2011).

This thesis explicitly excludes research on chemical parameters that are potentially dangerous for human health after long- or short-term consumption. Each of the following, selected chemical and physical water-quality parameters is directly related to the acceptability aspects, its affect on the cleaning success of the purification methods researched in this thesis (filtration, chlorination) or its importance for the evaluation of drinking-water quality in general.

4.2.1 pH-value

The pH-value is defined as the negative of the logarithm to the base of 10 of the molar concentration of hydrogen ions and it describes the acid or alkaline reaction of aqueous solutions. Neutral water is generally considered to have a pH of about 7, meaning that there is equilibrium of hydrogen ions (H+) and hydroxid ions (OH-) with a concentration of both components of 10-7 mole per liter. The lower the pH, the more acid is the aqueous solution. The higher the pH, the more alkaline is the solution (WILHELM, 2008).

Generally, the pH in drinking water has no negative effects on human health, but it is seen as one of the most important water-quality parameters. This is, because the concentration of hydrogen ions (H+) affects nearly all of the chemical and biological processes in water (FRITSCH et al. (2014)).

The German drinking-water regulations (TrinkwV 2001) recommend the use of water with pH in the range of about 6.5 to 9.5 (BMJV, 2016). These specific values do not directly relate to the effects on human health; they relate to the maintenance and operation of water distribution and treatment systems. Extreme pH values can have corrosive effects in distribution and treatment systems (although the Langelier index is much more indicative) and they can negatively influence the effectiveness of water treatment/disinfection (WHO, 2011). Higher pH tends to be scale-forming which can provide a protective layer on the inside of pipes, but also provide a better environment for the growth of biofilms. The WHO guidelines also recommend, in general, pH-values of 6.5 to 8.5. To ensure effective drinking-water disinfection by chlorination, the pH should be preferably lower than 8 (WHO, 2011).

4.2.2 Electrical conductivity

Electrical conductivity (EC) describes the sum of diluted salts in the water. These salts also include e.g. salts emerging out of metals or minerals in the water. Samples of pure water, de-ionised water or distilled water hardy conduct any electricity. These samples have a low value of EC. Water samples with high amounts of metals and minerals, as well as water samples with a high hardness conduct electricity rather well and therefore have higher values of EC. Because the EC is also dependent on the temperature of the measured water, the temperature should always be included with the general EC value (WILHELM, 2008).

Extraordinary high or low ECs in drinking water generally do not harm human health, but they can affect taste in a negative way (WHO, 2011). The EC is an important parameter used to assess the cleaning success of the filtration system researched within this thesis.

The WHO does not set any value for EC in its guidelines of 2011. The TrinkwV 2001 recommends that the EC in suitable drinking water should be below 2500 µS/cm for water with temperatures 20 °C and below and 2790 µS/cm in water with a temperature of 25 °C (BMJV, 2016).

4.2.3 Chlorine

Chlorine is used for drinking-water disinfection in many parts of the world. In general, it only appears in different chemical compounds; the chlorine atom itself is not common in nature. Chlorine is mostly prominently present in the form of chloride in nature. The most commonly known form of chloride is sodium chloride (better known as table salt) (FRITSCH et al., 2014).

The disinfective effect of chlorine is primarily due to the development of hypochlorous acid (HClO) within water. This acid is able to attack the cell walls and affect the metabolism of microorganisms. It either kills the organisms or it impedes their ability to multiply. The actual effective, disinfecting part of the chlorine within drinking water is often referred to as “free chlorine”. Free chlorine describes the sum of elementary chlorine Cl_2, hypochlorous acid, and

hypochloride ions (in ist different forms) with each having more or less strong disinfecting effetcs (HClO is seen as the most powerful in disinfection). Other common terms used are “combined chlorine”, which is the part of chlorine that is bound in organic and inorganic chloramines and “total chlorine”, which is describing the sum of free and combined chlorine (ROESKE, 2007).

In it s guidelines for drinking-water quality, the WHO sets several values for the amount of free chlorine within drinking water. Chlorine itself is highly toxic to human health. Because of that, the WHO set the critical value to be 5 mg/l or more in drinking water. The more relevant aspect is a practical one, that high chlorine amounts in drinking water heavily and negatively affect the odor and taste of drinking-water, making it undrinkable. For this reason, the WHO set its dosage guideline value to be between 0.6 and 1.0 mg/l. To provide effective disinfection, the WHO recommends that the residual amount of chlorine in drinking water should be greater than 0.5 mg/l (30 min after chlorination) and greater than 0.2 mg/l at the point of delivery to the consumers (WHO, 2011).

In Germany, chlorine is not commonly used for drinking-water disinfection. Chlorine is only used in emergency cases, such as biological contamination of drinking water. In these cases the TrinkwV recommends a maximum addition of free chlorine to be 1.2 mg/l, and the chlorine residual after treatment should be in the range of about 0.1 mg/l to 0.3 mg/l. If disinfection is not complete with these values, additions of up to 6 mg/l and chlorine residual after treatment of max. 0.6 mg/l are permitted to use (BMJV, 2016; UBA, 2015).

If water with organic ingredients is chlorinated, it is possible that potentially health-harming by-products like Trihalomethanes (THM), absorbable organic halogen compounds (better known as AOX) or similar are developed. These products are often assumed to have toxic or carcinogenic effects on human health (FRITSCH et al., 2014). Generally the concentrations of these products in chlorinated drinking water are far too low to directly have health-harming effects for human. Within this thesis, these by-products and their consequences from chlorination will not be further discussed.

4.2.4 Ammonia

Ammonia (NH_4) is nitrogen compound. Typical NH4-contents in aerobic ground- and surface-water are below 0.2 mg/l, in anaerobic groundwater, the content of ammonia can be up to 3 mg/l (WHO, 2011).

Ammonia concentrations that are higher than 0.2 mg/l are seen as indicator for anthropogenic pollution, those pollutions which are typically due to, for example, domestic, agricultural or industrial wastewater. NH_4 can also be formed by chemical conversion of Nitrate (NO_3) via Nitrite (NO_2), especially in water with low O_2-content and relatively high concentrations of iron and manganese. In general ammonia does not affect human health. But NH_4-concentrations higher than 0.1 mg/l can negatively affect disinfection by chlorination (FRITSCH et al, 2014).

Critical values for ammonia within drinking water are set in the WHO guidelines to be 35 mg/l (for health concerns), 1.5 mg/l (regarding odor) (WHO, 2011) and max 0.5 mg/l in the TrinkwV 2001 (BMJV, 2016).

4.2.5 Sodium

Sodium is one of the most common metals in the Earth´s crust and it is present in nearly all natural waters. High amounts of sodium in natural waters can relate to pollution from domestic or industrial sewage, but can also be due to natural circumstances (e.g. salty water that is rising into the groundwater). Sodium is an important mineral, which is needed by the human body to live (FRITSCH et al., 2014).

Sodium is mainly consumed through the intake of salt (sodium chloride). Typically about 3-5 g per day are necessary for life; higher intakes are generally not seen as harmful. But at very high levels, the health of young children and also grown-ups can be harmed by sodium (DANY, 2011). Health-based standarts for sodium are not set by the WHO or the TrinkwV 2001. In addition both regulations set standards for sodium to be 200 mg/l in regards to acceptability aspects (taste) (WHO, 2011; BMJV, 2016).

Sodium can be indicative of the cleaning success of a filter. Chlorination also affects sodium amounts within drinking water. For that reason, it will also be a part of the research within this thesis.

4.2.6 Potassium

Potassium has similar attributes to sodium, but it appears more rarely in nature. It is primarily found in greater or lesser amounts in nearly all forms of natural water (groundwater: about 1 to 5 mg/l; surface water: in some cases more than 30 mg/l). In very high concentration, potassium can be indicative of pollution by sewage, mines or dumps. If the amount of potassium within water exceeds the amount of sodium, this can be indicative of fecal contamination. Potassium is, similar to sodium, an essential mineral, needed by the human body to survive (FRITSCH et al., 2014).

Recommended daily intakes are seen to be at least 3 g per day. Naturally occurring amounts of potassium in drinking water (or other waters) are not regarded to have health-harming effects for the wide majority of people. For this reason, there is no WHO value set (WHO, 2011). The German TrinkwV also sets no critical value (BMJV, 2016). For this thesis, potassium can nevertheless give useful hints regarding to the cleaning success of the researched filter.

4.2.7 Hardness

The hardness of water is typically defined as the sum of the so-called water-hardening minerals contained in the water. These minerals consist of the alkaline earth metals (calcium, magnesium, strontium and barium). Because strontium and barium seldom appear in natural

waters, the water hardness is typically taken as the sum of dissolved calcium and magnesium within the water (WILHELM, 2008).

Because the hardness of water is seen as one of the most important water quality parameters, it is important to research, within this thesis, how filtration affects the amounts of dissolved calcium and magnesium. In addition, with these values it is possible to draw further conclusions about the general cleaning success of the researched filter.

The WHO guideline value for drinking water recommends the water hardness to be about 100 – 300 mg/l, to provide a proper taste (WHO, 2011). The hardness of water is not mentioned within the TrinkwV 2001 (BMJV, 2016).

4.2.8 Calcium

Calcium is also one of the most common elements in the Earth´s crust. In general, calcium appears in the chemically bound form of limestone, chalk and gypsum. In drinking water (or water) specifically, calcium primarily appears chemically bound in different forms of lime (FRITSCH et al., 2014).

The typically found levels of calcium in drinking water are not seen as harmful to human health. Furthermore, calcium plays an important role in the buildup of teeth, bones and for human metabolism. There is no specifically defined health-induced WHO guideline value for calcium. Indirectly, calcium values are set through the guideline value for the hardness of water (WHO, 2011). The TrinkwV 2001 has not set a critical value for calcium (BMJV, 2016).

4.2.9 Magnesium

Magnesium is another widespread metal found in the nature. It primarily appears together with calcium, in geologic formations as well as dissolved in water. Magnesium amounts within water can be from a natural source, but they also commonly indicate anthropogenic pollution with sewage or agricultural fertilizers (FRITSCH et al., 2014).

Magnesium is an essential element for many processes in the human metabolism and the function of muscles and nerves (SEYFARTH et al., 2000).

Typical amounts contained within drinking-water or natural waters are not seen to have any medical relevance. There is no explicit WHO guideline for drinking water regarding to magnesium, but it is (similar to calcium) indirectly regulated through the hardness of the water (WHO, 2011). Critical amounts of magnesium are not defined within the TrinkwV 2001 (BMJV, 2016).

4.2.10 Iron

Iron is one of the most common elements in the Earth´s crust, therefore it most often appears in natural water sources. In water with adequate amounts of oxygen, iron is mostly oxidized. This means that dissolved iron is not present in high amounts in these waters. Normally

groundwater and other waters low in oxygen can gain iron amounts of 0.1 to 10 mg/l. The amounts can reach up to 30 mg/l. In general, even relatively high amounts of iron are not seen to have any dangerous effects for human health (FRITSCH et al. (2014)).

Higher amounts of iron in metal (eg ductile iron pipe, cast iron pipe) distribution systems can be an indicator for extensive pipe corrosion or other contaminations (WHO, 2011).

While iron does not affect the overall appearance in anaerobic water (even in relatively high concentrations up to several mg/l), iron can be oxidized in aerobic water or in water that has contact with the atmosphere, leading to reddish- brown colorations, causing an increase of turbidity. With its influence on turbidity, it is able to directly affect the disinfection efficiency of chlorination (see also Chapter 7.3.1 Chlorination of unimproved drinking-water sources in Kalangalo). High amounts of iron are also able to negatively influence the taste of drinking water (WHO (2011).

According to the WHO guidelines there is no health-based value for iron. In regards to taste, the maximum value is set at 0.3 mg/l (WHO, 2011). The TrinkwV uses sets its critical value to be less than 0.2 mg/l (BMJV, 2016).

4.3 Acceptability aspects

Beside the aspects of drinking-water ingredients that may directly affect human health, the so-called acceptability aspects may be the most practically important points for the evaluation of drinking-water quality. Acceptability aspects include taste, odor and the overall appearance of drinking water. Often, people assess the overall appearance of drinking water in relation to their personal taste, which is influenced by what tastes, odors and appearance they are used to. So drinking-water habits in different regions may vary in terms of overall appearance, taste and odor. In general, the majority people characterize drinking water as enjoyable when it is cold, clear and fairly free of taste and odor.

4.3.1 Turbidity

Almost all of the acceptability aspects mentioned above are heavily influenced by turbidity. Turbidity in drinking water is primarliy caused by the presence of suspended particles of inorganic or organic matter. Often microorganisms attach to these suspended particles and decrease microbial drinking-water quality. Some ingredients which cause turbidity can also affect taste, odor and appearance as well as cause possible health issues. Turbidity not only affects the overall appearance, it can also be seen as an indicator for potential chemical or microbial contamination of drinking water (WHO, 2011).

In developing countries, such as Uganda, consumers often have to rely on their senses to assess drinking-water quality. This means that they are subjectively evaluating the drinking water quality in regards to taste, odor and general appearance. For example, high turbidity in drinking water can affect the appearance, the taste and (in some cases) the odor. The acceptance of potential consumers is therefore not guaranteed, even if the drinking-water quality is good in terms of chemical and microbial aspects. Turbidity values below 4 NTU (nephelometric turbidity units) can hardly be seen by the human eye, which means that the

water appears clear. In many cases, clear drinking water with good appearance, taste and odor does not safely guarantee good quality in terms of chemical or microbial aspects.

In it s guidelines, the WHO recommends consumption of drinking water with 1 or less NTU. In areas with small water resources or limited technical possibilities in terms of water treatment, values of 5 NTU (or preferably lower) should be tolerated. In fact, high turbidities in drinking water are seen to decrease the effectivness of disinfection (e.g. by chlorination). To ensure safe disinfection, turbidity in raw-water should be below 5 NTU, and at best below 1 NTU or lower (WHO, 2011).

The German TrinkwV 2001 recommends a maximum value of 1 NTU (BMJV, 2016).

4.3.2 Water temperature

Drinking-water temperature plays another important role in the assessment of drinking-water quality. Cold water is not only seen as more enjoyable than warm water in taste and odor; cold water-temperatures also prevent rapid growth of unwanted microorganisms. Most pathogenic bacteria which cause health issues in drinking water are mesophiles. That means that they reach their maximum growth rate in temperature ranges from about 20 to 40 degrees Celsius. The naturally occurring drinking-water temperature varies in different world regions and within different drinking-water sources, -distributions and -treatment. Optimal drinking water temperature is not specifically defined in the guidelines of the WHO. Drinking water should be, in the best case, as cold as possible in the specific region.

To summarize the critical values and recommendations of both the WHO and the TrinkwV 2001, the values mentioned above are represented within Tab. 1.

Tab. 1: Selected guideline values and recommendations of drinking-water parameters (WHO, 2011; BMJV, 2016), edited

Parameter	WHO		TrinkwV 2001	
	Guideline value	Reason	Guideline value	Reason
Total coliforms	< 1 cfu / 100 ml	Health	< 1 cfu / 100 ml	Health
Thermotolerant (fecal) coliforms/E.coli	< 1 cfu / 100 ml	Health	< 1 cfu / 100 ml	Health
Heterotrophic plate counts (HTC)	not used in WHO guideline values		< 20 cfu / ml (after treatment, to avoid regrowth of bacteria) < 100 cfu / ml (in general)	Health
pH	6.5 to 8	Operational value	6.5 to 9.5	Operational value to prevent corrosion
	< 8	Effectivity of Chlorination		
EC	not used in WHO guideline values		2500 µS/cm (with regard to water temperatures of 20 °C) 2790 µS/cm (with regard to water temperatures of 25 °C)	Operational value to prevent corrosion
Chlorine	5 mg/l	Health	no chlorination used in Germany / just in emergency cases: 1.2 mg/l (max regular addition) - up to 6 mg/l (max addition if necessary) 0.1 to 0.3 mg/l (after treatment) - max 0.6 mg/l (after treament if necessary)	
	< 0.6 to 1.0 mg/l	Taste		
	> 0.5 mg/l (after 30 min)	Effectivity of Chlorination		
	> 0.2 mg/l (at the point of delivery)	Effectivity of Chlorination		
Ammonia	35 mg/l	Taste	0.5 mg/l	-
	1.5 mg/l	Odour		
Sodium	n.v.	Health	200 mg/l	-
	200 mg/l	Taste		
Hardness	n.v.	Health	n.v.	-
	100 - 300 mg/l	Taste		
Potassium	n.v.	-	n.v.	-
Calcium	n.v.	-	n.v.	-
Magnesium	n.v.	-	n.v.	-
Iron	n.v.	Health	0.2 mg/l	-
	0.3 mg/l	Taste		
Turbidity	< 5 NTU	Health / Effectivity of Chlorination	< 1 NTU	Operational value
	< 1 NTU	Effectivity of Chlorination		

n.v. = no value

5. Testing procedures for drinking-water

5.1 Microbial test procedures

5.1.1 Membrane filter method (laboratory testing)

For the laboratory testing of E.Coli, total coliforms and HPC the “classical” membrane filter method was used. The membrane filter method is generally considered to be a relatively easy method to determine numbers of microbial colonys in water samples with acceptable accuracy. The pictures and general descriptions used in this thesis are partly adopted from DANY (2011); some of the content is taken from WILHELM (2016). Other sources are named. The membrane filter itself contains of the following parts, which can be seen in Fig. 17. The materials and devices needed to execute the membrane filter method can be seen in Fig. 18.

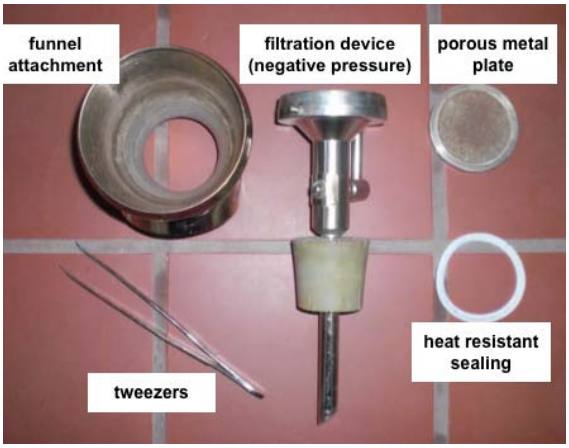


Fig. 17: Parts of the membrane filter device (DANY, 2011), edited

Fig. 18: Needed materials and devices for the membrane filtration method (DANY, 2011)

The tested water samples are filtered through sterile membrane filters. These membrane filters have standardized diameters and specific pore sizes. When the water sample is filtered through the membrane filter, everything contained in the water, which is bigger than the pores, is held back and remains on the membrane. This includes bacteria, parasites, and floating and suspended matters contained in the water samples. The execution of the membrane filter method is characterized by several repeated steps: these steps are identical in execution for every water sample that has to be tested for microbial contamination.

Fig. 19: Sterilisation of the porous metal plate (left) and funnel attachment (right) (DANY, 2011)

Before the water sample can be poured through the membrane filter device, every surface that is in contact with the tested water or the membrane filter must be sterilized. This includes the filtration device (insides of the funnel attachment, porous metal plate) and the tweezers used to move the membrane filter. To sterilize, the parts are covered with C_2H_5OH (an aqueous solution of 70% Ethanol and 30% water) and flamed with a Bunsen burner.

Fig. 20: Membrane filter on-top of porous metal plate (left), funnel attachment placed at the device (right) (DANY, 2011)

After the sterilised parts have cooled down, the membrane filter is placed on top of the porous metal plate. Each membrane filter is stored seperately in factory-sealed packages. The membrane filters have to be moved out of their packaging with a sterile tweezers: while moving the membrane filter there has to be taking care of, that the filters do not get in contact with any other, eventually microbial contaminated surface. After that, the funnel attachment can be placed on top of the device.

Fig. 21: Addition of water sample (left), water jet punp (right) (DANY, 2011)

The next step involves the addition of 100 ml of the testing sample into the funnel attachment. To reduce the time, which is naturally needed to filtrate the water sample through the membrane filter, a negative pressure is generated within the device, with the use of a water suction pump. Because of this negative pressure, the water sample is sucked through the pores of the membrane filter. Bacteria as well as floating and suspended matter, which is larger in size, remain on top of the membrane filter.

In the next step, the membrane filter is placed on top of nutrition pads, which were pre-placed in clear petry dishes by the factory. Before moving the membrane filters into the dishes, the nutrition pads must be moistened with 3 ml of sterile water. The petri dishes with the filter membranes are incubated for 40 ± 4 h with a constant temperature of 37 °C. This environment gives potential bacteria, which have been retained by the membrane filter, the ability to grow and form colonies.

Fig. 22: Incubator, open (DANY, 2011)

The nutrition pads are specially designed to specifically grow only the bacteria species that is to be researched and to specifically color that bacteria. For the microbial laboratory testing of this thesis, specific nutrition pad sets (NPS) of Dr. Möller & Schmelz GmbH were used. The data-sheets of these NPS are included in the annexes.

A Colichrom-NPS was used to test the samples for E.Coli and total coliforms. The nutrition pad of this kind contains chromogenic components specific to E.Coli and coliforms, which promotes growth and develops a specific color for these species. E.Coli appears as blue colonies; coliform colonies are either pink or purple colored. The NPS can also form beige or clear colonies; these colonies consist of non-coliform bacteria. The membrane filter is standardized in size: it is 50 mm in diameter and has a pore size of 0.45 µm (Dr. Möller and Schmelz, 2015 a).

For researching of the heterotrophic plate counts (HTC), a specific CASO-NPS was used. The membrane filters are green-colored, the bacteria grows yellow, brown clear or beige colored colonies, depending on the specific type of bacteria contained in the water sample. The membrane has, similar to the Colichrom-NPS, a diameter of 50 mm and a pore size of 0.45 µm (Dr. Möller and Schmelz, 2015 b).

Depending on the expected degree of bacterial contamination, specific water-samples are diluted before filtering through the membrane. The aim of the dilution is that the amount of bacteria within the diluted water samples becomes low enough to provide simple and accurate plate counts after incubation. If the sample is, for example, diluted with a ratio of 1:100 and contains x colonies of E.Coli after incubation, the count of x would be multiplied by the degree of dilution (here: 100) to determine the exact number within the researched volume of water sample. This is due to the assumption that bacteria are distributed evenly within the raw- and wastewater samples. If the amount of bacteria within a sample is too high, accurate counts of colony forming units are not possible: either because the colonies are too numerous to reliably count or because the bacteria have grown together into big, unspecific colonies after incubation. If the dilution is too high, there is the possibility that bacteria is not contained in a representative number within the 100 ml of tested water.

5.1.2 Membrane filter method (on-site testing)

For the on-site microbial tests in Uganda, a mobile membrane filter set by the Wagtech Company was used (Wagetech Potatest PTW-10005). The principle of these mobile test kit is to adapt the classical laboratory technique of the membrane filter method for practical use in the field, with the approach to be scientifically correct and nevertheless as rugged and as low-tech as possible (see 5.1.1 Membrane filter method (laboratory testing) for further explanation of the classical membrane filter method). An simplified overall view of the process of the mobile membrane filter method can be seenin Fig 24.

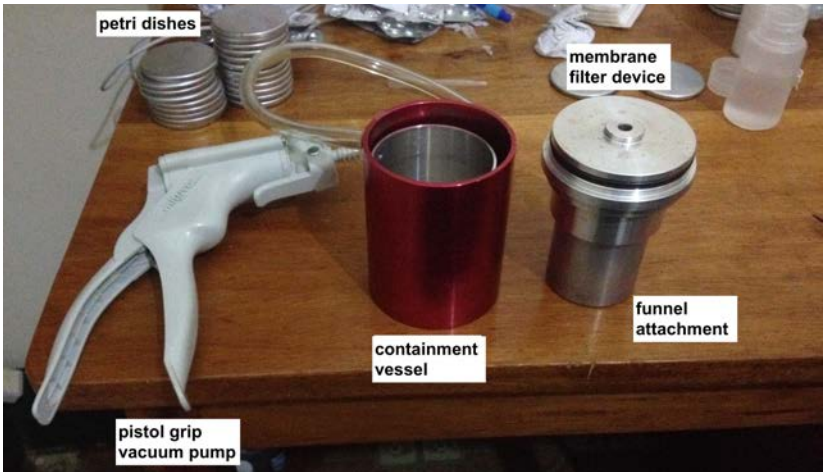


Fig. 23: Mobile membrane filtration unit (MFU) with pistol grip vacuum pump (left), edited

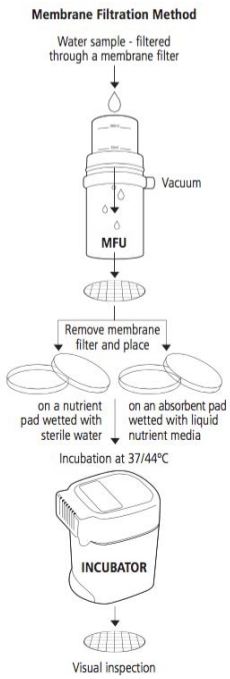


Fig. 24: Membrane filter method, overview (Wagtech, 2013)

The process execution is similar to the classical method, with slight differences in execution. A known volume of 100 ml of the tested water-samples is filtered through the membrane filter unit (MFU). The MFU contains membrane filters with specific diameters (47 mm) and specific pore sizes (0.45 µm). One of the slight differences is that, the negative pressure needed to pull the water through the membrane filter is produced by hand, with the included pistol grip vacuum pump. Thereafter the membrane filter contains the bacteria (if there was any bacteria present) and is moved onto absorbent nutrition pads.

These absorbent pads must be wetted with liquid nutrient media before use. This media is provided to grow the specific, researched bacteria while simultaneously inhibiting the growth of unwanted “non-target” bacteria. The liquid nutrient media is consists of “Membrane Lauryl Sulphate Broth (MLSB)” (Wagtech, 2013).

It is prepared on-site with the cleanest water available, in this case distilled water: this water must first be boiled and, after cooling, the powdered MLSB added. To ensure consistent mixing, the water-MLSB mixture is shaken by hand. The solution/liquid media becomes pink/reddish and is then useable for up to 3 months, if it is stored in as dark and cool place as possible.

To provide enough liquid nutrition for the duration of the residence in Uganda, a clean bottle was used to contain liquid nutrient media needed for the preparation of up to 200 nutrient pads. This bottle was rinsed several times with boiled water before filling with the liquid nutrient, to prevent, as much as possible, microbial contamination within the bottle. The on-site testing results afterwards show that there probably was not any contamination of the liquid nutrition media.

Fig. 25: Preparation of the liquid nutrient media (MLSB) and the nutrient pads, schematic sketch (Wagtech, 2013)

Afterwards, the petri dishes with nutrient pads and the membrane filters are incubated in a mobile incubator for 18-24 h (see Fig. 26). Depending on what bacteria is to be researched, this mobile incubator is able to be set to two constant temperature settings. With this temperature control, it is able to grow either total coliforms (37 °C) or thermotolerant (fecal) coliforms (44 °C). In this case, total coliform bacteria was researched.

Fig. 26: Wagtech Potatest mobile Incubator, closed (left), opened with petri dishes (right)

After the incubation time, the number of colonies, which have grown on the membrane filter, can be counted to determine the amount of total coliform bacteria within the water samples. Here, total coliform colonies appear to have a yellow color. Colonies that have other colors, e.g. red, pink, brown or clear, cannot be specifically named; probably they are water specific, harmless bacteria and should be ignored for the count of the total coliforms (Wagtech, 2013). To further explain the terminology used within this thesis: if there has not been any detectable bacteria at all, the plate count is “0“. If there have been detectable bacteria on the plate, but these bacteria did not include coliform colonies (yellow), the term “no visible coliforms“ was used. If the amount of bacteria is too high to reliably count or if the colonies have grown together, the plate count is considered “too numerous to count” (tntc).

Before starting the filtration process itself, the MTU, the metal petri dishes, and the tweezers, which are used to move the membrane filters onto the nutrient pads, have to be disinfected. The metallic petri dishes are reusable. However, they have to be disinfected before every usage. This disinfection is accomplished by covering the clean inside surfaces of the dishes with alcohol (in this case a solution of 90% methanol and 10% water), burning the alcohol, closing the dishes and storing them in the sterile incubator until usage.

The disinfection of the MTU itself is handled separately from the classical membrane filter method. The MTU is separated from the containment vessel and the vessel is soaked with alcohol. The alcohol is burned and the separated MTU is inverted and placed into the vessel. The burning of the alcohol uses up the oxygen and develops an anaerobic vapor zone within the vessel, which disinfects the filter device and the funnel attachment after a specific amount of time (about 15 min).

Fig. 27: Process of disinfecting the mobile membrane filter unit: burning alcohol within the containment vessel (left), putting in the seperated MTU (middle), disinfection through anaerobic vapour (right)

5.2.3 Mobile petrifilms (on-site testing)

Fig. 28: 3M petrifilms (3M, 2016)

Additional to the mobile membrane filter method, mobile petrifilms by the 3M-Company were used to determine the total aerobic plate counts (see Fig. 28). This terminology of “total aerobic plate counts“ can hereby more or less be compared with the terminology used within this thesis, namely “heterotrophic plate counts“.

The instructional use can be adequately seen in Fig. 29 down below.

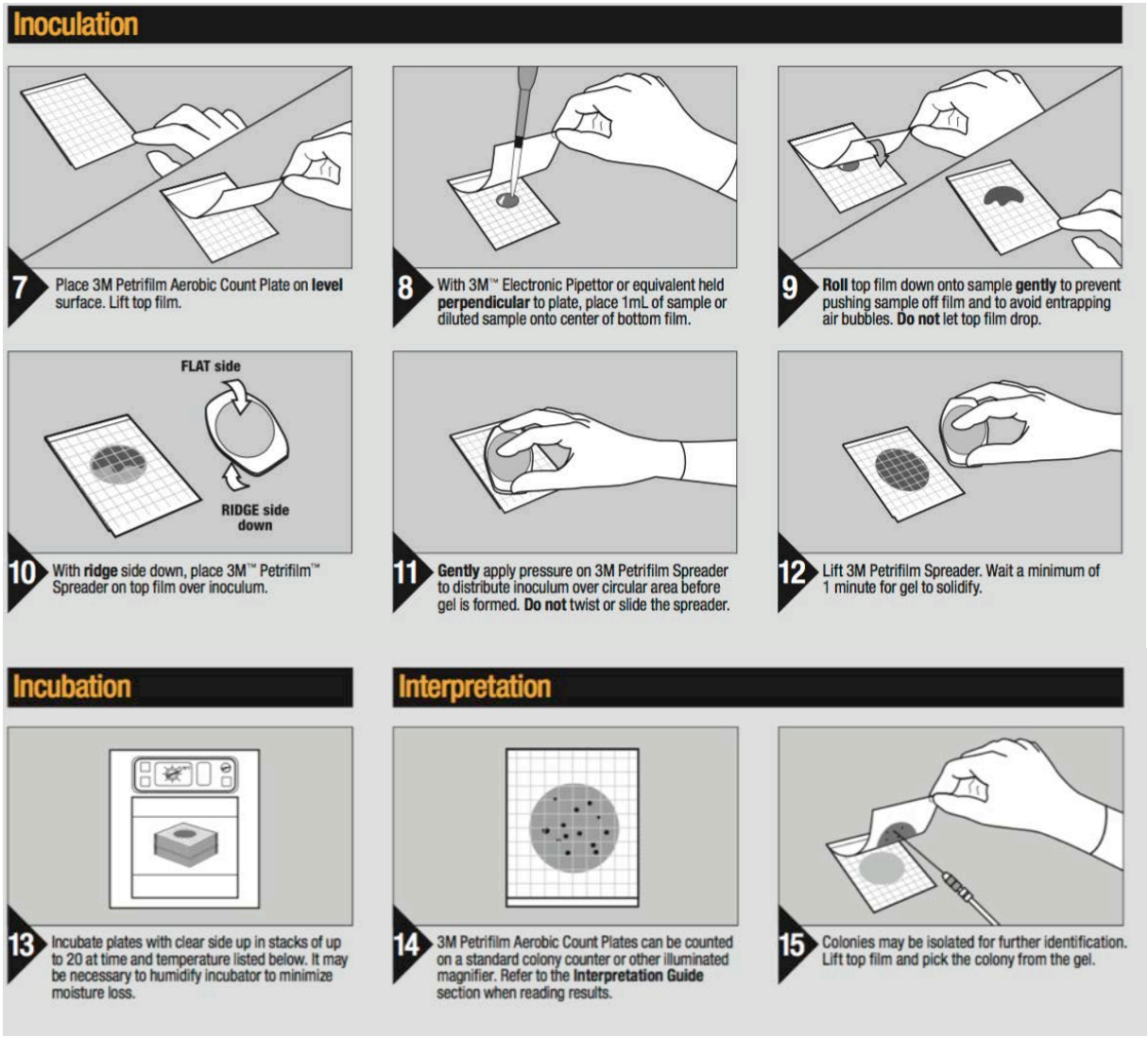


Fig. 29: Water-sample testing with 3M petrifilms, Inoculation, Incubationm Intrepretaion (3M, 2014)

After the sampling, the petrifilms were incubated for 18 – 24 h within an incubator constantly set to about 37 °C. Afterwards the bacteria within the sample appear as red colonies/dots and can be counted in cfu/ml.

However, this method did not deliver results as specifically accurate as the mobile membrane filter method. This is partially due to the fact that the petrifilms do not differentiate between microorganisms (they all appear as red colonies) and are explicitly not tested for bacteria, which specifically appear in drinking-water (these Petrifilms are mainly tested and used for food testing). Further, since the petrifilms require pressing a disk to form a circular “plate”, they are much more susceptible to cross-contamination from either the prior sample or bacteria on the surface where the samples are prepared. Despite that, the 3M petrifilms can give general information about the contamination levels of aerobic, heterotrophic bacteria with a minimum of effort. Therefore, they seem to be suitable for on-site testing in Uganda. They also provided a useful insight into the cleaning success of purification systems. The overall counts should be relatively comparable to the heterotrophic plate counts (HTC).

5.2 Physical-Chemical test procedures

5.2.1 pH meter

The electrodes of digital pH meters are typically equipped with a thin-walled membrane (mostly made of glass). This membrane is filled with a reference solution, which has a constant, known pH. After the electrode is submerged into the tested sample, an interfacial potential is generated and measured. The pH meter uses this measurement to automatically determine the pH (WILHELM, 2016). In laboratory conditions the water sample is constantly stirred while testing, to reach a constant distribution of H^+-ions within the sample.

For the on-site testing a portable Wagtech pH meter was used (Wag-WE30200). In laboratory, a pH meter from the Mettler Toledo Company (Mettler Toledo SevenCompact) was used.

Fig. 30: Portable Wagtech pH meter for on-site testing (left), Mettler Toledo pH meter with measuring electrode and magnetic stirrer for laboratory testing (right)

5.2.2 Conductivity meter

Most digital conductivity meters automatically determine the EC of water-samples by measuring the electric resistance of the sample with high-frequency alternate current (AC). The high-frequency AC prevents the tested samples from starting chemical reactions (caused by electrolysis) at the measuring electrode. These reactions could lead to measurement failures. Because the EC is dependent on temperature, the device also measures the water temperature of the testing-samples (WILHELM, 2016).

To measure the electrical conductivity, a portable, digital conductivity meter from the Wagtech Company was used (Wag-WE30210) on-site. In the laboratory, a digital conductivity meter manufactured by the Mettler Toledo Company was used (Mettler Toledo SevenEasy).

Fig. 31: Portable Wagtech turbidity meter used for on-site testing (left), Mettler Toledo Conductivity meter with measuring electrode used for laboratory testing (right)

5.2.3 Ion chromatography

To determine the amount of water-hardening minerals calcium and magnesium and other important water ingredients (sodium, potassium) an ion chromatography (IC) (also called ion-exchange chromatography) was used to test the water-samples before and after filtration (see Fig. 32 and Fig. 33).

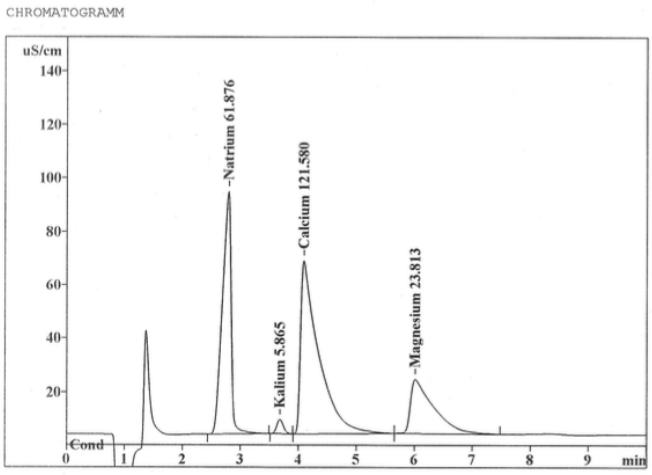
Fig. 32: Ion chromatograph, exterior

Fig. 33: Ion chromatograph, interior, details

The main principle of ICs is to separate ions and polar molecules from mixture of substances (here: water samples) based on their affinity to the ion-exchanger. With this principle it is possible to separate, detect and specifically determine the amounts of water soluble and charged molecules within the samples. The mobile phase (water sample and its ingredients, mixed with an eluent) is poured through the stationary phase (separation column with an ionizable functional group). The eluent is primarily added to dilute the sample in a suitable manner and to transport the sample through the separation column.

While moving through the stationary phase, the contained ions and molecules are passing the functional group in different amounts of time, relating to their specific affinity to the functional group. The time, which is needed by the molecules to pass the separation column, is called retention time.

These differences in retention times are represented in a chromatogram (see Fig. 34). They appear as peaks, which can be used to specifically characterize the molecules (sodium, potassium, calcium and magnesium in this case) present. The areas below the peaks can be used to determine the concentration of each molecule within the sample (WILHELM, 2016).



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.79	954.629	1594	61.876	Natrium
3.68	42.381	4950	5.865	Kalium
4.09	1405.139	811	121.580	Calcium
6.01	570.331	1044	23.813	Magnesium
10.01	2972.480	2100	213.133	

Fig. 34: Chromatogram and peak table of a water sample, example

5.2.4 Turbidity meter

The use of Turbidity meters (also called Nephelometers) is seen as an easy and accurate way to measure turbidity, especially for water-samples with low values of 5 NTU or less (WHO, 2011). In principle, the devices measure the refraction of light caused by suspended particles in the water sample in relation to the refraction of light in clear water. With this data, they calculate turbidities for the researched water samples. The water samples are poured into a clear glass tube (specifically designed for the turbidity meter device used), placed into the device and covered with a plastic cap to prevent measurement failure caused by ambient light (Wagtech, 2013; WHO, 2011).

The on-site testing was completed using a portable turbidity meter made by the Wagtech Company (Wag-WE30140). For laboratory turbidity testing, a turbidity meter made by the Aqualytic Company was used (Aqualytic AL450T-IR).

Fig. 35: Portable Wagtech Turbidity Meter used for on-site testing (left), Aqualytic Turbidity meter used for laboratory testing (right)

5.3 Acceptability test procedure

As mentioned several times above, the success of drinking-water purification systems also depends on drinking-water acceptability aspects (overall appearance, odor, taste). So the following drinking-water acceptability rating system is adopted from **DANY (2011)**. This rating system attempts to assess the treatment success of the laboratory testing in regards to the acceptability aspects. Odor, appearance and taste of each raw- and waste-water sample are rated separately. To make the rating system as clear and as easy as possible, the overall appearance, odor and taste is separately assessed with the grading system used in German schools.

0 = **no rating**

1 = **excellent:** no obvious differences to German drinking water

2 = **good:** comparable to German drinking water; with slight changes in color and taste; slight odor; suitable for long-term consuming

3 = **satisfactory:** still comparable to German drinking water; with changes in color and taste; abnormal odor; disturbing for long-term consume

4 = **adequate:** not comparable to German drinking-water; significant colorations, including some suspended matter; with abnormal taste and odor; still suitable for short-term consumption; not recommended for long-term consumption

5 = **poor:** taste and odor are not comparable to any drinkable water; including suspended matter (similar to 4, = adequate); not suitable for long-term consumption

6 = **very poor:** not suitable for consumption; abnormal appearance, odor and taste

6. Raw- and drinking-water quality in Uganda

6.1 On-site testing in Uganda

With the on-site testing of the drinking-water sources in Uganda, firstly the general drinking-water quality of the permanently used sources should be determined. Therefore the drinking-water sources were tested for microbial parameters (total coliforms, heterotrophic aerobic plate counts), physical-chemical parameters (turbidity, pH, EC) and chemical ingredients (ammonia, manganese, nitrite, phosphate, aluminium, cyanuric acid, iron and fluoride).

The on-site tests were executed in two weeks in June 2016 within Uganda. The trip was organized and carried out under leadership of Dipl.-Ing. Michael Ottensmann, in association with the Society of American Military Engineers (SAME) and Foundation Veolia.

The samples were taken from water-sources, mostly using empty PET- bottles, rinsed and emptied a minimum of 5 times with the raw-water before sampling. This procedure should preclude any contamination of the raw-water samples by ingredients formerly contained in the PET-bottles. After the water samples were taken at the sites, the bottles were stored and tested for the physical-chemical values in the evening. In other words, the water samples were tested (in the worst case) about 6 to 8 hours after sampling. During this time, the samples were stored as cool and dark as possible, and direct solar radiation was avoided.

Because of the time period between sampling and testing, some physical and chemical attributes of the water samples may have changed. In particular, turbidity may have slightly changed because of the natural sedimentation of the particles dissolved in the water. To ensure proper testing results, the bottles were carefully turned before measuring, to recreate plausible turbidities similar to the actual turbidity immediately after sampling. The time period also affects the measurement of the EC, mainly because the values of EC slightly interact with dissolved metals, salts and minerals in the water.

6.2 On-site testing results

The testing-results of turbidity, EC, and pH as well as the microbial tests for total coliforms and total aerobic plate counts can be seen in Tab. 2. The most important/prominent membrane filter and plate counts are presented in the following chapter.

Tab. 2: Physical-Chemical and microbial parameters, raw-water sources, on-site

Date	Village	Sample	Turbidity	electrical conductivity		pH-Value	colony forming units		water source	Marks
			[NTU]	EC [µS]	Temp [°C]	[-]	3M Petrifilms (total aerobic plate counts) [cfu/ml]	Membranefilter (total coliforms) [cfu/ 100 ml]		
12.06.16	Enro	-	-	80.1	26.1	7.0	816; 627	tntc	tab water from hotel	
12.06.16	Kabayiima	S1	67.4	72	28.1	7.1	820	tntc	pond (1)	
12.06.16	Kabayiima	S2	19.79	23.2	26.2	7.2	tntc	tntc	pond (2)	
12.06.16	Kabayiima	S1	85.5	67.1	26.3	7.2	tntc	120	pond (1)	Sample taken by villager
12.06.16	Kabayiima	S2	20.4	72.3	27.1	6.9	tntc	tntc	pond (2)	Sample taken by villager
16.06.16	Kabayiima	S1	69.9	164.4	24.3	6.9	tntc	tntc	pond (1)	
16.06.16	Kabayiima	S2	13.49	65.4	24.3	6.0	tntc	tntc	pond (2)	
16.06.16	Kabayiima (LCI)	-	38.1	53.5	24.5	5.9	tntc	tntc	pond	
12.06.16	Kampala-Kosovo	S1	1.14	150.9	25.5	6.1	51; 21; 21	143	piped distribution system	downstream (by church)
12.06.16	Kampala-Kosovo	S2	0.53	150.1	25.3	6.4	30; 44	tntc	piped distribution system	downstream (by church)
12.06.16	Kampala-Kosovo	S3	0.63	189.4	26.9	6.0	15; 8	162	piped distribution system	upstream
13.06.16	Kampala-Massaja	S	2.67	191.6	24.7	6.4	540	392	spring	from under the house
12.06.16	Kyamagemule	S2	28.9	63.3	27.6	6.2	8; 586; 730	2	shallow well	
12.06.16	Kyamagemule	S1	26.9	21.8	27.5	6.6	6	36	shallow well	
15.06.16	Kyamagemule	S	1.6	42.9	25	6.4	85	85	shallow well	
16.06.16	Mayobyo	S1	49.1	43	24.7	6.1	tntc	tntc	pond	
16.06.16	Mayobyo	S2	44.9	84	25	6.1	tntc	tntc	pond	
16.06.16	Mayobyo	S3	27.9	58.2	24	7.0	485	tntc	stream	
16.06.16	Mayobyo	S4	27.7	108.4	24.2	6.8	tntc	tntc	stream	
15.06.16	Mbiliddembiraba	S1	37.9	44.4	24.9	6.7	tntc	tntc	pond	
15.06.16	Mbiliddembiraba	S2	44.4	42.9	25	6.5	tntc	tntc	pond	
16.06.16	Mbiliddembiraba	S1	26	52.8	24.4	6.9	tntc	tntc	pond	
16.06.16	Mbiliddembiraba	S2	25.4	55.1	24.3	6.7	tntc	tntc	pond	
12.06.16	Namukomago	S2	44.7	56.8	27.8	7.1	860	tntc	pond (1)	
12.06.16	Namukomago	1	26.2	37.6	27.7	7.0	tntc	310	pond (1)	Sample taken by villager
12.06.16	Namukomago	S1	48.9	44.3	28.5	7.1	720	tntc	pond (1)	
16.06.16	Namukomago	S3	78.5	106.2	24.3	5.6	tntc	tntc	pond (2)	
12.06.16	Namukomago	2	49.7	40.2	28.6	7.0	800	tntc	pond (1)	Sample taken by villager
12.06.16	Namukomago	S3	62	39.1	27.8	6.2	129	tntc	pond (2)	
16.06.16	Namukomago	S1	28.5	291	24.1	6.1	tntc	tntc	pond (1)	
WHO guideline values (WHO, 2011)			<5 NTU	no value		6.5-8.5	no value	0 cfu/100 ml		
TrinkwV 2001 guideline value (BMJV, 2016)			<1 NTU	2500 µS/cm; 20°C 2750 µS/cm; 25°C		6.5-9.5	20 cfu/ml	0 cfu/100 ml		

tntc = too numerous to count

6.2.1 Physical-Chemical quality

Almost all of the raw-water sources showed high amounts of turbidity (between 13.49 NTU and 85.5 NTU). These values are consistently reached in unimproved water sources (ponds) in the most rural of the researched areas. One exception from these high turbidities is the shallow well in Kyamagamule, with a turbidity of 1.6 NTU in the sample of the 15.06.2016. This generally fits the WHO guideline value (< 5 NTU).

Strangely, the turbidity of the same borehole was surprisingly high (28.9 and 26.9 NTU) on the first testing day (12.06.2016). It seems unlikely at first glance that the turbidity of water from the same aquifer would naturally fluctuate that much in just three days between sampling events. Even if other studies have partly demonstrated that shallow groundwater can be rather vulnerable to quick water-quality changes especially immediately after short duration rainfall events (HOWARD et al., 2003). This phenomenon mainly affects microbial contaminations from the outside, but is probably also applicable to turbidity to some degree. Another possibility could be that the fluctuations are due to local sediment contamination from the pipe caused by extensive use of the shallow well by the villagers. The specific source of these differing values could not be adequately explained within this thesis, nor do they have any particular relevance to the purpose of the thesis.

A more striking discovery is that the piped distribution system in the urban areas of Kampala (Kosovo), which is generally seen as improved water source, also has very low degrees of turbidity (0.53 to 1.14 NTU). The Kampala piped system itself come from treated surface water, which is stored in reservoirs located in different parts of the city. This treatment includes filtration/sedimentation or combinations of both, so the turbidity of the water in the piped system should be considerably lower within such a system. In principal, turbidity changes could result, according to ECURU et al. (2011), from outside contamination or

inside pollution. Outside contamination are seen e.g. in foreign water entering through leaks or breakages into the system, while inside pollution of the system can be described as rust, scum, foam or slime appearing in reservoirs or distribution pipes due to age and poor maintenance. There is also the possibility of temporary turbidity (and microbial water-quality) deterioration, appearing immediately after heavy, short-duration rainfall or long-duration rainfall in the rainy season. In general, these values seem to correlate with results from similar studies (ECURU et al., 2011). Because of this, the results generally seem plausible, even if these turbidities could be negatively affected within the rainy season, where the probability (and the quantity) of possibly contaminated water entering the system seems to be higher.

In addition, the researched (unprotected) spring in Kampala (Massaja) shows low turbiditiy (2.67 NTU), which also seems to be generally plausible, relating to the general assumption that spring water is relatively clean in its appearance and relating to comparable researches of springs within Kampala (HARUNA et al., 2005). But studies like these also show that even protected springs are vulnerable to drinking-water quality deterioration by rainfall events and other things.

The EC does not show conspicuous or critical values in any case. All of the sources are within the guidelines of WHO and TrinkwV 2001. Some of the pH-values appear to be particularly low. They often do not even lie with the minimum guideline values of 6.5. Many of the samples have pH-values of about 6, some even less. One reason for this could be the chemical attributes of Ferrasols, also known as red clay soils, which can be found in nearly all of the researched areas in Uganda (NEMA, 2009; FAO/UNESO, 1973). Red clay soils are seen to be quite acidic, often having generally low pH-values. The red and yellow colours in the soil itself often result from accumulations of oxidised iron and they are able to heavily affect the color of encountered water (FAO, 2001). These points could also partly explain the turbidity of the samples, appearing with reddish/brown, sometimes yellow-ish color and the unusually low pH-values in some of the samples. Similar kinds of low pH-values have been detected in several researches of drinking-water sources in Uganda (HARUNA et al., 2005; OKOT-OKUMU & OTIM, 2015) therefore they seem to be plausible and have a natural source.

While pH-values within these regions are not seen to be generally health affecting, their slight acidic attributes could lead, in the long term, to problems related to corrosion of pipes or components (made of metal or concrete), which directly are in contact with the water (FRITSCH et al., 2014). This could affect, for example, the piped distribution system in Kosovo-Kampala: corrosion of metal pipes could result in local leaks or breakage, which thereafter could become (or potentially already are) potential sources for contamination from the outside. Especially in developing countries, constant maintenance and repair are often particularly unavailable or not affordable. Therefore problems like these are able to directly and continually affect qualities of the drinking water in a negative way, even for water sources, which are generally classified as improved ones. Problems in regards to corrusion is irrelevant for the villages in the rural areas of Kalangalo simply because of the absence of piped systems. In reverse, low pH values could be useful to foster the disinfecting effects of chlorine (FRITSCH et al., 2014), because low pH values positively affects the development of HClO (hypochlorus acid) within chlorinated water.

The water sources were also tested on-site for chemical parameters (ammonia, manganese, nitrite, phosphate, aluminium, cyanuric acid, iron and fluoride) through use of a digital photometer of the Wagtech Company (WAG-WE10441), and reagents of the Wagtech and Palintest companies. These parameters are numerous and extensively researched for their effect on drinking-water quality. Therefore only the relevant parameters were specifically researched within this thesis. The approach of this thesis is to research the practicability and disinfection effectiveness of a low-tech chlorination system and mobile filtration units. For this reason, only the specific values represented within this thesis that could directly influence the effectiveness or practicability of one of the systems were measured. This includes for example ammonia (can negatively affect chlorination) and iron (can indirectly affect chlorination because it increases turbidity).

For reasons of simplicity these parameters and the testing process itself are not explicitly represented within this thesis. The parameters are discussed while evaluating the effectiveness and practicability of the tested purification systems (if a direct correlation of the parameters and the results can be found). For the sake of completeness, a table with all of the tested parameters can be seen in the annexes.

6.2.2 Microbial quality

Generally, the on-site testing with the mobile membrane filter method cannot be directly compared to membrane filter methods practiced within a laboratory. In this special case, no specific dilutions of the raw-water samples were undertaken: the limited storage facilities within the available incubators, the limited amount of available petri dishes and limited timespan available to accomplish the microbial tests limited the number of potential microbial tests (with several different dilutions respectively) of each raw-water source. Potentially highly microbial contaminated raw-water sources almost inevitably lead to colony numbers, which are too numerous to count (tntc). Essentially, the testing conditions cannot be compared to laboratory conditions, because some of the microbial tests must be accomplished directly on-site: in hotel rooms, living rooms or kitchens of the villagers or in the trunk of the van. Because of this, the results of the microbial on-site tests should not be considered validated accurate data. They are best considered as overall estimations of the contamination level within the drinking water.

Despite this, the data appears accurate enough to assess the microbial contamination of the sources, in regards to the critical values of WHO and TrinkwV 2001. If the critical guideline value for total coliforms is set at < 1 cfu / 100 ml, it is not essential to evaluate the exact number of bacteria, if the amounts are well above the guideline values.

The microbial test results of the drinking-water samples in Kalangalo and Kampala show that there are massive amounts of total coliforms in nearly every water sample. The amounts of colony-forming units are in the most cases too numerous to count (tntc). An interesting point is the composition of the bacteria: the coliforms (yellow) either appear together with relatively large amounts of other, unspecific bacteria (appearing as pink, purple, red or clear colonies) (see Fig. 36) or the whole plate is covered with immense amounts of coliforms (see Fig. 37).

Fig. 36: Plate Count (total coliforms) of Kabayiima, 16.06.2016, tntc

Fig. 37: Plate Count (total coliforms) of Mayobyo, 16.06.2016, tntc

This confirms the assumption that the raw-water, especially from the unimproved, surface water sources (ponds/streams in Kabayiima, Namukomago, Mayobyo, Mbiliddembiraba) are heavily contaminated by fecal and other pollution. These results seem to be plausible in regards to the general assumption that the appearance of fecal contamination strongly corresponds to the use of unimproved drinking-water sources as well as with the use of un-piped drinking-water sources, which has been shown in numerous studies in Uganda and other parts of Africa (HARUNA et al, 2005; OKOT-UKUMU & OTIM, 2015; UDOUSORO & UMOREN, 2014; and many more).

Some individual samples had test results with considerably lower contamination with total coliforms (Kabayiima, 12.06.2016 with 120 cfu / 100 ml and Namukomago, 12.06.2016 with 310 cfu / 100 ml), which can still be seen as immense, unacceptable amounts of bacteria in drinking water. Conversely, the researched improved water sources have better results, such as the shallow well in Kyamagemule (with total coliforms of < 100 cfu/ 100 ml). One exceptionally good sample, Kyamagamule (12.06.2016), showed very low results of 4 cfu / 200 ml, and 2 cfu /100 ml respectively (see Fig. 38).

The piped distribution system in Kampala-Kosovo (with amounts of total coliforms ranging from about 143 cfu / 100 ml, 163 cfu / 100 ml and tntc) also showed slightly better results than the unimproved sources researched within the rural areas (see Fig. 39). While numbers appear to at least be better than the results from unimproved sources in the rural areas, they are possibly affected by short term contamination caused by inflow of rainwater (because the research project took place immediately after the end of the rainy season). But these levels of bacteria are still too high to meet the guidelines of the WHO or the TrinkwV 2001 for drinking-water quality.

Fig. 38: Plate Count (total coilforms) of Kyamagemule, 12.06.2016, 4 cfu/200 ml

Fig. 39: Plate Count (total coliforms) of Kampala-Kosovo (downstream), 12.06.2016, 285 cfu/200 ml

The aerobic plate counts, performed with the 3M petrifilms generally seem to support with the overall results of the total coliforms. They are almost consistently too numerous to count (tntc), indicating a very high number of bacteria in the raw-water sources. A striking observation is that the results of the 3M petrifilms of the same water-sample often differed greatly, which underscores the assumption, that this testing method cannot be seen as perfectly accurate. This is especially evident in the sample of Kyamagamule (12.06.2016) showing numbers varying from cfu/ml of about 586, 730 and 8 (which has to be seen as outlier value). For this reason, the test results of the 3M petrifilms were seen as “solid estimations”, rather than actual numbers of bacteria.

To identify the actual contamination source in the distribution pipe system in Kampala-Kosovo nearly seems impossible, because of the reasons presented in Chapter 3.3 Drinking-water and sanitation situation in Kampala, Uganda. There are overall simply too many potential sources that are able to directly or indirectly increase the risk of microbial or other contamination. In addition it is not the point of this thesis to localize problems in drinking-water systems.

The amounts of bacteria in the shallow well in Kyamagemule could be the result of prior maintenance work. Some construction work was recently completed on the pipe of the borehole, possibly microbially contaminating the pipe wall (see also Chapter 3.2 Drinking-water and sanitation situation in Kalangaalo, Uganda) through contaminated sediments, wastewaters or other pollutants being introduced into the well. A general problem like this, however, is directly related to the topic of this thesis. Problems like these could be tackled using the low-tech chlorination system that is partly researched within this thesis. As discussed further in chapter 7.3.2 “Shock chlorination” of a shallow well in Kyamagamule) of this thesis, this specific problem was addressed using a so-called “shock chlorination” of the well.

6.3 Discussion of the on-site results

The physical-chemical and microbial testing of the raw water sources in Uganda shows why permanent drinking-water purification is necessary, especially for drinking water gained from unimproved sources. These sources are generally seen as microbially-contaminated, either from natural, anthropogenic impacts or combinations of both, and need to be disinfected or treated permanently before use.

The test results also show that even improved sources, such as the piped distribution system in Kampala and the protected shallow well in Kyamagamule are not as reliable (especially in microbial water-quality) as desired. Despite this, systems of these kinds are nevertheless seen as the most reliable systems present in Uganda, generally able to achieve relatively safe drinking water. The fluctuations in microbial quality seem to be primarily result from problems related to sanitation, administration and maintenance, rather than from the general unsuitability of the system to achieve potable drinking water. In summary, even drinking-water quality in improved drinking-water sources should be frequently tested if possible (e.g. with the use of *Water Safety Plans* and *Risk Maps*). This was previously documented in other research and is also recommended by the WHO (HOWARD et al., 2005; WHO, 2011).

If this is not generally possible, due to financial, political or other reasons, there is a need for treatment or purification in specific times where suitable drinking-water quality cannot be guaranteed. This could include, for example, preventive drinking-water purification/treatment after maintenance work, construction, regularly scheduled cleaning, extreme rainfall events or other individual incidents, that could negatively affect water-quality.

7. Drinking-water purification: chlorination

One potential technique to overcome drinking-water quality deteriorations within developing countries is seen in chlorination. Chlorination in general is one of the most used water treatment/disinfection methods worldwide. Drinking-water disinfection through chlorination has the specific advantage, that it is able to disinfect large volumes of drinking water with relatively low dosages of chlorine solution. This means, that even individual chlorine production systems are suitable to ensure safe drinking water for high numbers of potential users. Because of that, a low-tech chlorination system is researched for its disinfection efficiency and its practicability in developing countries. The idea of this low-tech chlorination system is producing chlorine in small-scales in individual households in developing countries (here: Uganda). The chlorination system itself is working with the principle of chlor-alkali electrolysis, using car batteries as power supply. In the researched rural areas almost every household owns car batteries to light their house at night. Also most of these households own solar panels to recharge the battery during the daytime. With consideration of these techincal ressources a functional chlorine-producing prototype was designed by Dipl.-Ing.. Michael Ottensmann.

One potential application is that selected villagers/households produce chlorine solutions at night. When the children head to the water-sources to gain drinking water with jerry cans, the drinking water within the jerry cans could be chlorinated to specific concentrations. The chlorine within the jerry cans is able to disinfect the drinking water during the way home.

After about 30 min, when the children arrive at home the drinking water in the jerry cans is probably safe from microbial contamination (WHO, 2011). The chlorine producers could also start a micro-business. Besides that, other applications of locally and individually produced chlorine could be a regular cleaning of improved drinking-water sources or –components (hand-pumps of shallow wells, surroundings of wells) or to chlorinate collected rainwater for domestic use.

The system is designed with a clear low-tech approach. In other words the materials used to construct, operate and maintain the systems should be as widely available as possible in developing countries like Uganda; also the parts and operating ressources should be affordable for the potential users. In addition the process of chlorine production and water disinfection through chlorination should be as easy as possible, and the potential users should have the technical know-how that is needed to run these systems.

Four prototypes (identical in construction) were tested in villages within the sub-county Kalangalo in Uganda (Mbiliddembiraba, Namukomago, Kabayiima, Mayobyo). These tests were relating to battery charge, recharge with solar panels, disinfection effeciency, chlorine production, -addition and -decay, and practicability of the procedure. A reconstructed prototype of the chlorination system was also tested in laboratory conditions by B.Eng. Triet-Vuu Luu in the course of a prior bachelors thesis in the department of civil engineering (LUU, 2016) at the Trier University of Applied Sciences. This thesis was primarily concentrating on the microbial cleaning success and the practicability in developing countries (in this case Uganda) rather more than on the technical and chemical problems appearing in chlorine production and application. These general problems for example deal with (complex) interactions between battery load and chlorine production, chlorine addition, -residual and –decay in drinking water with different chemical attributes and many more.

7.1 Description of the system

In general both of the tested low-tech chlorination prototypes (in laboratory and on-site) are constructed similar (see Fig. 40 and Fig. 41): the system consists of a containment vessel with a known volume of at least six liters, a rechargeable battery (car battery or comparable), electrodes, connection cords and a non-conductive fixation device for the electrodes. The on-site tests includes solar panels to recharge the batteries after the production of chlorine.

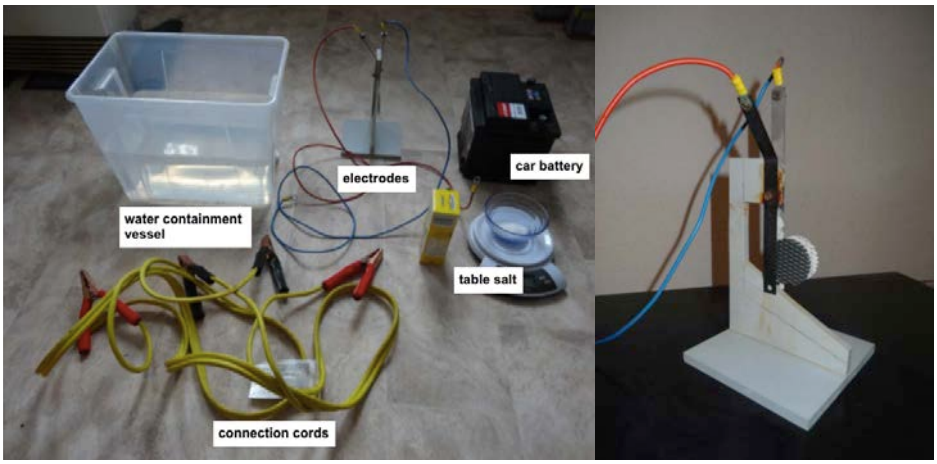


Fig. 40: Chlorination system, laboratory set-up (left), electrode with fixing, detail (right) (LUU, 2016), edited

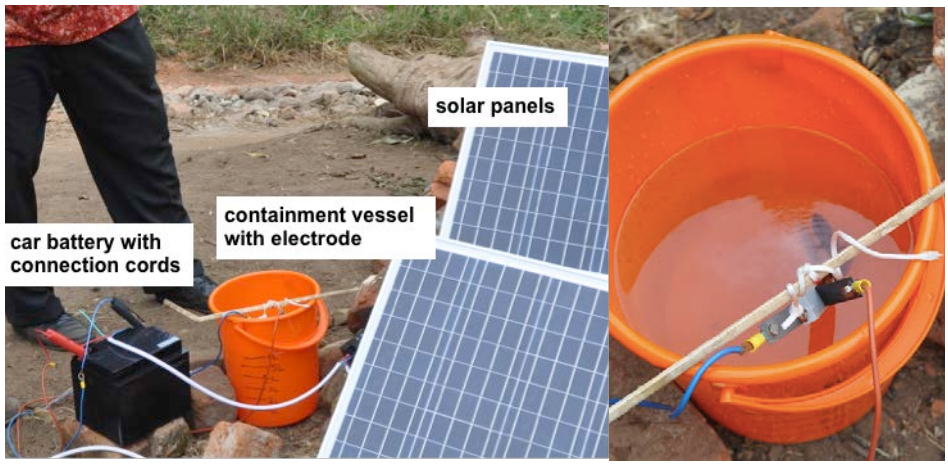


Fig. 41: Chlorination system, on-site prototype with solar panels to recharge batteries (left), electrodes with temporary fixing, detail (right), edited

Broadly speaking, the system is using the principle of chlor-alkali electrolysis with a low-tech approach. Six liters of water are mixed with 40 ml of tablesalt (NaCl), afterwards car batteries deliver the needed electricity for the electrolysis of the solution. After specific exposure times within the salted water the vessel contains a chlorine solution with concentrations depending on the chosen exposure time.

Electrolysis in general describes the process of using a direct electric current (DC) to start an otherwise non-spontaneous chemical reaction within conductive aquaeous solutions (electrolytes). When the DC is applicated to the electrodes the anode (positive charge) has an excess of electrons; the cathode (negative charge) has a deficite of electrons. Because of that, the negatively charged molecules or ions dissolved in the electrolyte are attracted by the anode, which is giving away excess eletrodes to the molecules or ions (reduction). Simultaneously the cathode attracts the positively charged molecules and ions within the solution and takes electrodes from them (oxidation) (see also Fig. 42). With this attributes it is suitable for the separation of elements and combounds within these solutions. The materials of both anode and cathode highly influence the reaction itself and the seperation of the elements and substances.

According to ROESKE (2007), the chlor-alkali electrolysis can be described as:

$$2\ NaCl + 2\ H_2O \Rightarrow Cl_2 + 2\ NaOH + H_2 \quad (I)$$
$$2\ NaOH + Cl_2 \Rightarrow NaClO + NaCl + H_2O \quad (II)$$

The development of the actual disinfecting hypochlorid acid (HOCl) can be described as:

$$NaClO + H_2O \Leftrightarrow HOCl + NaOH \quad (III)$$

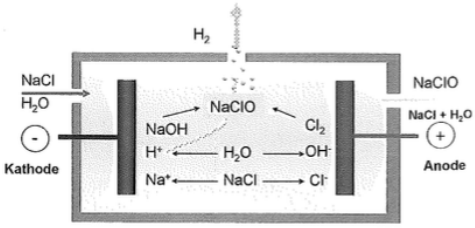


Fig. 42: Chlor-alkali electrolysis, schematic sketch (ROESKE, 2007)

In this case the electrolysis is used to produce chlorine in different forms. The electrolysis itself seperates NaCl (sodium chloride, better known as tablesalt) and H_2O in the first step and creates Cl_2 (chlorine gas), H_2 (hydrogen gas) and NaOH (sodium hydroxide) within the electrolyte (I). At the same time H_2 and Cl_2 escape from the electrolyte into the air. Nevertheless Cl_2 and NaOH react to form NaCl, NaClO (sodium hypochloride) and H_2O (II). The produced Cl_2 is important to form the actual disinfecting hypochlorous acid while parts of it simultaneously and permanently escape from the chlorine solution. The acutal disinfecting HOCl (hypochlorous acid) is developed in a balance reaction of NaOH, Cl_2 and HOCl, NaOH (III). This balance reaction depends on pH and temperature of the water and it takes place independently from the process of electrolysis (ROESKE, 2007).

Further explanations for example in regards to the technical background of the chlorination system can be read in LUU (2016). A complete list of components needed to construct a functional prototype similar to LUU (2016) can be found in the annexes, with detailed information related to the manufacturer of the specifically used parts.

7.2 Laboratory testing (LUU, 2016)

The following laboratory testing results are taken from LUU (2016). The laboratory tests in LUU (2016) consists of microbial and physical-chemical parameters, analogue to the laboratory tests presented in this thesis. This means that the disinfection efficiency related to E.Coli, total coliforms and HPC was researched, with different chlorine concentrations and with chlorine exposure times of about 30 min. Also the pH and EC was tested and an IC was executed (potassium, sodium, magnesium, calcium). With these tests detailed information about the disinfection efficiency and the general effects of drinking-water chlorination concerning to important water quality parameters should be gained.

The tests intented to compare the disinfection efficiency of “prototype-produced” chlorine in laboratory conditions with microbial cleaning efficiencies of chlorine produced by prototypes (identical in construction) on-site in Uganda and with other purification methods (here: Aquaforce 5 microfilters and other mobile pressureless filters researched by DANY (2011) also see 9. Comparison: filtration and chlorination). For reasons of simplicity the most important testing results of the laboratory tests related to the disinfection efficiency are summarized in the following: the microbial testing results can be seen in Tab. 3. The mean microbial cleaning efficiencies of chlorine in different concentrations are presented in Fig. 43. The testing results of chemical and physical parameters have minor influences on the

disinfection efficiency and are excluded from this thesis. In detail, they can be read in LUU (2016).

Tab. 3: Disinfection effeciency (Chlorination) with different chlorine concentrations, laboratory testing, data and numbers from LUU (2016)

Sample / Dilution	Membrane filter method			Marks
	COLICHROM [cfu/100ml]		CASO [cfu/100 ml]	
	E.Coli	total coliforms	HPC	
Sewage plant effluents raw / 1:100	2500	6300	22700	-
Sewage plant effluents chlor. ≈2.3 mg/l / 1:1	0	0	46	-
Sewage plant effluents chlor. ≈4.5 mg/l / 1:1	0	0	0	-
Sewage plant effluents chlor. ≈7.5 mg/l / 1:1	0	0	2	-
River water (Moselle) raw / 1:10	90	1420	870	-
River water (Moselle) chlor. ≈2.3 mg/l / 1:1	0	2	66	-
River water (Moselle) chlor. ≈4.5 mg/l / 1:1	0	0	0	-
River water (Moselle) chlor. ≈7.5 mg/l / 1:1	0	0	3	-
Well-water raw 1:1	0	0	3	-
Well-water chlor. ≈2.3 mg/l / 1:1	0	0	0	-
surface water raw 1:1	0	0	3	-
surface water chlor. ≈2.3 mg/l / 1:1	0	0	0	-
WHO guideline value (WHO, 2011)	**0 cfu/100 ml**	**0 cfu/100 ml**	**no value**	
TrinkwV 2001 guideline value (BMJV, 2016)	**0 cfu/100 ml**	**0 cfu/100 ml**	**2000 cfu/100 ml**	

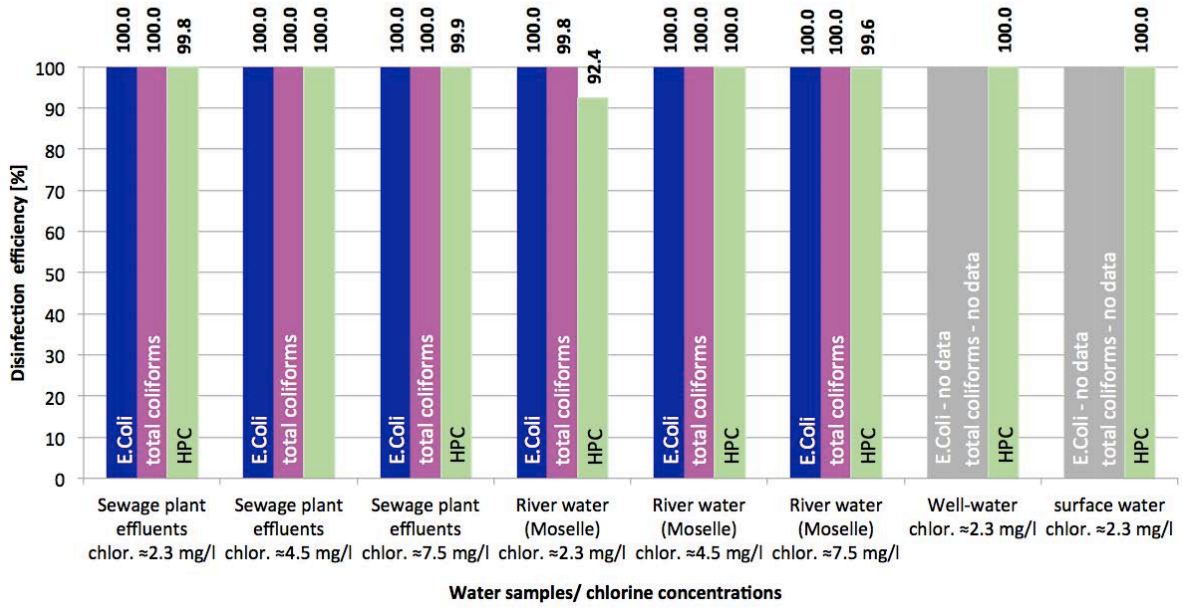


Fig. 43: Disinfection efficiency (Chlorination) with different chlorine concentrations, laboratory testing, data and numbers from LUU (2016)

7.3 On-site testing in Uganda

The results of the drinking-water testing on-site (in Uganda) have shown that there is an undeniable need for drinking-water treatment. More precisely, almost all of the researched drinking-water sources are contaminated strongly with fecal (and other) bacteria to different extents. This is affecting both unimproved and improved drinking-water sources. Resulting from the discoveries on-site, one potential application for chlorination seems to be the permanent disinfection of drinking-water gained from these (or similar) sources.

The disinfection efficiency of chlorine depends on numerous factors. These factors relate to technical, chemical and practicability aspects: battery charge and recharge as well as the exposure time of the electrodes influence the chlorine concentration of the produced solution. The concentration of the solution itself directly affects the needed dosage of chlorine in treated water: the chosen chlorine dosages and concentrations (and –residuals) within the drinking water are one of the most important parameters affecting the disinfection efficiency. But also chlorine decay and –residual after application, which depend on numerous physical and chemical parameters of the treated water, influence the success of the disinfection (for the good or the bad). In addition the chlorine residuals after treatment deteriorate the acceptability aspects of the drinking water (taste, odor).

Some of the results and impressions of the on-site tests related to the disinfection efficiency of chlorination are presented in the following chapter. Further details of the complex relationships mentioned above, and more data and numbers in regards to chlorine decay, -residual, -production and efficiency (that have been raised within the two weeks in Uganda) are not presented within this thesis: they will probably be published soon by Michael Ottensmann in the Nov/Dec 2016 issue of *The Military Engineer*.

7.3.1 Chlorination of unimproved drinking-water sources in Kalangalo

The produced chlorine was tested concerning to its efficiency on drinking water from the sources in the villages. The drinking water was sampled from the sources with 20 liters jerry cans, which were dosed with the prototype-produced chlorine to specific concentrations of chlorine (1 mg/l; 2mg/l or 3 mg/l). The samples were microbially tested as regularly as possible for up to 4 h after the addition of the chlorine into the samples. The results can be seen in Tab. 4. The table shows the specific chlorination concentrations that were aimed to achieve within the water samples at specific dates and specific villages, and the resulting bacteria numbers.

Tab. 4: Microbial testing, chlorination, on-site, with specific chlorine concentrations

Date	Village	Sample	colony forming units		Marks
			aerobic heterotrophic plate counts [cfu/ml]	Membrane filter method (total coliforms) [cfu/100 ml]	
Mbiliddembiraba 20.06.2016 - chlorinatd 1 mg/l					
20.06.16	**Mbiliddembiraba**	**raw**	**-**	**tntc**	
20.06.16	Mbiliddembiraba	chlorinated 1 mg/l about 30 min	-	0	
20.06.16	Mbiliddembiraba	chlorinated 1 mg/l 2 h	-	no visible coliforms	
20.06.16	Mbiliddembiraba	chlorinated 1 mg/l 3 h	-	no visible coliforms	
Mbiliddembiraba 20.06.2016 - chlorinatd 2 mg/l					
20.06.16	Mbiliddembiraba	chlorinated 2 mg/l 1h	-	8	
20.06.16	Mbiliddembiraba	chlorinated 2 mg/l 1 h	-	no visible coliforms	
20.06.16	Mbiliddembiraba	chlorinated 2 mg/l 2 h	-	no visible coliforms	
20.06.16	Mbiliddembiraba	chlorinated 2 mg/l 3,5 h	-	1	
Namukomago 20.06.2016 - chlorinatd 1 mg/l					
20.06.16	**Namukomago**	**Raw 70 ml**	**-**	**no visible coliforms**	**potentially high amounts of total coliforms**
20.06.16	Namukomago	chlorinated 1 mg/l 1/2 h	-	no visible coliforms	
20.06.16	Namukomago	chlorinated 1 mg/l 1h 10 min	-	no visible coliforms	
20.06.16	Namukomago	chlorinated 1 mg/l 2 h	-	12	
20.06.16	Namukomago	chlorinated 1 mg/h 3 h	-	no visible coliforms	
Namukomago 20.06.2016 - chlorinatd 2 mg/l					
20.06.16	Namukomago	chlorinated 2 mg/l 1/2 h	-	no visible coliforms	
20.06.16	Namukomago	chlorinated 2mg/l 1h 20 min	-	no visible coliforms	
20.06.16	Namukomago	chlorinated 2 mg/l 2 h	-	no visible coliforms	
20.06.16	Namukomago	chlorinated 2 mg/l 3 h	-	no visible coliforms	
Mbilliddembiraba 21.06.2016 - chlorinatd 2 mg/l					
21.06.16	**Mbiliddembiraba**	**raw**	**tntc**	tntc	
21.06.16	Mbiliddembiraba	chlorinated 2 mg/l 1/2 h	16	-	
21.06.16	Mbiliddembiraba	chlorinated 2 mg/l 1 h	8	-	
21.06.16	Mbiliddembiraba	chlorinated 2 mg/l 2 h	4	-	
21.06.16	Mbiliddembiraba	chlorinated 2 mg/l 3 h	14	-	
21.06.16	Mbiliddembiraba	chlorinated 2 mg/l 4 h	3	-	
Mbilliddembiraba 21.06.2016 - chlorinatd 3 mg/l					
21.06.16	Mbiliddembiraba	chlorinated 3 mg/l 1/2 h	11	-	
21.06.16	Mbiliddembiraba	chlorinated 3 mg/l 1 h	4	-	
21.06.16	Mbiliddembiraba	chlorinated 3 mg/l 2 h	2	-	
21.06.16	Mbiliddembiraba	chlorinated 3 mg/l 3 h	0	-	
21.06.16	Mbiliddembiraba	chlorinated 3 mg/l 4 h	4	-	
Namukomago 21.06.2016 - chlorinatd 2 mg/l					
21.06.16	**Namukomago**	**raw**	**tntc**	**tntc**	
21.06.16	Namukomago	chlorinated 2 mg/l 1/2 h	126	-	
21.06.16	Namukomago	chlorinated 2 mg/l 1,5 h	110	-	
21.06.16	Namukomago	chlorinated 2 mg/l 1,5 h	85	-	
21.06.16	Namukomago	chlorinated 2 mg/l 2 h	53	-	
21.06.16	Namukomago	chlorinated 2 mg/l 2,5 h	77	-	
21.06.16	Namukomago	chlorinated 2 mg/l 3 h	83	-	
Namukomago 21.06.2016 - chlorinatd 3 mg/l					
21.06.16	Namukomago	chlorinated 3 mg/l 1/2 h	120	-	
21.06.16	Namukomago	chlorinated 3 mg/l 1 h	78	-	
WHO guideline value (WHO, 2011)			**no value**	**0 cfu/100 ml**	
TrinkwV 2001 guideline value (BMJV, 2016)			**20 cfu/ml**	**0 cfu/100 ml**	

tntc = too numerous to count
no visible coliforms = bacteria on the plate does not contain coliforms

The results indicate that the effectivity of chlorine seems to be strongly fluctuating. On the one hand chlorination seems to be relatively effective in terms of total coliforms. The amounts of coliform bacteria seemed to be almost completely removed (mostly < 10 cfu/100ml) in the most cases. Also the heterotrophic aerobic plate counts (HPC) indicated that the disinfection efficiency was good: especially in the first hours the chlorine has decreased the numbers of bacteria immensely from tntc (probably hundredths of cfu/ml or more) to values of < 10 cfu/ml. Some samples did not even contain any bacteria anymore. On the other hand, some of the numbers indicated that the bacteria was able to come back after specific time spans. This is for example evident in the samples of Mbiliddembiraba and Namukomago at the 21.06.2016: in Mbiliddembiraba (chlorinated ≈ 3 mg/l) the bacteria counts were decreased instantly (after 30 min) from tntc to 11 cfu/ml, after 3 h all of the bacteria were gone. But after 4 h the bacteria seemed to show up again with 4 cfu/ml. Similar discoveries were made in Mbiliddembiraba (chlorinated ≈ 2 mg/l) and Namukomago (chlorinated ≈ 2 mg/l), where the bacteria counts were increasing again after about 2 – 3 h.

One potential explanation for these discoveries is that effective chlorination is impeded by relatively high turbidities of the water samples (as seen in Tab. 2). The turbidities of any of the researched unimproved drinking-water sources in the villages were constantly and significantly exceeding the WHO guideline values recommended for chlorination (WHO, 2011), ranging from values of about 26 to values up to almost 80 NTU. Bacteria often attach to turbidity causing particles: if the chlorine residual has completely decayed and there still are intact bacteria attached to these particles, the bacteria are able to regrow and to recontaminate the drinking water (ROESKE, 2007). As already mentioned in Chapter 6.2.1 Physical-Chemical quality the turbidites could be among other things affected by natural attributes of surface water in Uganda, due to the presence of (oxidised) iron within the raw-water. This assumption was generally confirmed by photometer measurements that have shown that the amounts of dissolved iron within the drinking-water sources are partly relatively high (up to 0.74 mg/l). The chlorination could also be negatively affected by ammonia (NH_4) that was detected in some of the drinking-water sources. Within these research, the amounts were often exceeding the recommended WHO (2011) value for effective chlorination, which is set to be < 0.1 mg/l: the detected peak values of ammonia within the unimproved drinking-water sources were for example ranging from 0.35 and 0.45 mg/l (e.g. in Namukomago at the 12.06.2016 and the 16.06.2016 respectively) to values of 0.53 mg/l in Kabayiima at the 12.06.2016. Ammonia in chlorinated water is causing that parts of the actual disinfecting hypochlorous acid of the react with ammonia to form chloramines. The disinfection efficiency of chloramines in general is seen to be much weaker than the one of hypochlorous acid (ROESKE, 2007), therefore it affects the disinfection efficiency for the bad.

All of the data and numbers related to the measured chemical ingredients of the water sources can be seen in the annexes.

7.3.2 “Shock chlorination” of a shallow well in Kyamagamule

Many improved drinking-water sources seem to be characterized by short-term, individual drinking-water quality deteriorations for example due to maintainance work, repair or other incidents. So one potential application for chlorination in developing countries is seen in individual, targeted application of chlorine: either to establish regular scheduled disinfection patterns to improve the reliability in terms of microbial drinking-water quality or to disinfect contaminated drinking-water sources after individual incidents that are potentially affecting the microbial drinking-water quality.

In case of this thesis, a so-called “shock-chlorination” of the contaminated pipe of the shallow well/borehole (mentioned in Chapter 3.2 Drinking-water and sanitation situation in Kalangaalo, Uganda) was executed on-site to reduce the microbial contamination of the source (18.06.2016). The term “shock chlorination” describes the process of a one-time introduction of a highly concentrated chlorine solution into the specific drinking-water source, in order to disinfect the whole source instantly and reliably. Therefore the head of the pumping unit was dismantled and the pipe was rinsed (from the insides and the outside) with a chlorine solution produced by the low-tech electrolysis prototypes. Because of the unknown volume of the well and the groundwater aquifer, unfortunately the reached chlorine concentration within the well is not available in this thesis. Measurements of the free chlorine

immedeatly after the introduction of the chlorine solution indicated that the chlorine concentration was about 2.4 mg/l. The chlorine was allowed to disinfect the drinking-water source for about 24 h, after this exposure time the well was flushed and the chlorine residuals within the drinking-water was measured. Immediately after pumping up the water no residuals of free chlorine were detectable anymore. The added chlorine was either decayed or it was diluted significantly. After the shock chlorination the drinking-water source was microbially tested for three days (total coliforms) to verify the success of the application. The results of the microbial drinking-water quality of the source before and after shock chlorination can be seen in Tab. 5.

Tab. 5: Microbial testing, shock chlorination in Kyamagamule, results

Date	Village	Sample	colony forming units		Marks
			aerobic heterotrophic plate counts [cfu/ml]	Membrane filtration (total coliforms) [cfu/100 ml]	
12.06.16	Kyamagemule	S2	8; 586; 730	2	-
12.06.16	Kyamagemule	S1	6	36	-
15.06.16	Kyamagemule	S	85	85	-
15.06.16	Kyamagemule	S1	-	25	-
15.06.16	Kyamagemule	S1	-	190	-
18.06.16	Kyamagemule	S1 (dirty)	-	40	-
18.06.16	Kyamagemule	chlorinated 1	-	0	after shock chlorination
18.06.16	Kyamagemule	chlorinated 2	-	0	after shock chlorination
19.06.16	Kyamagemule	raw	-	0	after shock chlorination
20.06.16	Kyamagemule	raw	-	no visible coliforms	after shock chlorination
WHO guideline value (WHO, 2011)			**no value**	**0 cfu/100 ml**	
TrinkwV 2001 guideline value (BMJV, 2016)			**20 cfu/ml**	**0 cfu/100 ml**	

tntc = too numerous to count
no visible coliforms = bacteria on the plate does not contain coliforms

The results seem to clearly reveal improvements in terms of microbial drinking-water quality. Numbers of total coliform bacteria within the tested water samples have decreased from relatively high numbers ranging between 2 and 190 cfu / 100 ml to numbers of about 0 cfu/ 100 ml. In one case (20.06.2016) the plate count of the membrane filter method was still showing some bacteria that was not categorized as coliform bacteria. In regards to the aerobic heterotrophic plate counts (HPC) the data basis is too weak to make any comprehensible conclusions. According to the assumption that in general (nearly) all bacteria are attacked by chlorine and the testing results from Capter 7.3.1 Chlorination of unimproved drinking-water sources, the HPCs should probably be relatively low after shock chlorination. This assumption is also supported by the facts that the chlorinated water from the shallow well is low in turbidity and relatively low in pH, also ammonia concentrations were low (< 0.1 mg/l, also see the annexes). Therefore the disinfective power of the chlorine probably should not be impeded by turbidity causing particles or ammonia and could furthermore be fostered by the relatively low pH values of the source, that were already presented in Tab. 2 .

The laboratory tests by LUU (2016) and the on-site tests have shown that low-tech produced chlorine is able to significantly improve microbial drinking-water quality in general, as it has relatively reliably removed a majority of bacteria in the tested drinking-water. Even if the chlorine was (especially on-site) partly not able to kill or inactivate 100 % of bacteria, the improvements related to microbial contaminations in pure raw water were immense. The application of chlorine (in different concentrations) has achieved mean disinfection efficiencies of 100 % related to E.Coli and total coliforms, and 98 % related to HPCs (with the

lowest tested concentration of ≈ 2.3 mg/l) in the laboratory (LUU, 2016). According to results of the chlorinated waters on-site related to the extraordinary high contaminations of the raw water, the on-site disinfection efficiencies should (in most cases) revolve in similar regions, even if they could not be explicitly determined within this thesis. The problem of recontamination after specific time spans, that was occuring on-site, was not researched in the laboratory.

7.4 Operational use in developing countries

The success of water-purification systems does not only refer to purely technical or chemical aspects, especially in developing countries. Even if purification systems are working perfectly, cleaning drinking water in a good and reliable manner does not guarantee that the system establishes itself in the everyday life of users or executives. An important point is the acceptability of the purification system within the targeted group of users: drinking-water purification methods in developing countries mostly include significant changes in taste and appearance of the drinking-water, also daily routines and living practices are affected. Because of that, the aspects of the chlorination system that are related to operation, maintainance and acceptability are discussed as follows.

7.4.1 Technical aspects

In technical ways the chlorination system is not that complicated to use, if the general instructions are followed: the battery has to be completely recharged with the solar panels during the day, in the evening the tablesalt has to be added to specific volumes of water and afterwards the process of electrolysis has to be executed for a specific exposure time. After this exposure time, the chlorine solution is ready to disinfect and can be used, for example at the next morning. A majority of the households within the villages in Uganda already have solar panels and batteries to light their houses at night, so using these systems for the purpose of chlorine production should not be problematic.

The process of chlorine dosing in drinking water is another important point, because the disinfective power of the produced chlorine solution seems to be quite vulnerable to several different parameters. One of these parameters is the charge of the battery and the exposure time of the electrodes. The chlorine concentrations of the prototype-produced chlorine solution were heavily fluctuating during the on-site tests. Because chlorine measurement devices are not widely available in developing countries, measurements of the chlorine concentration within the solution, and individual dosages to reach specific chlorine concentrations and -residuals within the disinfected drinking water are not possible. This means, that the chlorine production and dosage has to be managed with the intention to standardize the whole process: the aim of a standardized production-process could be, that the produced chlorine solution is in any case concentrated in ranges, that it is high enough to ensure a reliable disinfection and low enough to be still acceptable for consume, after specific standardized volumes of chlorine solution were added to drinking-water. For this reason the production of chlorine solution has to be managed with the intention to compensate fluctuations in chlorine concentration through misuse of the system. This means that the cleaning success and the acceptability should be still given if the producers did not

recharge the battery to 100 % or if the producers have exceeded or fallen short of the recommended exposure times of the electrodes.

The disinfection effectivity during the on-site tests was reduced especially by the presence of turbidities (and probably by the presence of ammonia) within the treated water. If the disinfective success is not given reliably and the consumers do not notice positive effects in regards to the common health situation, for example if they do not recognize reduced numbers of diarrhoeal diseases within their community, the acceptability for the purification method is potentially low and the consumers do not use it, or lose their trust in drinking-water purification systems in general. Because of that, either the process of chlorine production and application have to be adapted to reach concentrations of chlorine that reliably guarantee a safe and sustainable disinfection even in very turbid water or the turbid water has to be pre-treated to reduce the turbidities to ranges of < 5 NTU. The first potential solution has the danger, that the needed chlorine concentration to reliably disinfect the turbid drinking water is too high and results in drinking water that is unpotable because of its odor and taste. Unfortunately the second potential solution includes another working step in the process of drinking-water purification, which could also decrease the acceptability of the users and the willingness to include this additional step into their daily routine. Nevertheless both potential solutions of the turbidity problem need further on-site researches to be assessed in their effectivity.

7.4.2 Social and socioeconomic aspects

One specific advantage of the chlorination system is that nearly all of the needed materials to construct, maintain and operation are widely available and affordable for the users. The only part of the chlorination system, that is not widely available in Uganda is the electrodes. These electrodes are besides the solar panels to recharge the battery the most expensive part of the system. All in all the system itself seems to be affordable for specific villagers in Uganda in the long-term, with total construction costs of about 200 US$ (with batteries, solar panels and electrodes). This is due to the facts that the life-span of the system itself should be relatively high and the costs for operation ressources (tablesalt) are low. The manufacturer of the electrodes and the solar panels attest them to have a lifespan of at least 10 years. With this potentially long life span in consideration, the relatively high price of the system seems to be justified.

Depending on how the system is used, for instance to start a microbusiness of individual households, the electrodes could be self-financed after a while. But the introduction of a microbusiness is also endangering the potential success of the system: the system and the need for drinking-water treatment in general have to be accepted among potential users before they are willing to pay for drinking-water treatment. Teachers, executives of public schools, or pastors could probably affect the success of the chlorination system the most. In general it could be imagined that potential users trust these persons more than individual private people. In developing countries such as Uganda, the willingness to pay for drinking-water treatment (or O&M of engineered drinking-water sources for example) is often lacking (VAN DEN BROEK & BROWN, 2015). Because of that, the users and executives in developing countries have to become more educated for the need of safe drinking water and have to become more aware for the need to pay for O&M of drinking-water treatment systems. Therefore O&M of chlorination systems (or other drinking-water purification

systems or engineered drinking-water sources) by teachers, pastors or other highly accepted persons within the villages seems to have a good influence to improve acceptability and chances of success of engineered solutions for drinking-water treatment in the long-term. Nevertheless this (or similar) management structures have a risk of abuse or misuse: the system could for example be abused to enrich the executive, or to exploit, to discriminate or to extort potential users. Thus the acceptability to pay or to change daily habits for safe drinking water could completely get lost among the users.

Another disadvantage of the chlorination systems is questioning the chlorine-producers, in other words it is not clear who is taking the responsibility, if misuse or abuse of the produced chlorine lead to health issues or other problems among the users. If the chlorine is not produced properly and applied properly for example, the chlorine dosage within the drinking water is potentially too high or too low, leading to an unpotable taste or to ineffective disinfection. Problems like these are fundamentally endangering the success of individual, homemade chlorination as drinking-water purification system, related to the acceptability and the willingness among the users/executives to use the system.

7.4.3 General outlook

Nevertheless the permanent use of this (or similar) low-tech chlorination systems could probably improve the health issues related to water-borne diseases in significant ways. Even if the chlorine is not able to kill or inactivate 100 % of pathogenic (or other) bacteria in the drinking water, for example because the raw-water conditions or misuse in application impede the effectivity of the produced chlorine, the health situation is improved anyway: the numbers of pathogenes within the drinking water and the probability to fall ill from water-borne diseases would probably be significantly reduced.

In addition proper drinking-water treatment can affect positive changes in many inter-disciplinary aspects of life in larger scales: according to an interesting example of ELLIS via DESSIE et al. (2015), about one kg of wood is needed in developing countries to disinfect one liter of drinking-water through boiling. Depending on how much volume of drinking water can be disinfected with homemade chlorine (or other drinking-water treatment systems), the needed amounts of wood within the communities/households is drastically reduced, potentially leading to savings of several tons of wood per community/household a year. This is leading to numerous positive changes within the daily life of the users: even though the users have to spend time producing and applying chlorine (or to run other drinking-water treatment systems), the needed time effort for the disinfection is still less than the effort that was originally needed to disinfect the water through boiling. This is disburdening the users from the work needed to chop the wood and to boil the water. They can for example concentrate on other work or school, therefore the progress in drinking-water treatment can indirectly improve economy and education, and with this attributes it is able to indirectly fight poverty. Simultaneously the savings of wood are protecting the environment to different extends.

The general technical, social and socioeconomic aspects seem to show that effective drinking-water disinfection with individual produced chlorine can be seen as an relatively complex interaction of several different parameters. But in general the benefits related to

drinking-water quality seem to exceed the deficites and difficulties that arise from construction, operation, maintainance, management and chlorine application. To sucessfully utilize the potential of the system further research to optimize the chlorine production and application as well as further education of the potential chlorine producers seem to be needed to improve the relieability, disinfection effectivity and acceptance of the chlorination system. Also the parameters that are directly affecting the chlorine-production and application have to be further investigated: this means that electrode exposure times, battery recharge, and the needed dosage of the chlorine solution have to be optimized in further on-site tests. On top of that the effects of prototype produced chlorine solution in pre-treated drinking-water (e.g. with low-tech filtration or sedimentation to reduce the detrimental effects of turbidities on disinfection efficiency) has to be researched. Some potential solutions for these problems are probably published soon by Dipl.-Ing. Michael Ottensmann in a more detailed way.

8. Drinking-water purification: filtration

The testing results of the drinking water sources have shown that unimproved drinking-water sources essentially seem to need water purification or treatment at all times prior to use, especially in regards to acceptability aspects. Improved drinking-water sources should also be temporarily purified, if necessary, because suitable microbial water quality may not be permanently guaranteed. Besides the application of chlorine, ultra- and microfiltration seems to be another possible purification technique for these purposes.

Ultra- and micro- filtration systems have already proven themselves in numerous humanitarian missions. Mobile filtration systems are, among other things, widely used by humanitarian or other organizations such as the German Federal Agency for Technical Relief (THW) (see Fig. 44) or the Foundation Veolia (see Fig. 45) in situations where drinking water supply has broken down because of natural- or man-made disasters, war or epidemics. Ultra/microfiltration has also proven effective in drinking-water purification for every day use in developing and industrialized countries.

Fig. 44: Mobile water treatment plant (THW, 2016)

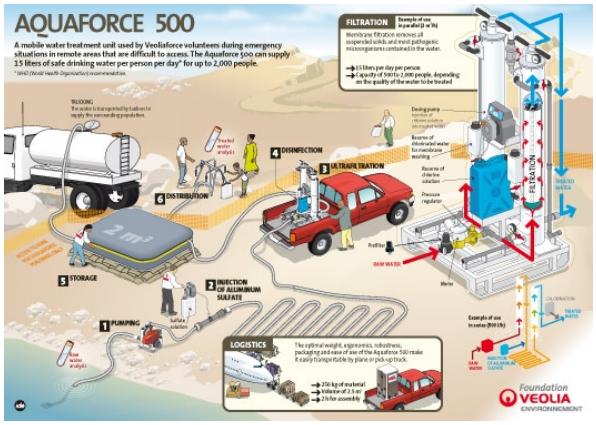


Fig. 45: Mobile ultrafiltration unit, Aquaforce 500 (Foundation Veolia, 2016 a)

Nevertheless these larger filtration systems have disadvantages, as there are deficiencies in mobility and independency. For the most part, at a minimum, they need power supplies from

a mobile power unit and technical ability relating to transport (pickup, trucks or others). In most cases, the systems also need staff from industrialized countries, at least supporting the potential users at the beginning of any mission by sharing know-how that is related to construction, maintenance and operation. Despite the fact that these systems are able to supply numerous people with clean and safe drinking water especially where high numbers of potential users are locally concentrated (for example in cities, urban centers or refugee camps), one specific disadvantage is that these systems do not seem to be the best solution to cover large and sparsely populated areas or areas with large distances between potential users.

Smaller mobile pressure-less ultra/microfiltration systems not requiring a power supply seem to better fit these purposes, especially for temporary drinking water purification in remote or in isolated areas where the infrastructure that is needed to support larger filter systems is not available or where population densities are sparse. Smaller systems seem to be more independent from circumstances that could impede the development of larger, centralized water treatment systems, and they do not necessarily need staff to built, maintain or operate. They have also partly proven that they are able to assure drinking-water supply for high numbers of people.

One interesting example for this is the “LIFESAVER®cube™” (see Fig. 46), that was, amongst other things other things, airdropped in large numbers by the British Royal Airforce into an area in northern Iraq, providing safe drinking-water for about 75,000 war-induced dislocated people (LIVESAVER, 2016). But also long-term usage to suit drinking water needs, for example in developing countries, could be imagined under special circumstances.

Fig. 46: LIFESAVER cube, mobile ultrafiltration system (LIFESAVER, 2016)

To gain a general overview of the specific capabilities, benefits, disadvantages, challenges and potential use of small, mobile pressure-less filter systems, the Foundation Veolia Aquaforce 5 was extensively tested, both on-site in Uganda (as an example of a developing country with temporary or permanent deficiencies in drinking-water quality) and in the laboratory in Germany.

8.1 Foundation Veolia Aquaforce 5

The following technical details and advices for the use and maintenance of Foundation Veolia Aquaforce 5 filtration kits are taken from the included instructions and the inscriptions of the filtration cartridge.

8.1.1 Manufacturer´s instructions (technical details)

Fig. 47: Foundation Veolia Aquaforce 5, description

Fig. 48: Foundation Veolia Aquaforce 5, content

The Foundation Veolia Aquaforce 5 Microfiltration kit contains following components (see Fig. 48):

- Filtration cartridge
- 0.5 m transparent tube for raw water
- 0.5 m green tube for drinking water
- Cleaning plunger

As stated in the manufacturer´s instructions, the filtration kit is effective against (see Fig. 47):

Bacteria and viruses:

- Cholera
- Botulism
- Typhoid
- Amoebic Dysentery
- E. Coli
- Coliform Bacteria
- Streptococcus
- Salmonella

Protozoan microorganisms:

- Giardia
- Cryptosporidium
- Cytospora

Salt or chemicals are not removed by the filtration.

The inscription on the cartridge also says:

Microfiltration:	0.1 µm (= 0.0001 mm)
Max. Temperature:	60 °C

Also some general specifications for the filtration cartridge are:

Weight:	≈ 150 g
Width:	5 cm in diameter
Lenght:	15 cm
Cartridge endurance:	filtration of up to 10 m^3 of raw-water (estimated), probably dependent on the quality of the filtered water
Filtration technology:	hollow fiber membrane (by polymem company) with 3,500 cm^2 effective membrane area
Price:	estimated 50 US-$

The working principle of a hollow fiber membrane is purely physical: hollow fiber membranes are porous plastic tubes with pores of specific size (see Fig. 49). The raw water is carried by capillary forces, gravity and water pressure through a cartridge containing numerous fibers, with pores holding back suspended matter, microorganisms and viruses larger in size (see Fig. 50). This principle functions for several pore sizes, depending on the required cleaning success and the intentional use of the filtered water: Nanofiltration has pore sizes < 0.005 µm, Ultrafiltration has pore sizes of 0.005 to 0.1 µm, Microfiltration has pore pore sizes of 0.1 to 1 µm (POLYMEM, 2016).

Fig. 49: Foundation Veolia Aquaforce 5, hollow fiber membrane, barely used, interior (input)

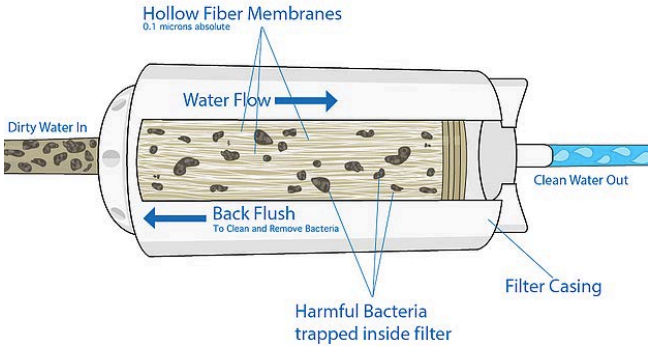


Fig. 50: Hollow fieber membrane, working principle (Life Through Water, 2016)

But the smaller the pores are, the longer the raw water needs to pass the filtration naturally. Conversely, this means that in order to reach an acceptable discharge while filtering, higher

water pressures are needed to push the raw water through the pores faster. In this case, the Aquaforce 5 is designed with pore sizes of 0.1 µm, to gain a reliable cleaning-success while still working self-sufficiently with low water-pressures and without power supply. With these attributes, it is meant to ensure drinking water supplies for a small number of individual people or families in emergency situations (e.g. after natural disasters, political crises, war, or other situations leading to breakdowns in drinking water supply).

8.1.2 Manufacturer´s instructions (instructional use)

The manufacturer´s instructions do not really influence the filtration process in any way, because the general usage itself is quite self-explanatory. This is probably due to the approach that usage of the filtration kit should be as easy, rugged and low in maintenance as possible. The system itself is ready to filtrate immediately after connection of the tubes for input and output. If the outflow from the filtration cartridge breaks down (or decreases drastically over a short period of time), or sediments, bacteria or other particles have clogged the pores in the fiber and the cartridge needs to be cleaned by a manual backwashing. The backwashing process is executed using a syringe, pressing clean water in the reverse direction of the indicated filtration direction (see Fig. 51). This process should ensure the washing out of the majority of pore-clogging particles, sediments, bacteria and other things.

The life span of the disposable cartridge is at its end when the outflow cannot be restored, even after backwashing. In general, if the outflow of the system breaks down and cannot be restored by backwashing, the cleaning success of the filtration is no longer assured and the filtration cartridge should be disposed of. Overall, the cartridge should be able to filtrate up to 10 m^3 of raw-water in its life span (Foundation Veolia, 2016 b).

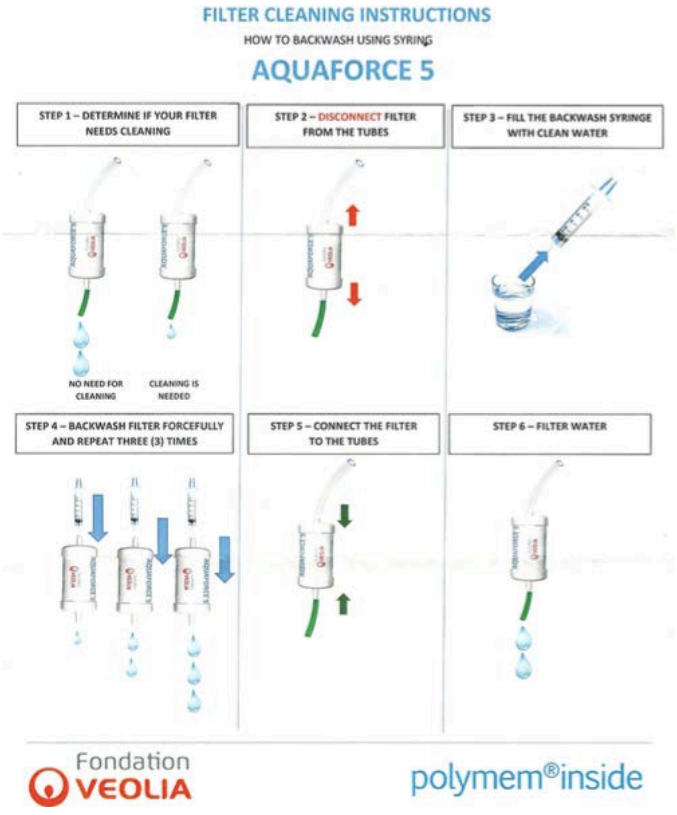


Fig. 51: Foundation Veolia Aquaforce 5, filter cleaning instructions

8.2 On-site testing in Uganda

The Aquaforce 5 was tested on-site at the raw-water sources of Namukomago and Mbiliddembiraba. These villages/drinking water sources were chosen because of the high degree of contamination in the sources: primarily in terms of microbiology, but also because of high turbidity. With these attributes, the water sources in the villages seemed to be suitable for extensive testing of the chemical-physical and microbial cleaning efficiency of the filter in conjunction with potential problems caused by the presence of high turbidity and other particles in the raw-water. Another point for choosing the villages is that these surface water sources (ponds) are quite typical for many other drinking water sources in the area. Many communities, especially in rural, poor areas use similar drinking water sources with approximately similar chemical, physical and microbial qualities.

The raw-water samples were taken from permanently used drinking water sources with clean, collapsible water containers of 20 l in volume. Afterwards 10 l of the raw-water were filtered by the Aquaforce 5 into a 10 l clean jerry can. The samples of the filtered, potentially safe drinking water were taken directly from the 10 l jerry cans after the filtration process was completed. This procedure was meant to imitate a potential everyday use of the filtration units by the villagers. The discharge rate of the filtration units was determined by measuring of the amount of time needed to fill one of these 10 l jerry cans (see Fig. 52).

Fig. 52: Filtration of raw-water in Namukomago, with detail (right)

Because the water pressure probably affects the discharge rates of the system in positive ways, attention was given to locating the apparatus in such a way that the input of the cartridge and parts of the input tube were, if possible, constantly filled. This was achieved by hanging up the raw-water containers in a tree.

8.3 On-site testing results

The results of phyisical, chemical and microbial testing can be seen in Tab. 6.

Tab. 6: Physical, chemical and microbial testing of the filtration units, on-site

Date	Sample	Turbidity	electrical conductivity (EC)		pH-Value	colony forming units [cfu]		filtration duration	discharge rate	Marks
		[NTU]	EC [µS/cm]	Temp [°C]	[-]	3M Petrifilms (total aerobic plate counts) [cfu/ml]	Membranefilter (total coliforms) [cfu/100ml]	[min/10 l]	[l/min]	
20.06.16	Mbiliddembiraba (raw)	46.9	43.5	23.6	5.9	-	tntc	65	0.15	
20.06.16	Mbiliddembiraba (microfiltration)	< 0.1	45.2	23.7	6.1	-	no visible coliforms			
20.06.16	Namukomago (raw)	30.8	51.4	23.7	6.3	-	no visible coliforms	45	0.22	
20.06.16	Namukomago (microfiltration)	0.1	45.5	23.6	6.1	-	5			
21.06.16	Mbiliddembiraba (raw)	40.4	44.4	23.6	5.8	tntc	tntc	75	0.13	Water sample contained a large amount of plant matter/algae that also flowed into the filter. Subsequent cleaning the next day removed the plant matter
21.06.16	Mbiliddembiraba (microfiltration)	< 0.1	44.5	23.7	6.1	169; 91	2			
21.06.16	Namukomago (raw)	41.3	39.0	23.8	6.2	tntc	tntc	60	0.17	
21.06.16	Namukomago (microfiltration)	< 0.1	72.8	23.7	6.3	5	0			
22.06.16	Mbiliddembiraba (raw)	41.4	35.2	23.7	6.3	-	tntc	30	0.33	after backflushing of the unit
22.06.16	Mbiliddembiraba (microfiltration)	< 0.1	190.1	23.7	4.0	-	0; no visible coliforms			
22.06.16	Namukomago (raw)	39.1	37.9	23.7	6.1	-	tntc	26	0.39	after backflushing of the unit
22.06.16	Namukomago (microfiltration)	0.12	54.7	23.7	5.1	-	no visible coliforms			
23.06.16	Mbiliddembiraba (raw)	31.4	43.4	24.0	6.2	-	tntc	120	0.08	3/4 of the Jerrycan in about 100 min -> cartridge was backwashed, ultimately finishing the jerrycan after 120 min
23.06.16	Mbiliddembiraba (microfiltration)	3.58	54.8	24.0	6.0	-	no visible coliforms			
23.06.16	Namukomago (raw)	41.7	38.0	23.8	6.3	tntc	tntc	55	0.18	
23.06.16	Namukomago (microfiltration)	0.45	41.1	24.4	6.2	0; 3	no visible coliforms			
WHO guideline value (WHO, 2011)		**< 5 NTU**	**no value**		**6.5 to 8.5**	**no value**	**0 cfu/100ml**			
TrinwV 2001 guideline value (BMJV, 2016)		**< 1 NTU**	**2500 µS/cm (20°C) 2750 µS/cm (25°C)**		**6.5 to 9.5**	**20 cfu/ml**	**0 cfu/100ml**			

tntc = to numerous to count
no visible coliforms = bacteria is detectable, but there is no coliform bacteria

8.3.1 Discharge rates

The duration of time that was needed to fill the jerry can increased with higher turbidities and especially with the presence of other particles in the water (algae, plant matter or insects). Also, the more raw water was filtered, the longer it took to finish the filtration process. These two points were especially evident in the filtration duration of Mbiliddembiraba. Filtering the defined testing volume of 10 l during the first testing day (20.06.2016) took about 65 min. On the second testing day, the filtration took about 10 min more for the same, non-backwashed filtration cartridge (75 min at the 21.06.2016). Because the discharge rate was decreasing rapidly in the final minutes of the filtration on 21.06.2016, the cartridge was backwashed. The backwashing removed surprisingly large amounts of plant matter and algae from the interior of the cartridge. The results of the third testing day (22.06.2016) revealed that the backwashing was effective: the filtration duration decreased significantly to about 30 min, although the amounts of plant matter and algae in the raw-water were about the same as the days before. The forth testing day (23.06.2016) again showed a massive increase of the filtration duration: on this day, the amounts of plant matter and algae seemed to be

noticeably high, causing the filtration process to stop after about 100 min requiring another backwash (with about ¾ of the 10 l jerrycan filled). After the backwashing process, the discharge rates increased and the last ¼ of the volume was finally filtered in about 20 min. The observed filtration durations in Namukomago were similar, which confirms the effects and assumptions mentioned above.

Discharge rates fluctuated strongly (from more than 0.39 l/min down to 0.08 l/min or less), which seems to be mainly dependant on the amounts of larger particles of plant matter, algae, insects, and other floating or suspended matter in the raw-water. High turbidities in the raw-water did not seem to be the critical factor influencing the filtration duration and the discharge rates. Comparing this observation to the working principle of hollow fiber membranes, this seems to be plausible: larger particles are able to cover parts of the surface of the filter area, impeding parts of the incoming raw-water from entering the actual effective filtration fibers. This effect should not be as strong with higher turbidities, which is generally caused by very much smaller particles.

8.3.2 Physical-Chemical parameters

All in all, the testing results of the physical-chemical parameters appear to be plausible (see Tab. 6). After filtration, the turbidities decreased considerably, from relatively high values in the raw water (30.8 to 46.9 NTU) to very low values of about 0.1 NTU and less.

PH values and electrical conductivites (EC) (for the most part) were not really affected by the filtration. This also seems plausible: pH-values are affected by the concentrations of H^+ and OH^- ions respectively, which should not be directly held back or affected by pores of about 0.1 µm in general. EC does not significantly change because the value is mainly influenced by the sum of diluted salts in the water, which should not be removed by the filtration process either (as it is mentioned in the manufacturer´s instructions).

The filtered sample of Mbiliddembiraba (23.06.2016) does not seem to fit into the overall pattern of results. The pH changes from 6.3 in the raw-water to 4.0 after filtration. This value seems to be extraordinary low (meaning acidic) for drinking water as well as for water from natural sources. While testing this water sample, the results for pH and EC seemed to be unrealistic. Because of this, the testing was repeated with a second pH meter and a second conductivity meter, both identical in construction, without a significant difference in results. The reason for this anomaly in pH and EC cannot be reasonably researched in this thesis. For this reason, the sample should not be used to assess the cleaning success of the filtration units.

For the sake of completeness, the filtration process was also tested for its effect on dissolved ammonia, manganese, nitrite, phosphate, aluminum, cyanuric acid, iron and flouride (see Tab. 7). These tests did not reveal any information of special interest for this thesis: the filters decreased especially the amounts of dissolved metals and minerals (manganese, aluminum and iron), but also purely chemical parameters such as nitrite (NO2), phosphate and acid cyanuric were removed to different extents.

Tab. 7: Effects of microfiltration (Aquaforce 5) in regards to dissolved chemicals, metals and minerals

		Ammonia		Manganese	Nitrite (Nitricol)		Phospate LR		Aluminium	Acide Cyanuric
		N (mg/l)	NH4(mg/l)	Mn (mg/l)	N (mg/l)	NO2(mg/l)	PO4 (mg/l)	P (mg/l)	Al (mg/l)	Acide Cyanuric (mg/l)
No	Village Name	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample
1	Namukomago 21/06/16 raw	0.09	0.12	0.004	0.027	0.09	1.6	0.52	0.08	5
2	Namukomago 21/06/16 ultrafiltration	0.05	0.07	<<	0.005	0.02	0.13	0.04	0.03	1
3	Mbiliddembiraba 21/06/16 raw	0.05	0.06	0.005	0.03	0.1	0.42	0.12	0.2	6
4	Mbiliddembiraba 21/06/16 ultrafiltration	0.08	0.11	<<	0.005	0.02	0.15	0.05	0.02	3

8.3.3 Microbial parameters

The microbial testing of the filtration process showed that the filter has a good, reliable removal success in terms of coliform bacteria. The number of colony-forming units decreased from high levels, which were mostly too numerous to count, to significantly lower amounts of coliform bacteria. Two of the filtered samples (Namukomago, 21.06.2016 and Mbiliddembiraba, 22.06.2016) did not contain any detectable bacteria (see Fig. 53 and Fig. 54).

Fig. 53: Plate counts (total coliforms) of Namukomago (21/06/2016), raw-water (left), filtrated water right)

Fig. 54: Plate counts (total coliforms) of Mbiliddembiraba (22/06/2016), raw-water (left), filtrated water (right)

One of the most interesting points is that, besides the fact that nearly all coliform bacteria was gone after the filtration, in many cases an amount of other bacteria was still present (see Fig. 55 and Fig. 56). Regarding to the instructions of the Wagtech Company, these bacteria cannot be specificly named, but should not be any type of coliform bacteria. Mostly these colonies were appearing red, clear or pinkish (in the most cases < 10 colonies of unknown origin / 100 ml) and could barely be seen by eye. The filtration, overall, seemed to decrease the amount of bacteria in a significant way, even if there still were smaller amounts of other bacteria left in the filtrated water.

Fig. 55: Plate counts (total coliforms) of Namukomago (22/06/2016), raw-water (left), filtered water (right)

Fig. 56: Plate counts (total coliforms) of Mbiliddembiraba (23/06/2016), raw-water (left), filtered water (right)

The results of Namukomago (06/20/2016) appeared unlikely. In the raw water, the plate counts were detected as “no visible coliforms“. The logical assumption is that there are bacteria, but these bacteria are not coliforms bacteria, similar to some of the filtered samples. Other raw-water testing results and the results of the filtered water (containing 5 cfu of coliforms) returned a positive value for coliform bacteria within the raw-water sample. The raw-water plate, as below, showed a large number of red and clear colonies, which may have completely covered the coliform bacteria contained in this sample (see Fig. 57).

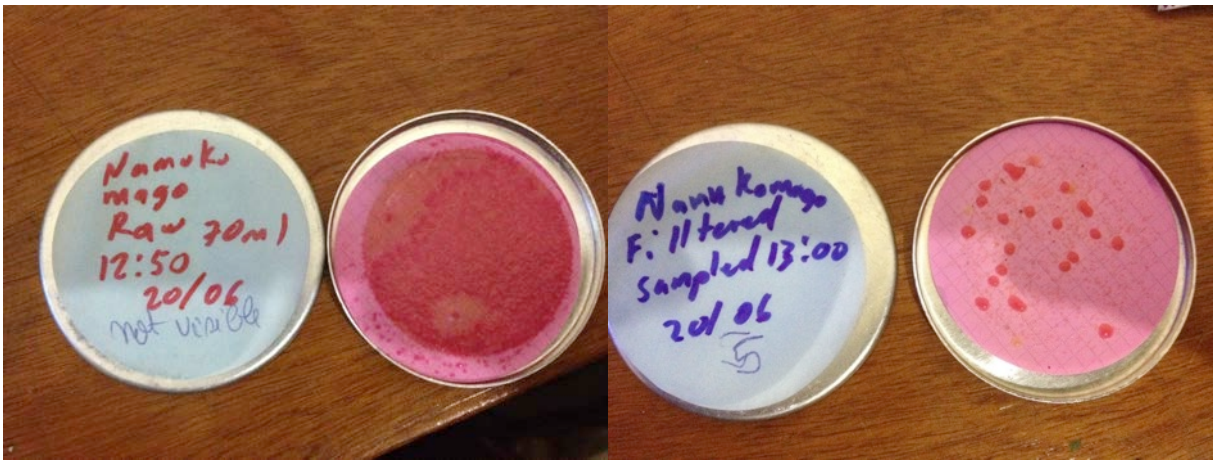


Fig. 57: Plate counts (total coliforms) of Namukomago (20/06/2016), raw-water (right), filtered water (left)

The coloration of the membrane filters after incubation is another interesting point. While some of the filtered samples (irrespective of whether there are 0 bacteria or no visible coliforms) became pinkish, and some became yellowish: good examples are Fig. 55 and Fig. 56. Neither membrane filters contained coliform bacteria, but one of the membrane filters appeared pinkish and the other yellow after incubation. This is quite puzzling because coliform bacteria are meant to grow in yellow colonies: so if the membrane develops a yellow color, this should be an indication that there may be some coliform bacteria in the filtered water.

According to the technical support of the Palintest Company, the coloration of the broth is designed to form yellowish colors under acidic conditions. With this design it is possible to detect coliform bacteria on the membrane filter, because coliform bacteria produce lactic acid while growing on the nutrient. So a yellowish colors for the whole membrane filter could be indicative of massive contamination with coliform bacteria if there are colonies (which has already been documented in the membrane filters of the tested raw-water samples in 6.2.2 Microbial quality). If there are no visible colonies on the membrane filter and the membrane filter is nevertheless yellow, this can most likely be explained by the relatively low pH values of the sampled water itself. The yellow color in this case is probably initiated by the low pH of the water samples and explicitly not because of the presence of coliform bacteria. This means that the overall testing results appear to be valid, despite the different colors of the membranes.

8.4 Laboratory testing

To verify the results of the on-site testing in Uganda and to gain a better knowledge of the cleaning efficiency of the filters, turbidity, pH, EC and microbial quality (total coliforms, E.coli, HTC) were tested again in laboratory conditions in Germany. For this reason, 5 German raw-waters were tested related to these values, before and after filtration with the Aquaforce 5.

The researched raw-waters included: water from a rainbarrel, water of a rainwater-fed garden pond, well water, sewage plant effluents and river water. Acceptability parameters, including appearance, odor and taste were tested for the filtered samples. All of the following

chemical and microbial tests were done in the food technology laboratory at the University of Applied Sciences in Trier.

Some people in Uganda and in other developing countries collect rainwater in rainbarrels to cover (beside irrigational usage) at least part of their domestic, mostly non-consumed drinking water needs. In this context, one of the laboratory-tested raw waters is **rainwater**. The rainwater researched in this thesis was collected from a roof made of corrugated iron and is drained by copper pipes into a plastic storage tank with a volume of about 2000 liters. The roof was fairly free of rust, bird droppings, plant matter or other pollution. The water in the tank is not altered by any filtration or cleaning devices.

To research water which has relatively high turbidities and amounts of algae/organic matter, relatively similar to water from surface water sources (ponds) in Uganda, water-samples from a garden pond were used. The raw water in this **pond** consists primarily of **rainwater** but has quite high turbidities, primarily resulting from algae. It is also inhabited by fish (carp and goldfish) and water plants (water lillys, water reed). There are no cleaning or filtration devices, which might affect the water quality.

Another water-source that is often used in developing countries is well water, either recharged from groundwater or directly from surface water sources (rivers, streams or lakes). The german **well water** tested in the laboratory was taken from a public well in Merschbach (Hunsrück). This well receives its water from a surface fresh water spring nearby.

Often consumers in developing countries directly use surface water from rivers or streams. Because of this, **river water** from the Moselle was researched. The Moselle, ending in the Rhine, is the sixth longest river in Germany, with about 544 kilometers in length, and is heavily used for shipping-traffic. The raw-water was sampled in Trier next to the Kaiser-Wilhelm bridge.

Municipal wastewater in industrialized countries, such as Germany, is often seen to have similar qualities to raw-waters in developing countries (DANY, 2011). Working with raw municipal wastewater would have an increased infection risk, therefore **sewage plant effluents** were researched within this thesis. Sewage plant effluents should still contain specific amounts of bacteria in conjunction with relatively low turbidities. The water-samples were taken from the municipal sewage plant in Gräfendhron (Hunsrück).

The filtration process in the laboratory was executed in similar ways to the on-site process used in Uganda (see Fig. 58). The water was taken from the raw-water sources with 20 l foldable water containers; 10 l of these raw-water were filtered into a separate jerry can. For all these filtration processes, the same filter cartridge was used and backwashed if needed. The final samples of the filtered water were taken from the 10 l cans after they were completely filled. Again, with this procedure, the potential use of the filtration system in developing countries can be imitated as closely as possible.

Fig. 58: Filtration of raw-water samples in the laboratory, with detail (right)

8.5 Laboratory testing results

Tab. 8: Phyisical-Chemical parameters and discharge rates, laboratory testing

Date	Sample	Turbidity	pH	EC		Filtration duration	discharge rate	Marks
		[NTU]	[-]	[µS/cm]	T [°C]	[min/10 l]	[l/min]	
18.07.16	Rainwater (barrel) raw	0.7	5.7	21.9	22.8	52.0	0.19	-
18.07.16	Rainwater (barrel) filtr.	0.4	5.8	32.2	22.8			
18.07.16	Rainwater (pond) raw	66.2	9.2	40.7	22.8	> 120	-	filter backwashed after 40 min and 90 min because discharge was low; no significant betterment after backwashing -> filtration was stopped after 120 min with about 2/3 of the 10 l can filled
18.07.16	Rainwater (pond) filtr.	0.3	7.9	110.8	23.4			
18.07.16	Sewage plant effluents raw	13.4	7.3	405.0	22.6	115.0	0.09	-
18.07.16	Sewage plant effluents filtr.	0.2	7.5	406.0	24.8			
18.07.16	Well-water raw	0.2	8.5	221.0	22.8	50.0	0.20	-
18.07.16	Well-water filtr.	0.2	8.5	220.0	22.6			
19.07.16	River water (Moselle) raw	2.0	8.0	1009.0	24.8	105.0	0.10	-
19.07.16	River water (Moselle) filtr.	< 0.1	8.1	1004.0	24.7			

8.5.1 Discharge rate

The filtration durations and the discharge rates of the laboratory testing showed similar results to the measurements completed on-site in Uganda. In particular raw waters with relatively low turbidities and with extraordinarily low amounts of dissolved particles and floating materials had the shortest filtration duration and therefore the largest discharge rate. The raw water from the rain barrel and the well water contained significantly lower amounts of dissolved particles and floating materials (such as algae, plant matter and bugs) than the

other raw waters: because of this, the filtration durations were both quite short (about 50 min).

Turbidity itself did not seem to be critical for filtration durations and discharge rates, again: the filtration duration of the river water (Moselle) for example, took nearly the same amount of time as the sewage plant effluents, even if the turbidities of the river water (2.0 NTU) were significantly lower than those of the sewage plant effluents (13.4 NTU). In contrast, both raw-water samples appeared to contain relatively similar amounts of bigger dissolved particles and floating materials: the sewage plant effluent contained some visible particles of unknown composition and consistence (probably organic matter remaining from the wastewater cleaning process). The river water (Moselle) contained amounts of plant matter (leaf debris, algae and small sticks).

One exception to this assumption appears to be the rainwater, which was taken from the pond. Even after multiple times of manual backwashing the filter, the discharge was very low and finally broke down almost completely after about 120 min. Because of this, the filtration process was stopped after about 120 min with about 2/3 of the 10 l jerrycan filled. These low discharge rates hereby did not seem to result exclusively from the high degree of turbidity (66.2 NTU), rather, these durations seemed to result from the very high amounts of other materials in the raw water sample. This raw water was distinguished from the other raw-water samples by having a much higher amount of plant matter, algae and bugs (see Fig. 59).

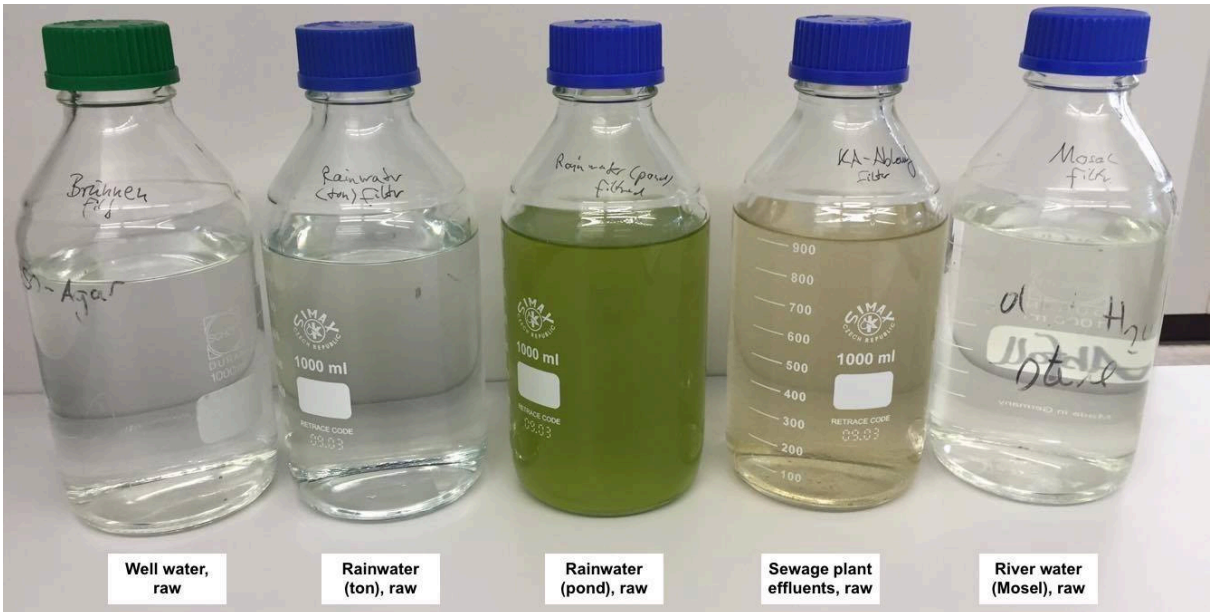


Fig. 59: Raw-water samples in comparison, edited

These results seem to confirm the assumption that turbidity indeed can specifically affect the discharge rates of the filters, but the critical aspect is not the turbidity alone. The discharge rate seems to be mostly influenced by the presence of larger-sized natural and anthropogenic particles in the water, such as algae, plant matter (leaf debris, sticks), bugs, flies, waste residues and other things. Materials and particles like these probably affect the discharge much faster than high turbidities could ever do all alone, because turbidities in raw waters are mostly and predominantly caused by much smaller particles. But, turbidity as an important indicator of water pollution in general often correlates with higher amounts of these

materials/particles. With this, the assumption that higher turbidities can negatively affect the filtration duration seems to be at least partly confirmed. This seems to directly correlate with the impressions gained on-site in Uganda. Both the mean discharge rates of the on-site (0.21 l/min) and the laboratory tests (0.15 l/min) did not match up with the discharge rate given by the manufaturer (about 0.41 l/min).

8.5.2 Physical-Chemical parameters

Turbidity decreased significantly in all of the filtered samples. The turbidities decreased from relatively high amounts of up to 66.2 NTU (rainwater pond) to values of about 0.4 NTU and some values < 0.1 NTU. With these values, all of the filtered samples meet the WHO drinking-water guidelines, which recommend turbidities of 1 NTU or less for suitable drinking water.

PH and EC were not affected by the filtration for the most part. The only exception from this was, once again, the rainwater sample taken from the pond. The pH decreased from 9.2 to 7.9. The relatively high (alkali) pH in the raw-water sample could result from massive amounts of algae contained in the raw-water. PH values of freshwater bodies are among other things influenced by chemical interactions related to carbon dioxide and oxygen (TUCKER & D´ABRAMO, 2008): algae and other underwater plants tend to increase the pH of water bodies during daytime as they remove carbon dioxide from the water (as a part of the sunlight-driven photosynthesis). After filtration, the algae were removed and the water was probably able to slowly convert to relatively neutral ratios of oxygen and carbon dioxide and therefore to relatively neutral pH values.

The results of the ion chromatography are presented in Tab. 9: these include the levels of the researched parameters (sodium, potassium, calcium and magnesium) for each water-sample (raw, filtered) and the percentage change of these parameters after filtration. The data-sheets of the ion chromatography can be found in the annexes.

Tab. 9: Ion chromatography (sodium, potassium, calcium and magnesium), results

Sample	Sodium		Potassium		Calcium		Magnesium		Marks
	amount [mg/l]	change in [%]	amount [mg/l]	change in [%]	amount [mg/l]	change in [%]	amount [mg/l]	change in [%]	
Rainwater (barrel) raw	0.222	3	0.942	4	3.620	27	0.294	40	-
Rainwater (barrel) filtr.	0.229		0.981		4.585		0.411		
Rainwater (pond) raw	2.093	8	-	-	11.416	23	0.414	42	no amounts of potassium detectable
Rainwater (pond) filtr.	2.260		-		14.094		0.588		
Sewage plant effluents raw	20.947	0	8.787	0	35.245	3	14.837	0	-
Sewage plant effluents filtr.	20.952		8.806		36.421		14.893		
Well-water raw	12.843	2	1.379	6	31.429	6	8.932	5	-
Well-water filtr.	13.095		1.462		33.195		9.338		
River water (Moselle) raw	61.676	0	5.865	2	121.580	1	23.813	-1	-
River water (Moselle) filtr.	61.843		5.960		122.732		23.581		

The ion chromatography did not show any significant changes in the researched parameters of sodium, potassium, calcium and magnesium before and after filtration. For the most part, the percentage change is too low to conclusively indicate that these specific changes directly result from the filtration process.

The only parameters that either partly or significantly changed after filtration were the amounts of dissolved calcium and magnesium within both of the water samples of the rain barrel and the rainwater pond. The percentage increase of calcium was about 27 % after filtration of the rain barrel water (raw); simultaneously, the amounts of magnesium increased by about 40 %. In the rainwater pond, the percentage rise was similar: the percentage increase of calcium was about 23 %, while the magnesium increased by 43 %. This directly affects the hardness of the water in these cases; more precisely the filtration seems to slightly increase the hardness of the water.

8.5.3 Microbial parameters

Because the amounts of bacteria contained in most of the researched German raw- and wastewaters are probably high, the raw- and wastewater samples were individually diluted with sterile water before testing with the membrane filter method. The filtered water should not contain high amounts of bacteria. In best case, it should not contain any bacteria at all; therefore these water-samples were not diluted before testing.

In the following (Tab. 10), the microbial testing results are presented. Fig. 60 shows the overall percentage of the filter's removal efficiency. Some of the most striking membrane filter plate counts are presented with explanations.

Tab. 10: Microbial testing results, microfiltration, laboratory

Sample / Dilution	Membrane filter method			Marks
	COLICHROM [cfu/100ml]		CASO [cfu/100 ml]	
	E.Coli	total coliforms	HPC	
Rainwater (barrel) raw / 1:10	20	50	600	
Rainwater (barrel) filtr. / 1:1	0	0	19	
Rainwater (pond) raw 1:10	360	tntc	tntc	
Rainwater (pond) raw / 1:100	900	not countable	tntc	COLICHROM (Coliform) plate was blurred -> not countable
Rainwater (pond) raw / 1:1000	1000	2000	29000	
Rainwater (pond) filtr. / 1:1	0	0	58	
Sewage plant effluents raw / 1:10	1210	2700	tntc	
Sewage plant effluents raw / 1:100	1900	9500	10500	
Sewage plant effluents filtr. / 1:1	0	0	6	COLICHROM with pinkish-blue impurities
Well-water raw / 1:10	0	0	510	
Well-water filtr. / 1:1	0	0	75	
River water (Moselle) raw / 1:10	310	tntc	tntc	
River water (Moselle) raw / 1:100	400	4500	6400	
River water (Moselle) filtr. / 1:1	0	0	45	
WHO guideline value (WHO, 2011)	**0 cfu/100 ml**	**0 cfu/100 ml**	**2000 cfu/100 ml**	
TrinkwV 2001 guideline value (BMJV, 2016)	**0 cfu/100 ml**	**0 cfu/100 ml**	**2000 cfu/100 ml**	

tntc = too numerous to count

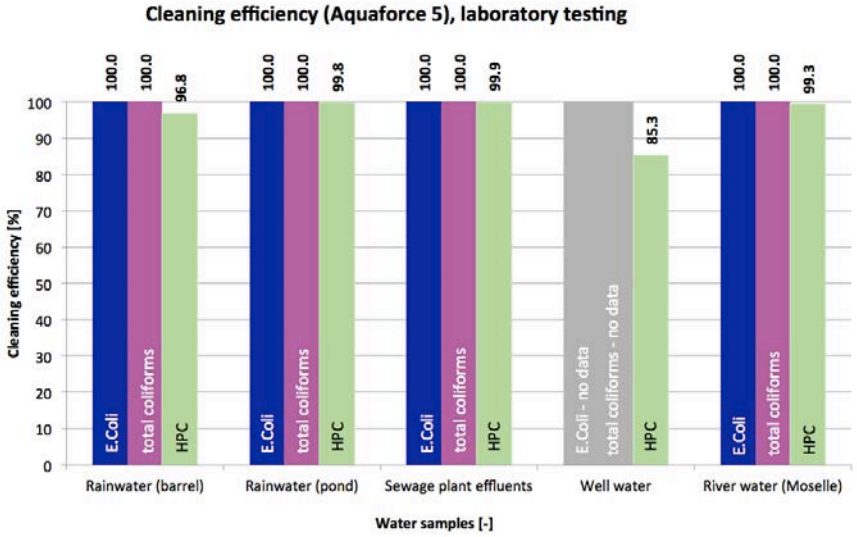


Fig. 60: Microbial cleaning efficiency (Aquaforce 5), laboratory testing

The results of the microbial testing show that the filters seem to have a good cleaning efficiency, particularly in terms of indicator bacteria: E.Coli and coliforms. The laboratory testing indicates that the filters seem to remove nearly all bacteria under laboratory conditions. This positive result is especially evident in the filtered samples of the raw and wastewater with the highest contamination levels appearing in these indicator organisms. With these results, the filtered samples met all requirements made by the WHO (2011) and the TrinkwV for E.Coli and total coliforms. The removal efficiency of the filter relating to indicator bacteria E.Coli and total coliforms in well water cannot be taken into consideration, because the raw water did not contain detectable amounts of these bacteria.

The raw water samples from the sewage plant effluent and river water (Moselle) both contained high amounts of E.Coli and coliforms. These amounts reached levels of up to 1900 cfu / 100 ml of E.Coli and up to 9500 cfu / 100 ml of coliform bacteria in the sewage plant effluent. River water (Moselle) contained less bacteria (400 cfu / 100 ml of E.Coli and 4500 cfu / 100 ml of coliforms). After filtration, the bacteria were completely removed in both cases (see Fig. 61 and Fig. 62).

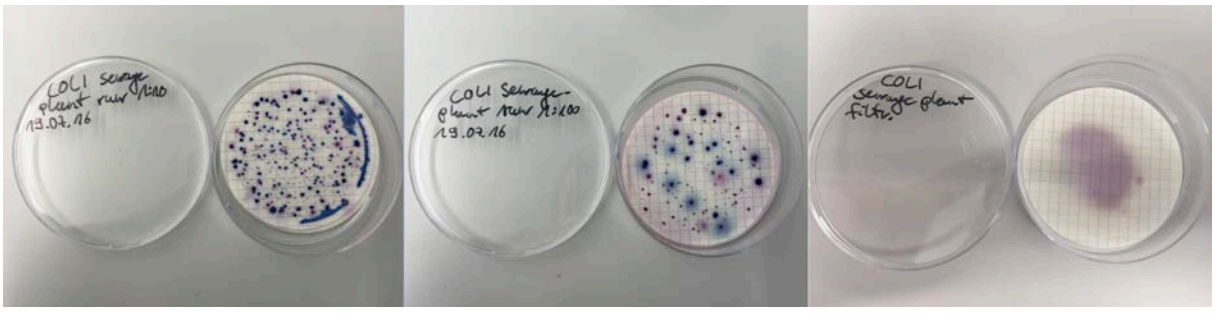


Fig. 61: Plate counts (E.coli and coliforms) of sewage plant effluents, laboratory testing

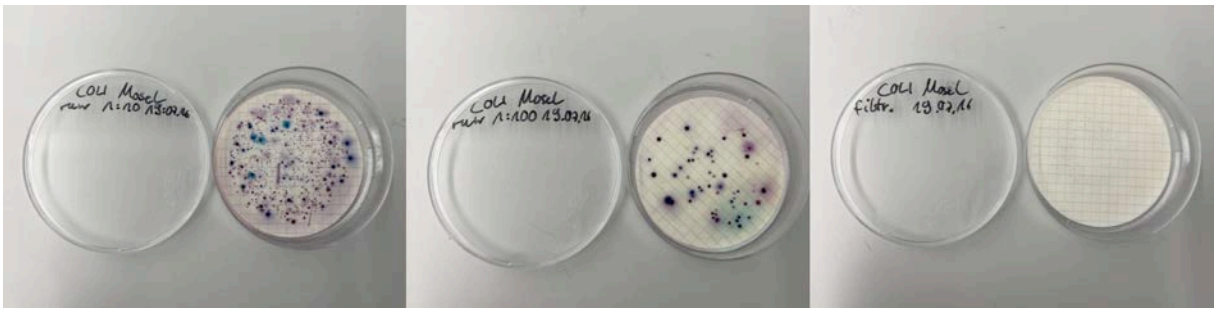


Fig. 62: Plate counts (E.Coli and coliforms) of river water (Moselle), laboratory testing

Regarding the HPC, specific amounts of bacteria were always left in the water samples after filtration. These amounts ranged from 6 cfu/100ml (sewage plant effluents) to 75 cfu/100 ml (well water). An interesting point is that differing amounts of bacteria appeared in all of the tested samples. However, the bacteria count in the filtered samples was, despite the relatively high raw-water contamination, extraordinary low in every case. The filter removed 85.3 to 99.9 % of bacteria.

In particular, the raw water samples with very high amounts of HPC decreased in bacteria count, namely the rainwater (pond) (29000 cfu/100 ml before filtration, 58 cfu/100 ml after filtration) and the sewage plant effluents (10500 cfu/100ml before filtration to 6 cfu/100 ml after filtration). This is equivalent to a removal of 99.8 and 99.9 % of the bacteria respectively. The other, considerably less contaminated samples of the river water (Moselle) and the rainwater (barrel) reached similar removal percentages (99.3 respectively 96.8 %). The only slight difference in percentages of the removal efficiency is the filtered well water: here the percentage of removed bacteria contained in the raw-water is slightly lower (85.3 %). Despite this, this water is, in principle, only contaminated to a very low extent (400 cfu), and already meets the requirements for German drinking water. After filtration, all of the filtered samples met the requirements of the German drinking-water regulations (HPC< 2000 cfu / 100 ml).

An interesting point is the composition of the bacteria that remained in the filtered water. According to Dr. Müller & Schmelz, the used CASO-NPS are able to differentiate between E.Coli, Pseudomonas aeruginosa, Staphylococcus aureus and Bacillus subtilis by differences in color and appearance of the colonies (see Tab. 11).

Tab. 11: CASO-NPS, microorganism appearance (Dr. Möller & Schmelz, 2015 b)

Microorganism	Test strain	Specification	Appearance
Escherichia coli	WDCM 00012	$P_R \geq 0,7$	Beige
Bacillus subtilis	WDCM 00003	$P_R \geq 0,7$	Light beige with fringed edge
Pseudomonas aeruginosa	WDCM 00024	$P_R \geq 0,7$	Beige to light greenish
Staphylococcus aureus	WDCM 00034	$P_R \geq 0,7$	Beige to light yellow

There was no detectable amount of E.Coli (beige colonies) in any of the filtered samples. This seems to be plausible, as this result directly corresponds to the results of the Colichrom-

NPS. The main part of the plate counts consisted of Pseudomonas aeruginosa (Beige to light greenish colonies) and Staphylococcus aureus (Beige to light yellow colonies), both considered to be directly relating to drinking water quality in several ways (WHO, 2011).

Bacillus subtilis (appearing as light beige with fringed edge colonies) was not considered within the counts of this thesis. Despite the fact that this organism (in several types) appears in many kinds of soils and water, it is not generally used to significantly assess drinking water quality: for the most part it does not have pathogenic effects on human health and does not affect other qualities of drinking water (taste, etc). In addition, it is known for being relatively resistant to disinfection processes and for re-growing quickly after disinfection (WHO, 2011). Therefore, it was not taken into consideration in the removal efficiency of the filters, although it did occur in quite high amounts in the filtered water samples of the rainwater (barrel), the well water and the rainwater (pond).

As a side note, two blackish organisms appeared in the filtered water of the rainwater (pond) and are probably some sort of mold.

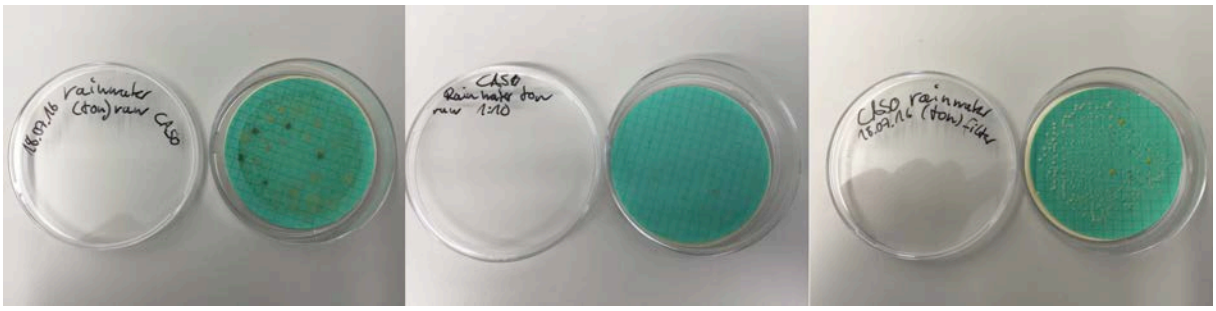


Fig. 63: Plate counts (HPC) of rainwater (barrel), laboratory testing

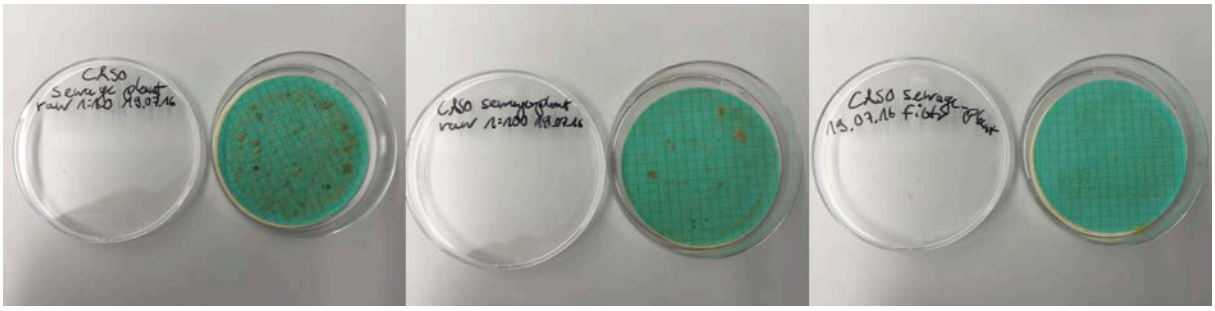


Fig. 64: Plate counts (HPC) of sewage plant effluent, laboratory testing

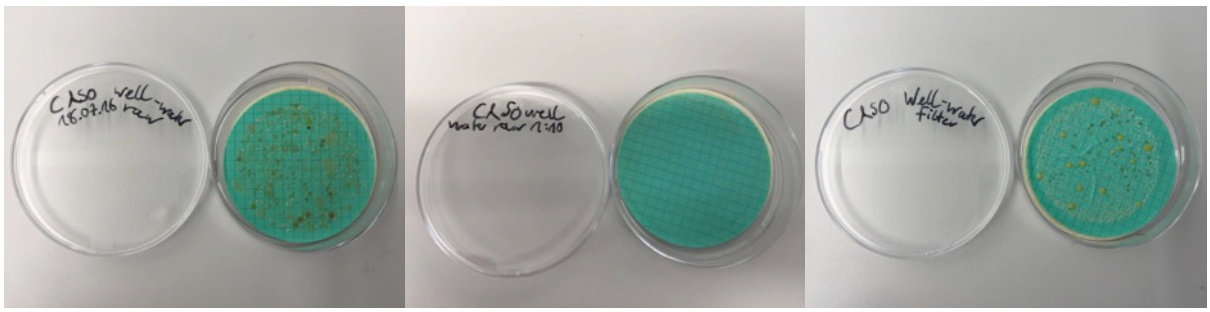


Fig. 65: Plate counts (HPC) of well water, laboratory testing

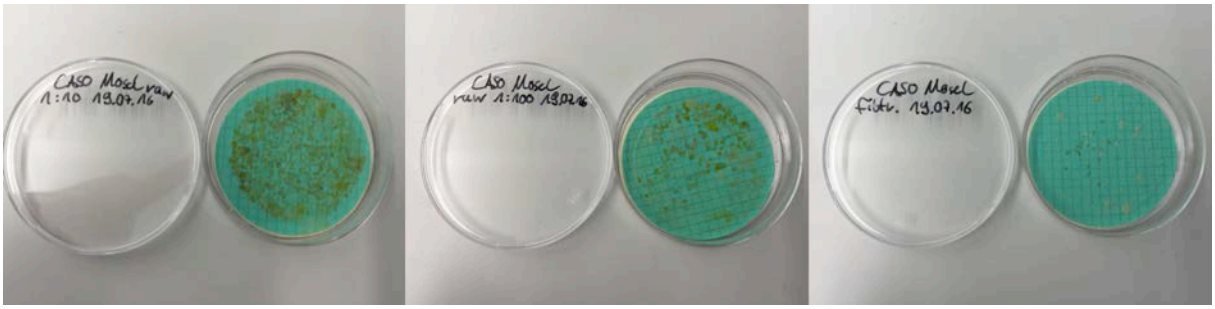


Fig. 66: Plate counts (HPC) of river water (Moselle), laboratory testing

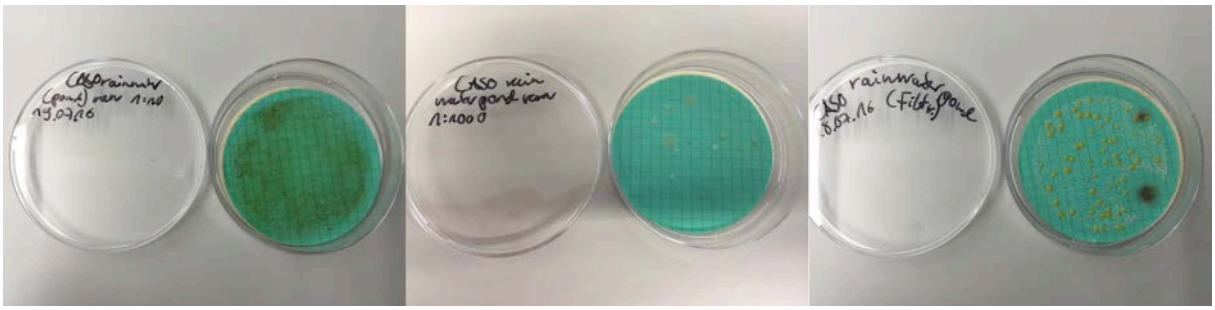


Fig. 67: Plate counts (HPC) of rainwater (pond), laboratory testing

Recapitulating the testing in Uganda, these results seem to correlate with the results gained on-site, even if the on-site testing and the laboratory testing are not directly comparable. This is due to differences in conditions: meaning that different equipment and testing procedures were used, that the German raw- and wastewaters are not directly comparable to the raw waters which were encountered in Uganda and the fact that the working conditions were generally different in each place.

But the comparison of the results can at least give an overall view about the removal efficiency of the filters: they work well for E.Coli and coliform bacteria. In laboratory conditions, the filter has removed 100 % of the indicator organisms E.coli and total coliforms. In the field, the filters decreased the total coliforms count from unspecifically high numbers that were tntc (probably hundredths or thousands of bacteria) to numbers of 0 or at a minimum < 10 cfu/100 ml. Other bacteria were able to overcome the filtration process in relatively small numbers, both on-site and in the laboratory. Under laboratory conditions, the filter removed a mean percentage of 96,2 % of drinking water-related, heterotrophic aerobic bacteria.

8.5.4 Acceptability parameters

Tab. 12: Acceptability parameters, before and after filtration

Date	Sample	Odor	Appearance	Taste	Marks
18.07.16	Rainwater (barrel) raw	3	2	0	slight organic odor
18.07.16	Rainwater (barrel) filtr.	1	1	1	-
18.07.16	Rainwater (pond) raw	6	6	0	strong green colouration; large amounts of plant matter/algae; strong organic odor
18.07.16	Rainwater (pond) filtr.	2	4	3	yellow-greenish coloruing; slight organic odor and taste
18.07.16	Sewage plant effluents raw	6	6	0	strong organic odour; large amounts of suspended matter
18.07.16	Sewage plant effluents filtr.	1	2	1	slight yellow colouring
18.07.16	Well-water raw	2	2	0	-
18.07.16	Well-water filtr.	1	1	1	-
19.07.16	River water (Moselle) raw	4	6	0	larger amounts of plant matter; organic odor
19.07.16	River water (Moselle) filtr.	1	2	1	-

All of the filtered samples showed significant improvements in odor: there was no sample, whose odor was in any case disturbing for a potential drinking water usage, i.e. there was no abnormal or disturbing odor. The only sample that showed a slight organic odor was the filtered water from the rainwater pond. In terms of appearance, (see Fig. 68 for a visual comparison of the filtered samples) the filtration produced significant improvements in every water sample, except for the filtered water sample of the rainwater pond. This raw water sample was characterized by a strong green coloration. But the improvement in coloration was significant. The filtered samples of the sewage plant effluent and the Moselle (river water) did have a slight yellowish coloration, but this coloration did not negatively affect the overall look: it still seemed to be comparable with German drinking water, not disturbing for long-term consumption. In particular the raw water from the sewage plant effluent and the Moselle (river water) contained amounts of suspended matter, which was completely gone after the filtration: there were no particles visible anymore in the filtered water.

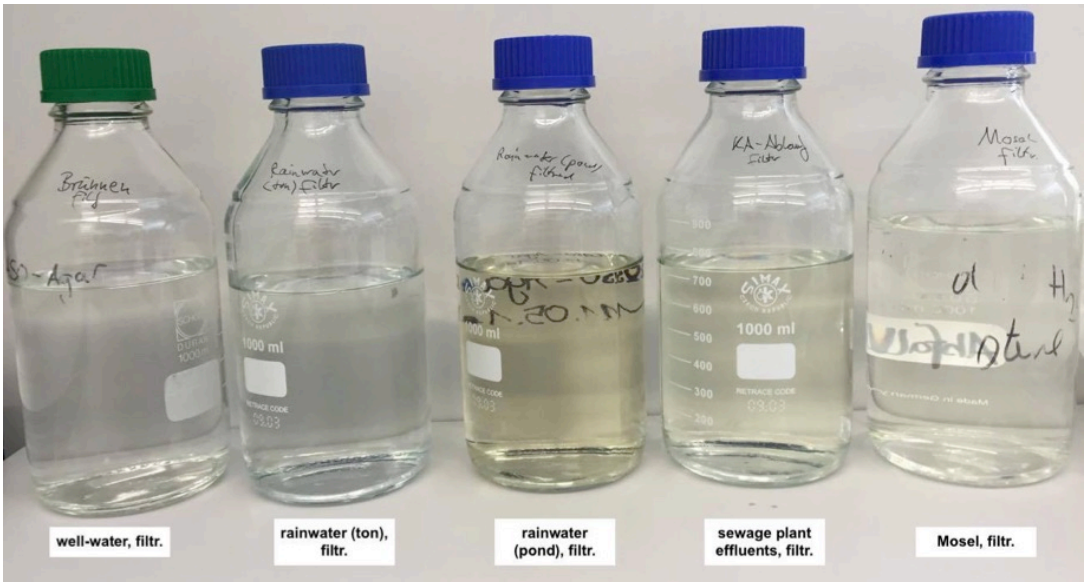


Fig. 68: Filtrated water-samples in comparison, overall appearence, edited

Regarding the taste of the filtered water-samples there was, in almost every case, no longer an obvious difference to German drinking water. The only exception to this was again the filtered sample of the rainwater pond: a slight organic taste was obvious, but this taste was still justifiable at least for potential short-term consumption of the filtered water.

To sum up, the acceptability of the filtered water seemed to be suitable for drinking water. In only one case (rainwater pond) did the filtered sample show slight deficiencies in odor, taste and appearance. This was probably due to the extraordinarily high degree of pollution in the raw water, which negatively influenced the acceptability aspects in the filtered water. But the improvements after filtration of the most unsuitable rainwater from the pond were immense, making a potential short-term usage imaginable.

8.6 Filtration with additional chlorination

The results of the on-site testing in Uganda have revealed that there are still amounts of unspecific bacteria left in the purely filtered water. One consideration in this context is to combine different water purification methods. In this case, some on-site tests in Uganda were completed relating to raw-water samples that were filtered as a first step and chlorinated to a specific amount in the second step. Because the number of tests done in this context was low, the results do not raise a claim to be scientifically approved. These tests were done with the approach to at least estimate potential benefits of this combined water treatment.

Tab. 13: Microbial parameters, microfiltration plus additional chlorination (≈1 mg/l)

Date	Village	Sample	colony forming units		Marks
			aerobic heterotrophic plate counts [cfu/ml]	Membrane filtration (total coliforms) [cfu/100 ml]	
20.06.16	Mbiliddembiraba	raw	-	tntc	
20.06.16	Mbiliddembiraba	microfiltration	-	no visible coliforms	
20.06.16	Mbiliddembiraba	microfiltration + chlorinated 1 mg/l 1/2 h	-	0	
20.06.16	Namukomago	Raw 70 ml	-	no visible coliforms	membrane filter method stopped after 70 ml; possibly high contamination with total coliforms
20.06.16	Namukomago	microfiltration	-	5	
20.06.16	Namukomago	microfiltration + chlorinated 1 mg/l 1/2 h	-	no visible coliforms	
21.06.16	Mbiliddembiraba	raw	tntc	tntc	
21.06.16	Mbiliddembiraba	microfiltration	169; 91	2	
21.06.16	Mbiliddembiraba	microfiltration + chlorinated 1 mg/l 1/2 h	1	-	
21.06.16	Mbiliddembiraba	microfiltration + chlorinated 1 mg/l 1 h	12	-	
23.06.16	Namukomago	raw	tntc	tntc	
23.06.16	Namukomago	microfiltration 2	0	no visible coliforms	
23.06.16	Namukomago	microafiltration 1	3	no visible coliforms	
23.06.16	Namukomago	microfiltration + chlorinated 1 mg/l 1/2 h	0	-	
23.06.16	Namukomago	microfiltration + chlorinated 1 mg/l 1 h	4	-	
WHO guideline value (WHO, 2011)			no value	0 cfu/100 ml	
TrinkwV 2001 guideline value (BMJV, 2016)			20 cfu/ml	0 cfu/100 ml	

tntc = too nomerous to count
no visible coliforms = bacteria on the plate does not contain coliforms

To sum up, the initial results of this combination seemed to have a good potential in regards to the removal and disinfection success. In almost all of the water samples, the amount of

bacteria was decreased to values near zero after chlorination. In one case, Mbilliddembiraba (21.06.2016), the amounts of HPC still left after filtration (169 respectively 91 cfu/ml) were almost completely removed by the chlorination. This effect also appeared in terms of the total coliforms in the sample of Mbilliddembiraba (20.06.2015), and in relatively similar amounts. In general, this seems quite plausible because the filtration should have decreased the factors that eventually impede effective chlorination. This affects mainly turbidity (but also other parameters such as ammonia, etc.), which was significantly decreased by the filters (as mentioned in several previous parts of this thesis). In nearly all of the filtered water samples in Chapter 8.5 Laboratory testing results turbidities decreased to values that are recommended by the WHO (2011) to ensure effective chlorination. Conversely, the chlorination probably overcame the slight deficiencies of the filters in terms of the HPC. Due to the assumption that the HPC should be very low in the samples after the filtration anyway, the chlorination should reliably kill all of the bacteria that were still left in the filtered water.

Combining microfiltration and chlorination seems to have a good potential to remove nearly all (or all) of the bacteria in contaminated water samples. But according to the limited number of evaluated data, further research is necessary to validate this assumption.

8.7 Operational use in developing countries

8.7.1 General outlook

Similar to the manual chlorination of raw water before drinking, the filtration of raw water is an additional step in the daily routine of the villagers. This means that to successfully integrate the filtration units into the living practices of the villagers, there must be an understanding of what the filter does and there must be a visible effect on the raw-water after filtration. Luckily one of the specific advantages of the filtration system is that the filtration disinfects and clarifies the raw-water in one step. The turbidities, after the raw-water were filtered, decreased significantly in the tests researched for this thesis. This effect clearly increases the probability that the villagers will eventually include the additional step of filtration of the raw-water before use in their daily routine.

However, because of the relatively low discharge rates achieved in the tests in rural Uganda (about 0.08 l/min to 0.39 l/h), the filtration units do not seem to be suitable to purify the whole amount of drinking water for a family. In order to supply an average Ugandan family of 6-8 people, with an estimated everyday use of about 20-25 l per day and capita (UNDP, 2006), the filtration unit(s) would have to purify about 150 to 200 l a day. The filtration process would simply take too much time. In addition, filtration of these amounts of water would require an intricate planning and execution. Because of the fluctuating discharge rates and the restricted storage capacities of the filtered water (jerry cans), the filtration process needs permanent personal surveillance: this person would have to substitute jerry cans and would have to backwash the filtration units as necessary. This is in addition to the fact that it is not particularly designed for these purposes and simply not practical for this usage.

Despite these disadvantages, an imaginable use of the system is to filtrate just the amount of water that is exclusively consumed by family members to drink. The filtration units could be hung up to filtrate about 20 l of raw-water, for example overnight. With this procedure the

families could create clean, safe water to fulfill their needs for consumption, with significantly smaller amounts of bacteria, bugs, parasites or other health harming ingredients in the drinking water. Simply using this safe water instead of the boiled water presently used for drinking could substantially improve the health situation, especially for fragile people, like young children, elders or pregnant women. People who are the most endangered by diseases caused by bacteria, viruses or parasites could benefit the most from this technique in general.

The system could also be effective in combination with other low-tech methods to gain drinking water for the non-consumed use. Rainwater collection, in particular, seems to be a suitable technique for households to gain relatively large amounts of water with minimum efforts. If rainwater collection is properly done, it is able to achieve relatively safe water (OKOT-OKUMU & OTIM et al., 2015; NAYEBARE et al., 2014), which could be used to complement the additional water needs of the users (for example for laundry, washing, etc.). Depending on the situation, the filters could be used in combination with rainwater to meet the consumed drinking water needs, because the Aquaforce 5 (as well as similar filters tested by DANY (2011)) have shown in the on-site and the laboratory tests that they are able to clean rainwater properly and to gain microbially safe drinking water. This could be another solution if, for example, the available drinking water sources are receive water with relatively good quality (that is, suitable for non-consumed water needs but not good enough for consumption).

These techniques seem to be especially suitable in developing countries with regular rainfall-patterns, such as Uganda, even more so because of the general impression gained on-site in Kalangalo, that the potential of rainwater collecting is not utilized in the slightest. Challenging points of the rainwater-collecting systems are the need for maintenance work (for example a regular cleaning of the roofs to remove bird excrements or other organic matter), basic knowledge about drinking-water treatment and –safety. Additionally, the users in the developing countries must figure out how to construct proper, cheap rainwater tanks, perhaps made of area-specific materials and working techniques, e.g. in form of low-tech concrete, brickwork clay, clay in general or combinations of them.

8.7.2 Technical aspects

The technical use of the filtration units is “as easy as it gets”. The potential users surely have the technical understanding of how the system is to be used, because the instructions of the system, and the use and maintenance of the system in general, are in principle self-explanatory. All in all, the system seems to be quite rugged, so that even abrasive or extensive use should not materially affect the system in general or its potential cleaning success. The filtration units should be backwashed by potential users as often as possible. In some cases while testing, the discharge rates seemed to decrease quickly, even during the relatively short filtration process of 10 l of raw-water. Maximum achievable discharge rates seem to appear immediately after backwashing. In addition, regular backwashing probably does not negatively influence the overall cleaning success, and could potentially increase the life span of the system.

8.7.3 Social and socioeconomic aspects

Another important aspect in this context is the price of the filter system. One filtration unit costs about 50 US-$ and the units are designed to filter about 10 m^3 of raw-water within their life span. For a family of the size mentioned above, using it to filtrate solely the amount required for drinking water consumption, one filtration unit could last up to two years (with an estimated everyday consume of 3 liters per day and capita). It is not possible to predict the acceptability of the system within the villagers. The villagers may not be willing to pay this sum even if they generally know and accept the reasons for the need of water purification.

The users could become, at least partly, independent of raw water quality changes, e.g. because of natural circumstances within the rainy season or regular phases of maintenance. They could also gain independence from problems or disadvantages related to drinking water management. This independency could combat (at least on very a small-scale) social problems such as corruption, discrimination or misuse of power of people by who are in charge of the water management and distribution.

In a broader sense, this independence goes hand-in-hand with an increasing dependency on industrialized countries. Filters, similar to the ones researched in this thesis, are not widely available in developing countries: it is doubtful that potential filter-selling companies could find profitable markets in all parts of developing countries like Uganda. Even if the filters were not be considered expensive, it could prove difficult to achieve a widespread distribution of mobile, pressure-less microfiltration systems. Many people are not mobile, in a sense that they cannot make their way to the capital or the biggest city near their village to potentially buy mobile filtration systems. Often people from rural areas have to travel long distances to get to the next urban area or city. These distances are a limitation to people without cars, mopeds or other motorized transportation abilities to take advantage of such a system. These problems especially affect to poorest of the poor, who ironically need water purification systems the most. Surely (and sadly) even if the filtration units can be used for purification of the amount of consumed drinking water, there is still the need to purify the water that is used in other aspects of life, developing more dependence on other purification systems.

This situation looks quite different in urban areas, even if the cleaning success of the Aquaforce 5 was not tested on these or similar areas. A potential use for the filters could be found in the temporary drinking-water purification at times when urban drinking-water sources are potentially contaminated.

9. Comparison: filtration and chlorination

To further classify the laboratory testing results of the Aquaforce 5, the laboratory results were compared with results from the already mentioned bachelors thesis by LUU (2016) and a masters thesis by DANY (2011).

DANY (2011) has tested 4 other filter systems, similar to the testing of the Aquaforce 5 within this thesis. These 4 filter systems contained two hollow fiber membrane filters (*Montain Safety Research* Autoflow Mikrofilter, *Platypus* Gravityworks) and two ceramic filters with

active coal (*Katadyn* Katadyn Drip Gravidyn, *Cerâmica Stéfani* Stéfani Advance). All of these filters are designed for a similar purpose: to work as flexible, mobile water treatment systems, without power supply. Surely the results of this thesis and DANY (2011) cannot raise the claim to be scientifically comparable. This is due to the fact, that the tests of both theses were done seperately with a time span of about 5 years in between. Also the filters partly do not use the same filtration technique/principle. Another point is that the raw- and waste waters researched by DANY (2011) are not exactly the same like the ones investigated in this thesis. Even if the same raw- and waste water sources would have been used, this should not have made any difference because the water-quality of the raw- and waste-water samples could have significantly changed in the last 5 years anyway. Despite these facts, it still makes sense to "compare" the cleaning success of the systems. Because the comparison can give at least basic information of which cleaning success can be expected from filter systems similar to the Aquaforce 5. These comparison can further categorize the cleaning success of the researched purification systems in a greater context. In practical senses it is not excluded anyway that the systems have to clean water from water-sources with generally different water-qualities and cleaning intentions.

9.1 Microbial aspects: comparison

A comparison of the mean microbial cleaning/disinfection efficiency of the Aquaforce 5, the filter systems researched by DANY (2011) and the low-tech chlorination (with different concentrations) researched by LUU (2016) can be seen in Fig. 69.

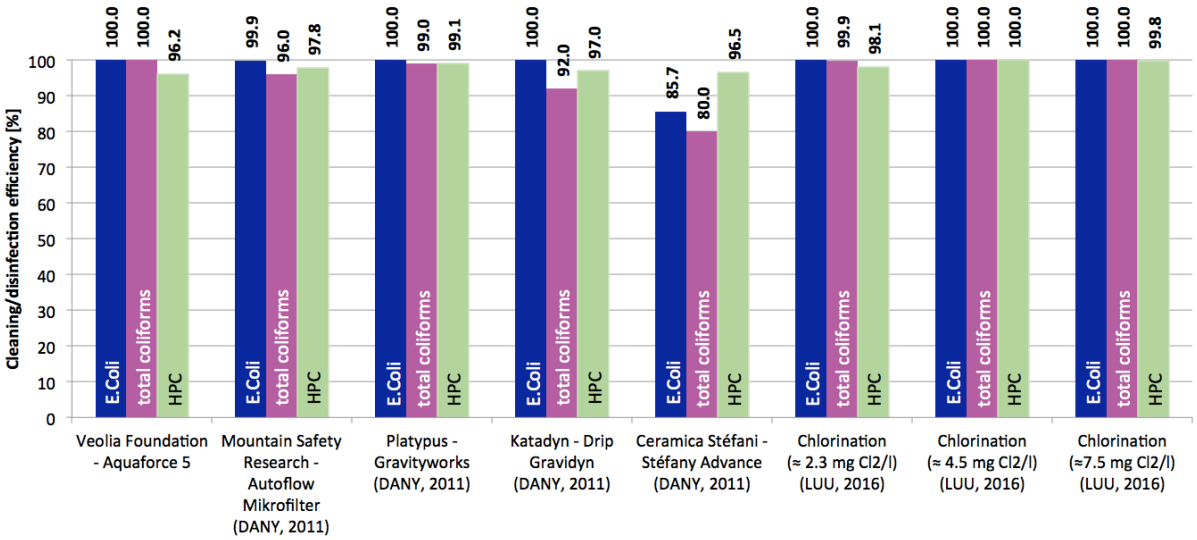


Fig. 69: Mean microbial cleaning/disinfection efficiency in laboratory conditions, comparison with DANY (2011) and LUU (2016)

Fig. 69 reveals that the cleaning success of the Aquaforce 5 in laboratory conditions is compareable to other, similar filter systems. This becomes especially evident in comparison with the *Mountain Safety Research Autoflow Mikrofilter* and the *Platypus Gravityworks*, which both use the same filter technique like the Aquaforce 5. The Aquaforce 5 has gained even better cleaning efficiencies in terms of E.Coli and total coliforms (100 % mean cleaning efficiency during the laboratory tests). In contrast, the Aquaforce 5 seems to have the weakest mean cleaning efficiency regarding to HPC, even if the mean cleaning efficiency

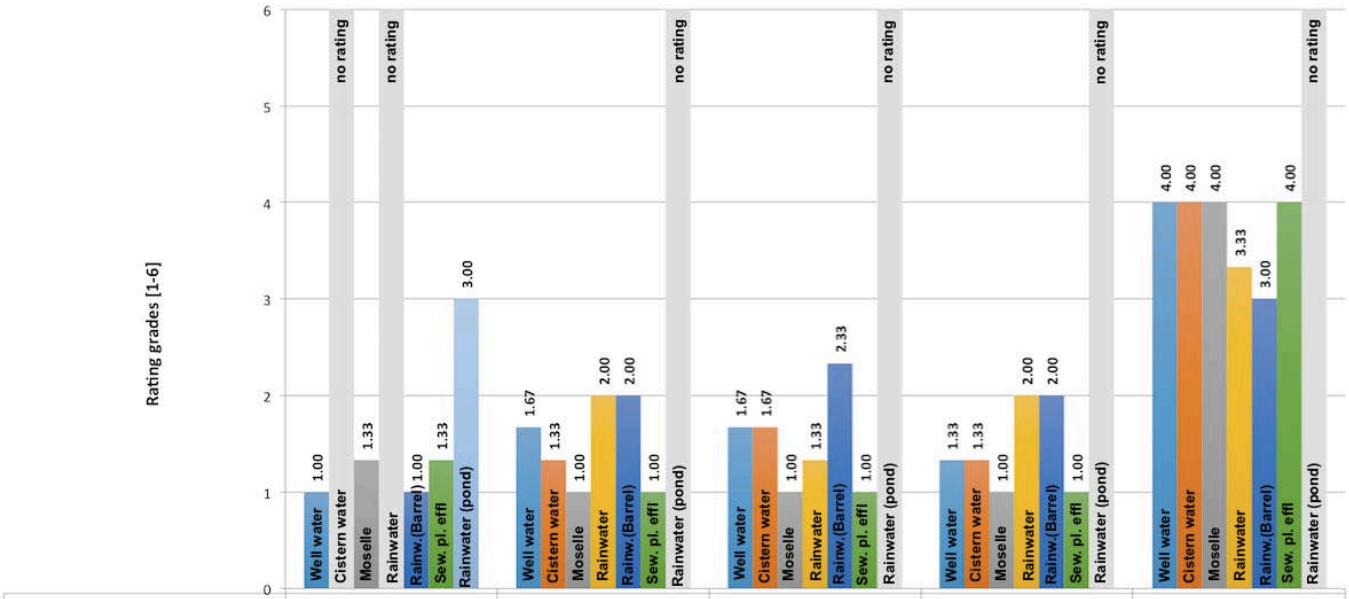
with about 96.2 % is still extraordinary good. Surprisingly, the hollow fiber membrane filters seem to be more efficient relating to microbial contaminations than techniqually more complex systems using ceramic filters with included active coal (Katadyn, Ceramica Stéfani).

In laboratory conditions the filters have reached efficiencies similar to chlorination. The mean disinfection efficiency of chlorine seems to be better in general, but a comparison to the filter systems with the best cleaning success during the tests (*Foundation Veolia Aquaforce 5*, *Mountain Safety Research Autoflow Mikrofilter* and *Platypus Gravityworks*) reveals that these differences can probably be considered as insignificant. One specific benefit of chlorine against filtration in general is the ability to develop buffering effects to microbial re-contamination. When the chlorinated water is suitable for chlorination in chemical/physical parameters, chlorine in sufficient concentrations can not only disinfect the bacteria that are already present within the water, it can furthermore impede bacteria to re-contaminate the disinfected water to specific extends. Filter systems themselfs cannot prevent their cleaned drinking water from potential recontaminations.

9.2 Acceptability aspects: comparison

Any comparison related to acceptability aspects of chlorinated water (LUU, 2016) with other purification methods (filtration) is skipped within this thesis. Chlorine residuals in drinking water are strongly affecting taste and odor; also the appearance of raw-water is not changed (for the good) after chlorination. Because of these points, the acceptability aspects of drinking-water chorination and -filtration cannot be comprehensively compared: chlorine in drinking water (even in low concentrations) would definetly and significantly worsen all of the researched acceptability aspects. The comparison bases on the acceptability rating that has already been mentioned in chapters 5.3 Acceptability test procedure and 8.5.4 Acceptability parameters.

In terms of the filter systems, scientifically approved comparisons of the Aquaforce 5 and the filter systems tested by DANY (2011) in regards to acceptability aspects does not seem to make much sense in the first glaze. This is resulting from the fact that evaluations of acceptability aspects heavily rely on subjective evaluation criteria. Also, as mentioned above, there was not used the same raw- and waste-waters within DANY (2011) and this review. But it is indeed useful to gain at least basic impressions about the general cleaning success while comparing the filter systems, even if the comparison can not claim to be physically or scientifically approved. For the most part, relatively samey raw- and waste-waters have been tested in both theses, namely well-water, river water (Moselle), collected rainwater from a barrel and sewage plant effluents. These waters should have, despite the fact that they were taken from different sources with an intervall of about 5 years in between, relatively similar qualities in taste, appearance and odor. Some of the other water sources mentioned in Fig. 70 (Cistern water, rainwater and Rainwater (pond)) were specifically researched in only one of the theses. Here, they are represented just for the sake of completeness and they are not used for the evaluation of the comparison.



Well-Water (DANY/KAUFMANN)	1.00	1.67	1.67	1.33	4.00
Cistern water (DANY)	no rating	1.33	1.67	1.33	4.00
Mosel (DANY/KAUFMANN)	1.33	1.00	1.00	1.00	4.00
Rainwater (DANY)	no rating	2.00	1.33	2.00	3.33
Rainwater (barrel) (DANY/KAUFMANN)	1.00	2.00	2.33	2.00	3.00
Sewage plant effluents (DANY/KAUFMANN)	1.33	1.00	1.00	1.00	4.00
Rainwater (pond) (KAUFMANN)	3.00	no rating	no rating	no rating	no rating

Fig. 70: Mean values of the acceptability rating (odor, appearance, taste), comparison with DANY (2011)

The cleaning success of the Aquaforce 5 related to acceptability parameters seems to be equivalent with the other filter systems, especially with both of the similar hollow fiber membrane filters (*Mountain Safety Research* – Autoflow Mikrofilter, *Platypus* – Gravityworks) and one of the ceramic/active coal filters (*Katadyn* - Drip Gravidyn). It even seems to have slightly better mean values than these filter systems. In general, all of the filters, beside the *Cerâmica Stéfani* - Stéfani Advance, have affected the tested raw- and waste-waters in a good manner, so that the accaptability aspects of the filtratated water do not show any significant difference between filtrated water and German drinking-water anymore. In general the results of this comparison seem to confirm the good overall cleaning success of the Aquaforce 5.

10. Drinking-water purification: UV-radiation

Besides the purification methods that were already researched in this thesis, another low-tech disinfection technique that is often used in many developing countries is drinking-water disinfection through UV-radiation (mostly solar radiation to be more precise). The general idea behind these technique lies within the fact that UV radiation is able to kill or inactivate pathogenic (or other) bacteria, virusses and parasites contained in drinking water. UV radiation in its different spectral ranges is able to affect the genetic material of microorganisms. Because of the genetic damages that result directly from UV radiation, the microorganisms lose their ability to grow (in masses) and they lose their potential health harming effects (ROESKE, 2007).

Today this drinking-water disinfection technique is getting more and more popular in industrialized countries. Here, the disinfection is mostly affected through irradiation

chambers, which are flowed through with water constantly. In developing countries UV radiation is primarily used with a low-tech approach: especially in areas with constantly and reliably high solar irradiation this technique is often practiced using transparent PET bottles filled with raw-water. To disinfect the drinking-water the bottles are subjected to direct sunlight for several hours (see Fig. 71 and Fig. 72). Cloudy weather increases the needed exposure time for reliable disinfection effects, whereas the technique is not recommended to use at rainy weather (SODIS, 2016). In contrast to the methods used in industrial countries, the disinfective effect of low-tech solar disinfection does not only result from the UV radiation alone. The disinfective effects also result from the heating of the treated water (up to temperatures of > 55 °C) through solar radiation. Therefore this principle works, however, the best in areas with hot climates: it is often applicated in desert-like, subtropical and tropical areas in parts of Africa, Asia and Latin America. Because of its easy application and relatively reliable disinfective effects, solar disinfection is also often used or recommended in emergency situations, in remote or very poor areas. The WHO, for example, is attesting the SODIS method a good potential within their guidelines (WHO, 2011), in particular for the treatment of collected rainwater or in areas where the resources of other technically more complex water treatment systems are not available.

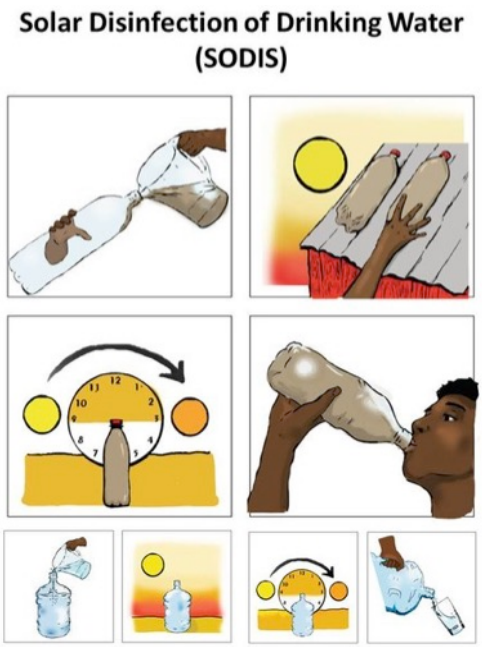


Fig. 71: Solar disinfection with PET-bottles, schematic sketch (GREENWATCH, 2016)

Fig. 72: Solar disinfection with PET-bottles in Senegal (SODIS, 2016)

In the following, some of the most important aspects, recommendations and (to a smaller extend) results from further researches and publications related to the efficiency of solar disinfection are represented. Many of the recommendations, explanations, data and numbers are taken from SODIS (2016). If other sources are used, they are specifically named.

One of the most referred benefits of disinfection through UV radiation is that no chemical byproducts or -residuals are arising from the desinfection method itself (ROESKE, 2007; WILHELM, 2008). Because of this, the acceptability aspects are not affected, which can be seen as benefit and disadvantage at the same time: UV treated water is not affected in regards to appearance, taste and odor; therefore drinking water with bad attributes referring

to these factors is not improved, in reverse drinking water of good acceptability is not negatively influenced.

The needed resources to practice the SODIS method are widely available in nearly all parts of the world: in general everything needed is a clear, white PET bottle or similar. Green or brown PET bottles filter parts of the UV radiation from sunlight and decrease the disinfective power of the radiation. In vessels with larger volumes the solar radiation could potentially fail to disinfect efficiently and reliably because the UV radiation is weakened with larger water depths and the heating of larger volumes takes longer. Because of that it is recommended, according to SODIS (2016), to not disinfect volumes greater thant three liters in one vessel at the same time. Also old, scratched PET bottles impede the disinfection efficiency: new, clear PET bottles allow about 60 % of the actual disinfecting UV radiation to pass through, while old, scratched PET bottles do not let UV radiation pass through in these percentages. SODIS (2016) recommends to replace daily-used PET bottles after 6 to 12 months. PVC bottles are not recommended to use for this technique because health harming byproducts can be formed from solar radiation of PVC bottles (SODIS, 2016).

Similar to chemical disinfection (e.g. chlorination), the presence of high turbidities and larger, dissolved particles within the raw-water can impede the disinfection efficiency of the UV radiation/SODIS method (ROESKE, 2007; WILHELM, 2008; SODIS, 2016). This is among other things due to similar effects, appearing while chlorination of turbid water: bacteria is able to attach to particles in the water (or to be contained directly within the particles). With this attributes they are partly able to overcome the disinfection process and to regrow after the process of the actual disinfection. Dissolved organic and inorganic particles are also able to weaken the intensity of disinfective UV radiation by absorbing parts of the UV spectral (ROESKE, 2007; WILHELM, 2008). In contrast, the effectivity of the SODIS method can be increased when water temperatures are high and when the PET bottles are placed at light-reflecting surfaces (for example corrugated iron roofs). According to WEGELIN et al. (1994) and DESSIE et al. (2015) turbidities greater than 20-25 NTU reduce the disinfection efficiency of the SODIS method significantly. In reverse, JOYCE et al. (1995) for example have indicated that high turbidities do not seem to impede the disinfection efficiencies if the water within the bottles is heated enough by solar radiation (about 50-55°C). Nonetheless solar disinfection does not seem to be suitable for turbid water: firstly it is not guaranteed that the specific solar radiation heats the water to the needed tempertures in specific areas with turbid water sources; secondly the technical abilities to control the water temperature are often not available within the poorest areas of developing countries. Because of that a reliable disinfection success for turbid drinking water does not seem to be given in every case, but the contradicting views in regards to the role of turbidity for SODIS indicate that further research work is necessary in this topic.

To this date several other publications have also confirmed, that SODIS in different applications can have positive effects related to disinfection. Most of these publications attest the SODIS method to have the ability to significantly decrease amounts of fecal indicator bacteria in drinking water to different extends (DESSIE et al., 2014; JOYCE et al., 1995; WEGELIN et al., 1994; and others). On-site and laboratory studies like JOYCE et al. (1995) for example have shown that E.Coli were not detectable anymore after highly contaminated raw-water was exposed for 7 hours in the Kenyan sun. UV radiation combined with heating of the treated water by solar radiation therefore seem to be effective to inactivate fecal

indicator bacteria. Researches of DESSIE et al. (2014) in Ethiopia have also confirmed, that the SODIS method can reliably and successfully disinfect drinking water in regards to fecal indicator bacteria without bacteria regrow within the disinfected water samples, especially if the SODIS method is specifically optimized. If the shallow depth of the water is as low as possible and the heating of the water is supported with half surfaced black PET bottles.

Unfortunately some field trials in Kenya have also shown, that solar disinfection all alone probably cannot significantly reduce the number of water-borne diseases (in this specific case: diarrhoea) appearing with extremely contaminated drinking water (CONROY et al., 1996; CONROY et al., 1998). However, the disinfection method was widely accepted within the tested communities and the use of the purification method was independently continued by the communities after the field trials of CONROY et al. (1998) ended. This reveals some general advantage of the SODIS method: solar disinfection is easy to apply, requires low working effort and the needed resources are widely available in developing countries. Despite that, potential users seem to accept the method and seem to trust in its benefits after they have used it once. Nevertheless, this is in contrast to some articles (GREENWATCH, 2016) that attest, that the SODIS method is not trusted by potential users related to its reliability and disinfection effect. This appears to correspond to impressions gained in Uganda concerning to the chlorination of water: the potential users seemed to be sceptical in regards to the disinfective effects of the treatment, because the disinfection process is quite abstract, meaning that the users could not see any progress in the disinfection itself and they could not see any progress in the general look of the treated water.

Other extensive (literature) studies of field trials and research papers (CLASEN et al., 2015) have noticed that solar disinfection is probably achieving reductions of diarrhoeal disease numbers of up to one third in all ages and up to 50 % in children under five. The need for further researches within this topic seems to be given for the future because the number of publications (especially open access articles) seems to be low in comparison with other low-tech water treatment methods.

11. Conclusions

The microbial, chemical and physical testing results of drinking-water sources in rural and urban Uganda have shown, that both improved and unimproved drinking-water sources seem to be temporarily or permanently contaminated with fecal indicator bacteria. Often the degrees of the fecal (and other) contaminations were high: numbers of total coliforms for example appeared to revolve around hundredths or thousands per 100 ml in many cases. This means, that consuming the raw-water taken from these sources could temporarily or permanently lead to health issues for consumers.

In the four testing villages the prototype-produced chlorine has achieved mixed results. In general the disinfection efficiency of the chlorine within the drinking water was good, the chlorine has removed significant amounts (up to 100 %) of total coliforms and heterotrophic aerobic bacteria instantly, in other words after exposure times of about 30 min. Nontheless, the bacteria was partly able to come back after time spans of 2-4 h. These recontaminations were probably caused, among other things, by turbidities and other chemical ingredients (ammonia, iron) within the drinking water, that were possibly impeding effective chlorination.

Comparisons with microbial disinfection efficiencies in laboratory conditions (LUU, 2016) seemed to confirm the overall impression, that low-tech prototype-produced chlorine is able to remove nearly 100 % of bacteria after exposure times of about 30 min. Despite the problems of recontamination on-site, the practicability of the low-tech chlorination system seems to be given in general. Even if the chlorine is not removing 100 % of the bacteria contained in drinking water sustainably, the improvements in microbial drinking-water quality against non-treated drinking water seem to be immense. The applications of chlorine could range from permanent disinfection of drinking water from unimproved sources to individual disinfection of imroved drinking-water sources to ensure safe drinking water in times when good microbial drinking-water quality is not reliably given.

Both on-site and in the laboratory, the Aquaforce 5 has also achieved significant improvements in microbial drinking-water quality. The Aquaforce 5 has removed 100 % of E.Coli and total coliform and about 96 % of non-coliform bacteria during the laboratory tests in Germany. The on-site tests have also shown that the Aquaforce 5 was partly able to remove all bacteria that were contained in the highly contaminated drinking-water sources. Probably because of the presence of high contaminations, turbidities and larger floating materials (algae, plant debris) within the tested drinking water, low numbers of mostly non-coliform bacteria were able to overcome the filtration process. In the laboratory and on-site, the microfiltration did not change the tested physical and chemical parameters pH and EC; Turbidity was significantly and reliably reduced to values of about 0.1 NTU or less. In the laboratory, the filters mostly did not permanently affect the amounts of magnesium, calcium, sodium and potassium dissolved in the tested raw- and waste waters: in two cases the filters increased the amounts of magnesium and calcium of about 25 and 40 % respectively, therefore the filtration was slightly increasing the hardness of the water. The filters have also significantly improved the acceptability aspects appearance, odor and taste. Within the testing, the mean discharge rate of 0.41 l/min (given by the manufacturer) was not achieved. The discharge rate of the microfiltration units seemed to be negatively influenced mainly by the presence of large floating plant (or other organic) materials, and high turbidities. During the laboratory and the on-site tests, the mean discharge rate was revolving of about 0.19 l/min. Large-scale usage of the filtration units, for example to supply drinking water for a whole family seems to be impractical due to this point. Nevertheless the Aquaforce 5 could significantly improve the health situation in developing countries: for temporary drinking-water treatment in particular, or in combination with other water treatment systems. Also combined with for example relatively safe drinking-water sources like rainwater collecting the system could gain safe drinking water for the purely consumed use, especially for high-risk groups for water-borne diseases.

In comparison with the Aquaforce 5 and several other mobile filter systems priorly tested by DANY (2011), the prototype-produced chlorine by LUU (2016) showed the most efficient disinfection success in laboratory conditions. The efficiencies of the Aquaforce 5 and the most efficient mobile filter systems (*Mountain Safety Research* – Autoflow Mikrofilter, *Platypus* – Gravityworks) were almost equally high. To sum up, both the low-tech chlorination system and the high-tech filter systems of the Aquaforce 5 (and similar) have achieved significant improvements in microbial drinking-water quality during the tests of this thesis. With these attributes, both types of mobile drinking-water treatment systems could generally play an important role in the fight against water-borne diseases, and other problems arising from microbially contaminated drinking water.

Both systems have advantages and disadvantages of course: the chlorination system could be used in many ways and with many intentions, but the construction, operation and application is relatively difficult. To use homemade chlorine for drinking-water disinfection, specific know-how about drinking-water quality and chemistry is needed. The resources to built, operate and maintain are widely available and inexpensive (except for the electrodes and solar panels). The mobile filter units could probably be only used to disinfect parts of the every day drinking-water need, but usage, operation and maintainance is significantly easier than the proper operation and application of a chlorination system. Moreover one huge advantage of the microfiltration seems to be, that it clarifies and disinfects in one step: this is increasing the acceptability of the system among the users, because the cleaning success is clearly visible and comprehensive. In reverse the use of microfiltration units as high-tech product does increase the dependency of developing countries from industrialized countries, and the price of about 50 US$ per unit and the non-availability in rural, poor or remote areas does probably impede the system from being a widespread solution for permanent drinking-water purification in developing countries.

According to several publications, reviews and articles, the solar disinfection method could also positively affect drinking-water situations in developing countries. In areas where climate and raw-water are suitable, solar disinfection seems to be a relatively reliable and effective way to disinfect drinking water. Disadvantages are that the disinfective power of the method does not seem to be given in turbid water and that the users often mistrust the method because the microbial cleaning success cannot be comprehensively recognized. The potential of solar disinfection is not adequately utilized to this date, although the potential benefits of it seem to be immense. Because of that further researches of this topic are necessary: some of its current scientific contradictions could be eradicated, the popularity and acceptance of the technique could be increased and solar disinfection could become a more widely known and more widely used alternative to other water treatment systems.

Drinking-water problems in developing countries cannot be completely solved by mobile, individual water treatment systems all alone. Drinking water quality, sanitation and hygiene are linked in too many ways to solve the worldwide problems of water-borne diseases just by solving one of both components. Furthermore these problems on safe drinking water and proper sanitation are often linked to widespread problems in almost all aspects of everyday life in developing countries. To improve the general situation structural changes in larger dimensions are necessary, for example related to politics, education, socioeconomy and economy. Sustainable positive changes need proper funds to develop centralized, widespread drinking-water and sanitation facilities, so that the wide majority of people in rural or poor areas could also benefit of them. This could be reached by construction of widely spread, improved (engineered) drinking-water sources such as protected shallow-wells or boreholes. In addition these facilities need proper and regular maintainance and repair to be sustainably and permantently able to gain safe drinking water. That seems to be of the most important challenges of governments and users/communities in developing countries: to develop individual, functional management and operation systems for each drinking-water source, to reach suitable and permanent access to safe drinking-water in improved drinking-water sources.

However, drinking-water purification systems should be specifically designed for every region under special consideration of the natural ressources, and technical, social, socioeconomic and cultural aspects. The low-tech chlorination system by Dipl.-Ing. Michael Ottensmann is a good example for an individually designed, engineered solution that could potentially improve drinking-water quality in Uganda. In reverse, the Foundation Veolia Aquaforce 5 as high-tech purification system could serve as an example for a potential solution of specific drinking-water problems, despite the fact that the system is explicitely not designed for the purposes of permanent drinking-water purification in developing countries. Nevertheless individual drinking-water treatment systems like the ones in this thesis can serve as a first step towards a better drinking-water and sanitation situation. To be more precise the development of systems like these can start a rethinking process among potential users and executives in developing countries. Successful examples for individual improvements in drinking-water treatment, sanitation and hygiene that directly result in improvements in life quality, have the potential to initiate a better awareness and better knowledge of drinking water, sanitation and hygiene among the users. Improvements in drinking-water treatment, sanitation and hygiene are also able to directly or indirectly lead (in the long term) to improvements in almost every other aspect of life: in health, education, economy, infrastructure, living standard and more. But first of all, small steps in the right direction, that means small, individual improvements in drinking-water treatment seem to be able to ultimately lead to a healthier, better life in Uganda and in other developing countries.

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Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references.

Daniel Kaufmann Trier, September 8, 2016

Annexes

Population Characteristics

Table 1.1: Total population by age group and sex, Mityana District , 2014

Age group	Male	Female	Total
0-9	56,610	50,593	107,203
10-19	43,862	41,904	85,766
20-39	40,678	42,974	83,652
40-59	17,074	18,504	35,578
60+	7,493	9,272	16,765
District	**165,717**	**163,247**	**328,964**

Table 1.2: Total Population by sex and Sex Ratio by Sub-County; Mityana District, 2014

Sub-County	Male	Female	Total	Sex Ratio*
	Mityana Municipality			
Busimbi Division	7,651	7,626	15,277	100.3
Central Division	26,727	30,023	56,750	89.0
Ttamu Division	11,674	11,727	23,401	99.5
Bbanda	7,018	6,579	13,597	106.7
Butayunja	5,579	5,304	10,883	105.2
Kakindu	9,510	8,913	18,423	106.7
Maanyi	11,066	10,220	21,286	108.3
Malangala	11,933	12,226	24,159	97.6
Bulera	15,583	14,442	30,025	107.9
Kalangaalo	15,652	14,980	30,632	104.5
Kikandwa	15,281	14,418	29,699	106.0
Namungo	8,858	8,303	17,161	106.7
Ssekanyonyi	19,185	18,486	37,671	103.8
District	**165,717**	**163,247**	**328,964**	**101.5**

** Number of Males per 100 Females*

Household Characteristics

Table 2.1: Number of households by main source of livelihood and remittances from abroad by Sub-County; Mityana District, 2014

Sub-County	Total Households	Main Source of Livelihood			Households that received Remittances	
		Subsistence Farming	Other	Percent depending on subsistence farming	Number	Percentage
Mityana Municipality						
Busimbi Division	3,748	2,449	1,299	65.3	1,059	28.3
Central Division	14,946	3,240	11,706	21.7	3318	22.2
Ttamu Division	5,478	3,524	1,954	64.3	1188	21.7
Bbanda	3,147	2,418	729	76.8	563	17.9
Butayunja	2,613	2,171	442	83.1	507	19.4
Kakindu	4,337	3,064	1,273	70.6	595	13.7
Maanyi	5,046	4129	917	81.8	867	17.2
Malangala	5,742	3,391	2,351	59.1	1137	19.8
Bulera	7,439	5,341	2,098	71.8	1847	24.8
Kalangaalo	6,921	5,787	1,134	83.6	1276	18.4
Kikandwa	7,301	5,844	1,457	80.0	1173	16.1
Namungo	4,188	3,185	1,003	76.1	684	16.3
Ssekanyonyi	8,997	5,883	3,114	65.4	1427	15.9
District	**79,903**	**50,426**	**29,477**	**63.1**	**15,641**	**19.6**

Table 2.6: Number of households, source of drinking water and toilet facility by Sub-County;Mityana District, 2014

Sub-County	Total Households	Source of drinking water		Toilet facility		
		Unprotected	Protected*	Improved Toilet**	Unimproved Toilet	No Toilet
Mityana Municipality						
Busimbi Division	3,748	2,346	1,402	1,135	2,510	103
Central Division	14,946	3,250	11,696	4,848	10,049	49
Ttamu Division	5,478	2223	3,255	1,738	3,622	118
Bbanda	3,147	1759	1,388	432	2,553	162
Butayunja	2,613	1,255	1,358	525	1,947	141
Kakindu	4,337	2,050	2,287	1,308	2,855	174
Maanyi	5,046	2968	2,078	1062	3813	171
Malangala	5,742	2,893	2,849	1,330	4,149	263
Bulera	7,439	4,891	2,548	1,554	5,730	155
Kalangaalo	6,921	4,940	1,981	1481	5,222	218
Kikandwa	7,301	3,937	3,364	1,883	5,159	259
Namungo	4,188	2,386	1,802	871	3,186	131
Ssekanyonyi	8,997	4,880	4,117	2083	6,658	256
District	**79,903**	**39,778**	**40,125**	**20,250**	**57,453**	**2,200**

**Protected water source includes piped water, borehole, protected well/spring, gravity flow and bottled water*
*** Improved toilet facility includes flash toilet, VIP latrine, covered pit latrine with a slab, compost toilet that is not shared with other households*

Population Characteristics

Table 1.1: Total Population by Sex and Age Group; Kampala District, 2014

Age Group	Male	Female	Total
0-9	195,332	182,208	377,540
10-19	137,414	181,628	319,042
20-39	295,908	348,163	644,071
40-59	71,264	66,188	137,452
60+	12,844	16,131	28,975
District	**712,762**	**794,318**	**1,507,080**

Table 1.2: Total Population by sex, Sex Ratio and Population Density by Sub-County; Kampala District, 2014

Sub-County	Male	Female	Total	Sex Ratio*	Land Area (Sq. Km)	Population Density**
Kampala Capital City						
Central Division	37,435	37,733	75,168	99.2	15.2	4,945
Kawempe Division	158,768	179,897	338,665	88.3	31.0	10,925
Lubaga Division	176,762	206,454	383,215	85.6	36.9	10,385
Division	186,368	206,640	393,008	90.2	54.2	7,251
Nakawa Division	153,429	163,594	317,023	93.8	52.8	6,004
District	**712,762**	**794,318**	**1,507,080**	**89.7**	**190.1**	**7,928**

** Number of Males per 100 Females*
*** Number of Persons per Square Km of land area*

Table 1.3: Household Population by broad age groups and Sub-County; Kampala District, 2014

Sub-County	0-4	0-8	0-17	6-12	13-18	18-30	14-64	60+
Kampala Capital City								
Central Division	8,610	14,417	26,998	9,413	9,580	28,392	53,357	1,731
Kawempe Division	50,195	81,228	139,681	46,980	43,140	119,666	214,603	5,952
Lubaga Division	58,663	93,839	160,479	53,085	49,494	135,804	243,544	6,824
Makindye Division	54,674	89,852	159,663	54,491	51,533	141,018	255,485	6,824
Nakawa Division	41,080	67,548	120,761	41,477	39,390	112,196	205,265	5,553
District	**213,222**	**346,884**	**607,582**	**205,446**	**193,137**	**537,076**	**972,254**	**26,884**

Household Characteristics

Table 2.1: Number of households by main source of livelihood and remittances from abroad by Sub-County; Kampala District, 2014

Sub-County	Total households	Main Source of livelihood			Households that received remittances	
		Subsistence farming	Other sources	Percent depending on subsistence farming	Number	Percent
Kampala Capital City						
Central Division	23,322	164	23,158	0.7	5,802	24.9
Kawempe Division	94,683	1,227	93,456	1.3	24,423	25.8
Lubaga Division	105,778	1,170	104,608	1.1	25,111	23.7
Makindye Division	108,778	1,157	107,621	1.1	25,778	23.7
Nakawa Division	84,242	1,043	83,199	1.2	20,264	24.1
District	**416,803**	**4,761**	**412,042**	**1.1**	**101,378**	**24.3**

Table 2.2: Ownership of selected Household Assets and Mosquito Nets by Sub-County; Kampala District, 2014

Sub-County	Total Households	Selected Household Assets			Households with at least a Mosquito Net	
		Radio	Bicycle	Motorcycle	Number	Percent
Kampala Capital City						
Central Division	23,322	11,893	1,583	1,488	19,067	81.8
Kawempe Division	94,683	57,482	6,733	7,070	82,724	87.4
Lubaga Division	105,778	66,853	5,783	7,503	91,691	86.7
Makindye Division	108,778	67,054	6,957	7,140	91,784	84.4
Nakawa Division	84,242	50,301	7,344	5,559	72,137	85.6
District	**416,803**	**253,583**	**28,400**	**28,760**	**357,403**	**85.7**

Table 2.5: Number of Households and Main Source of Energy for Lighting by Sub-County; Kampala District, 2014

Sub-County	Total Households	Electricity	Paraffin-Lantern	Paraffin-Tadooba	Other
Kampala Capital City					
Central Division	23,322	20,249	604	535	1,934
Kawempe Division	94,683	76,699	5,854	3,010	9,120
Lubaga Division	105,778	90,382	4,998	2,353	8,045
Makindye Division	108,778	92,705	4,346	3,031	8,696
Nakawa Division	84,242	71,039	3,677	2,645	6,881
District	**416,803**	**351,074**	**19,479**	**11,574**	**34,676**

Table 2.6: Number of Households, Source of drinking water and Toilet facility by Sub-County; Kampala District 2014

Sub-County	Total Households	Source of Drinking Water		Toilet facility		
		Unprotected	Protected*	Improved Toilet**	Unimproved Toilet	No Toilet
Kampala Capital City						
Central Division	23,322	860	22,462	7,684	15,563	75
Kawempe Division	94,683	7,600	87,083	27,003	67,232	448
Lubaga Division	105,778	5,211	100,567	28,033	77,639	106
Makindye Division	108,778	6,688	102,090	31,885	76,156	737
Nakawa Division	84,242	4,349	79,893	29,750	54,176	316
District	**416,803**	**24,708**	**392,095**	**124,355**	**290,766**	**1,682**

**Protected water source includes piped water, borehole, protected well/spring, gravity flow and bottled water*
*** Improved toilet facility includes flash toilet, VIP latrine, covered pit latrine with a slab, compost toilet that is not shared with other households*

Colichrom-NPS

Version:	12/2015
M&S item numbers:	1035 (50 / PK) and 1035-H (100 / PK)
Profile:	Dehydrated nutrient pad sets 50 mm in petri dishes, sterile
Color:	White
Storage:	Dark and dry at room temperature
Shelf life:	2 years after sterilization

Description and application range

Colichrom-NPS are used for the detection of *Escherichia coli* and other coliforms from water with low accompanying flora (according to DIN EN ISO 9308-1:2014) and from beverages. With Colichrom-NPS coliforms can be cultivated and differentiated selectively by color. Gram-positive bacteria are largely inhibited by Tergitol-7 and the chromogenic components easily allow detection of *E. coli* (blue colonies) and coliforms (pink to purple colonies) among accompanying non-coliforms growing as beige colonies. The medium is manufactured and quality tested in compliance with DIN EN ISO 11133:2014 standard.

Typical composition

Enzymatic digest of casein	3.0 g/l
Sodium chloride	5.0 g/l
Sodiumdihydrogenphosphate	2.2 g/l
Disodiumhydrogenphosphate	2.7 g/l
Sodiumpyruvate	1.0 g/l
Tryptophan	1.0 g/l
Sorbitol	1.0 g/l
Tergitol-7	0.15 g/l
Chromogenic mix	0.4 g/l

Final pH: 7.0 ± 0.2 at 25 °C

Microbiological quality control

Bacterial contamination

Incubation: aerobically at room temperature for 3 days, specification: no growth

Productivity quantitative analysis
Incubation: aerobically at 36 ± 2 °C for 21 ± 3 h, approx. inoculum: 80 – 120 CFU

Microorganism	Test strain	Specification	Appearance
Escherichia coli	WDCM 00012	$P_R \geq 0,8$	Blue
Enterobacter aerogenes	WDCM 00175	$P_R \geq 0,7$	Pink to purple

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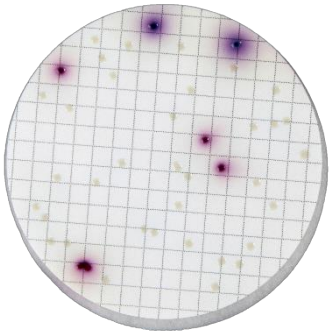
Selectivity qualitative analysis
Incubation: aerobically at 36 ± 2 °C for 21 ± 3 h, approx. inoculum: 10,000 – 1,000,000 CFU

Microorganism	Test strain	Specification	Appearance
Enterococcus faecalis	WDCM 00009	Full inhibition	-

Specificity qualitative analysis
Incubation: aerobically at 36 ± 2 °C for 21 ± 3 h, approx. inoculum: 80 – 120 CFU

Microorganism	Test strain	Specification	Appearance
Pseudomonas aeruginosa	WDCM 00024	Growth	Beige



Mixed culture with *Escherichia coli* (2 blue colonies), *Enterobacter aerogenes* (4 purple colonies) and *Pseudomonas aeruginosa* (many beige colonies) after 20 hours at 37 °C.

Caso-NPS

Version:	12/2015
M&S item numbers:	1030 (50 / PK) and 1030-H (100 / PK)
Profile:	Dehydrated nutrient pad sets 50 mm in petri dishes, sterile
Color:	Beige
Storage:	Dark and dry at room temperature
Shelf life:	2 years after sterilization

Description and application range

Caso-NPS are used for total colony count in water, foodstuffs and pharmaceutical non-sterile products. The formulation is acc. to DIN EN ISO 9308-1 and complies with the requirements of harm EP/USP/JP (2006). It is a universal medium without any inhibitors and additives for the growth of fastidious microorganisms. It can be used to individually add antibiotics or other supplements. The medium is manufactured and quality tested in compliance with DIN EN ISO 11133:2014 standard.

Typical composition

Enzymatic digest of casein	15.0 g/l
Enzymatic digest of soy flour	5.0 g/l
Sodium chloride	5.0 g/l

Final pH: 7.2 ± 0.2 at 25 °C

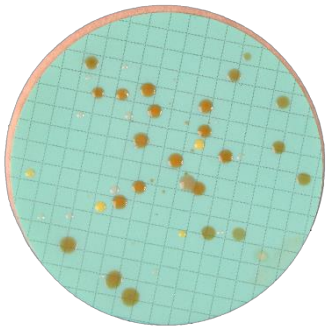
Microbiological quality control

Bacterial contamination

Incubation: aerobically at room temperature for 3 days, specification: no growth

Productivity quantitative analysis
Incubation: aerobically at 30 - 37 °C for 24 - 48 h, approx. inoculum: 80 – 120 CFU

Microorganism	Test strain	Specification	Appearance
Escherichia coli	WDCM 00012	$P_R \geq 0,7$	Beige
Bacillus subtilis	WDCM 00003	$P_R \geq 0,7$	Light beige with fringed edge
Pseudomonas aeruginosa	WDCM 00024	$P_R \geq 0,7$	Beige to light greenish
Staphylococcus aureus	WDCM 00034	$P_R \geq 0,7$	Beige to light yellow



Sample from surface water after 36 hours at 37 °C

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		Ammonia		Magnese	Nitrite (Nitricol)		Phospate LR		Aluminium	Acide Cyanurique	FER LR	Flourure	Chlorine Chloraminses DPD			Chlorine Chloraminses DPD			Chlorine Chloraminses DPD		
		N (mg/l)	NH4(mg/l)	Mn (mg/l)	N (mg/l)	NO2(mg/l)	PO4 (mg/l)	P (mg/l)	Al (mg/l)	Acide Cyanurique (mg/l)	Fe (mg/l)	F (mg/l)	DPD1			DPD2			DPD3		
No	Village Name	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Test Sample	Free	Mono	Di	Free	Mono	Di	Free	Mono	Di
1	Kosovo by church (downstream) S1 12/06/16	0.05	0.06	<<	0.019	0.06	0.18	0.06	0.01	3	0.05	0.64	V	V	V	V	V	V	V	V	V
2	Kosovo by church (downstream) S2 12/06/16	0.11	0.14	<<	0.006	0.02	0.37	0.12	0.08	0	0	0.35		<<	0.04		0	0.04	0.28	<<	0.3
3	Kosovo Kampala S3 12/06/16	0.06	0.08	<<	0.002	0.01	1.8	0.54	0.02	0	0.02	1.27	0.07	<<	<<	0.1	0	0	0.09	<<	0
4	Namukomago S2 12/06/16	0.08	0.1	0.001	0.009	0.03	0.36	0.11	0.02	3	0.11	0.24	0.2	<<	0	0.17	0	0	0.2	0	0
5	Namukomago S1 12/06/16	0.06	0.08	0.001	0.019	0.07	0.28	0.09	0.02	3	0.11	0.62	0.14	0	0	0.13	0.01	<<	0.18	<<	0
6	Namukomago (George) 12/06/16	0.35	0.45	0	0.008	0.03	0.14	0.04	0.01	3	0.07	0.01	0.19	<<	0	0.13	0	0	0.17	0	0
7	Namukomago 2 (George) 12/06/16	0.06	0.08	<<	0.02	0.07	0.26	0.08	0.06	4	0.29	<<	0.4	0	0	0.41	0	<<	0.37	<<	0
8	Kalangaalo Kyamagemule S1 12/06/16	0.04	0.06	D	0.011	0.04	1.7	0.56	0.04	4	0.06	0.15	0.18	0	0	0.17	<<	0	0.19	<<	0
9	Kalangaalo Kyamagemule S2 12/06/16	0.07	0.09	<<	0.008	0.03	0.41	0.13	0.03	2	0.04	0.88	0.17	<<	0	0.1	0	0	0.15	<<	<<
10	Kabayiima S1 12/06/16	0.15	0.19	0.008	0.04	0.14	1.25	0.37	0.1	6	0.44	0.15	0.46	0	0	0.46	0	0	0.46	<<	<<
11	Kabayiima S2 12/06/16	0.04	0.06	0	0.014	0.04	1.6	0.5	0.02	2	0.13	0.11	0.17	<<	0	0.15	<<	<<	0.19	<<	<<
12	Kabayiima S1 (julie) 12/06/16	0.41	0.53	0.006	0.036	0.12	0.49	0.14	0.3	6	0.35	<<	1.54	<<	<<	1.6	<<	<<	1.36	<<	0.02
13	Kabayiima S2 (julie) 12/06/16	0.03	0.04	<<	0.011	0.04	0.34	0.11	0.04	3	0.74	<<	0.21	0	0	0.17	0	0	0.17	<<	0
14	Masajja 12/06/16	0.04	0.06	<<	0.04	0.01	2.5	0.82	0.03	1	0.02	0.88	0.33	<<	<<	0.09	<<	<<	0.1	<<	<<
15	Enro 12/06/16	0.03	0.04	<<	0.009	0.03	0.54	0.17	0.01	1	0.02	0.34	0.16	<<	0	0.11	0	0	0.15	<<	<<
16	Kalangaalo Kyamagemule 15/06/16	0.02	0.03	<<	0.003	0.01	0.25	0.09	0.01	1	0.02	0	0.04	0	0	0.06	0	0	0.09	0	0
17	Mbiliddembiraba S2 15/06/16	0.08	0.11	0.005	0.03	0.12	0.23	0.08	0.07	4	0.28	0.28	0.29	0.01	0	0.26	0.01	0	0.26	0	0.01
18	Mbiliddembiraba S1 15/06/16	0.08	0.1	0.004	0.04	0.1	0.026	0.09	0.11	6	0.48	0.99	0.68	<<	0.02	0.58	0.01	<<	0.58	0	<<
19	Namukomago S1 16/06/16	0.13	0.17	0.003	0.028	0.09	0.82	0.26	0.05	4	0.17	0.22	0.38	0.01	<<	0.4	0	0	0.37	0	0
20	Namukomago S3 16(06/16	0.27	0.35	0.009	0.056	0.18	1.35	0.44	0.18	9	0.48	0.03	0.85	<<	0	0.75	0	0	0.75	0	0
21	Mbiliddembiraba S1 16/06/16	0.06	0.08	0.007	0.02	0.07	0.64	0.21	0.04	4	0.19	0.28	0.33	<<	0	0.29	0	<<	0.25	0	0
22	Mbiliddembiraba S2 16/06/16	0.04	0.05	0.001	0.015	0.05	1.85	0.6	0.02	3	0.1	0.21	0.21	0	0	0.22	0	<<	0.18	0	0
23	Kabayiima S1 (Julie) 16/06/16	<<	<<	0.012	0.11	0.033	0.84	0.27	0.14	8	0.48	0.84	0.83	<<	0	0.73	<<	0	0.75	<<	0
24	Mayobyo S4 (stream) 16/06/16	0.07	0.09	0.007	0.07	0.02	2.4	0.79	0.06	4	0.41	0.06	0.29	<<	<<	0.26	<<	0	0.26	<<	0
25	Kabayiima (LCI) 16/06/16	0.03	0.04	0.005	0.022	0.07	0.45	0.15	0.09	5	0.28	<<	0.32	0	<<	0.3	0	0	0.28	<<	0
26	Mayobyo S1 16/06/16	0.14	0.18	0.007	0.028	0.09	0.33	0.11	0.09	5	0.53	<<	0.52	<<	0.01	0.42	0	0	0.39	0	0
27	Mayobyo S2 16/06/16	0.04	0.06	0	0.042	0.14	1.45	0.55	0.09	5	0.53	0.15	0.48	<<	0	0.26	<<	0.01	0.34	0.01	0.01
28	Mayobyo S3 (stream) 16/06/16	0.07	0.09	0.007	0.07	0.09	0.64	0.19	0.03	5	0.36	0.17	0.36	0	0.01	0.26	0	<<	0.24	<<	0
29	Mbiliddembiraba 21/06/16 ultrafiltration	0.08	0.11	<<	0.005	0.02	0.15	0.05	0.02	3	0.06	0.17	0.18	<<	<<	0.05	<<	<<	0.14	<<	0
30	Namukomago 21/06/16 ultrafiltration	0.05	0.07	<<	0.005	0.02	0.13	0.04	0.03	1	0.02	0	0.44	<<	0	0.31	0.02	0	0.37	0	<<
31	Namukomago 21/06/16 raw	0.09	0.12	0.004	0.027	0.09	1.6	0.52	0.08	5	0.28	0.27	0.38	<<	0	0.37	<<	<<	0.27	0	0
32	Mbiliddembiraba 21/06/16 raw	0.05	0.06	0.005	0.03	0.1	0.42	0.12	0.2	6	0.42	<<	0.36	<<	0.01	0.35	<<	<<	0.32	0	<<

Annex 5

Prototyp	**Nachbau**
Aufbewahrungsbox Multi-Box M (Hersteller: keeeper GmbH)	Aufbewahrungsbox Multi-Box M (Hersteller: keeeper GmbH)
Batterie (Hersteller: GT Start)	Batterie (Hersteller: GT Start)
Titankathode • Hersteller: Qixin Titanium (Baoji) Co. • Homepage: http://www.qixinti.com/enindex.asp	Titankathode • Hersteller: k.A. (China) • Verkäufer: Paraboo GmbH • Homepage: www.paraboo.com
Titananode mit Ruthenium-Iridium-Beschichtung • Hersteller: Qixin Titanium (Baoji) Co. • Homepage: http://www.qixinti.com/enindex.asp	Titananode mit Bleidioxid-Beschichtung • Hersteller: k.A. (China) • Verkäufer: Paraboo GmbH • Homepage: www.paraboo.com
Starthilfekabel	Starthilfekabel

Gedruckt am: 19/07/2016 10:39:38
Gedruckt von: Wasserlabor

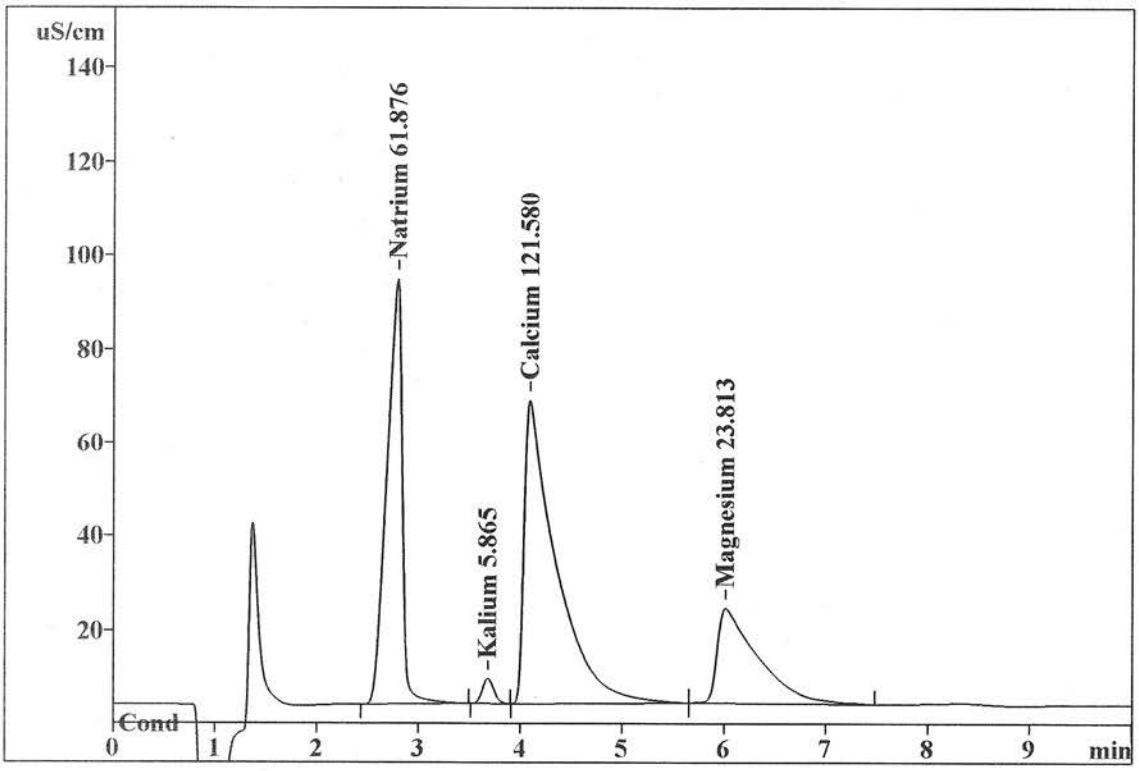
Ident: Mosel
Analyse vom: 19/07/2016 10:25:53
Datei: _2016-07-19_ gespeichert: 19/07/2016 08:35:52
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1469

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.1 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.79	954.629	1594	61.876	Natrium
3.68	42.381	4950	5.865	Kalium
4.09	1405.139	811	121.580	Calcium
6.01	570.331	1044	23.813	Magnesium
10.01	2972.480	2100	213.133	

Gedruckt am: 19/07/2016 10:48:10
Gedruckt von: Wasserlabor

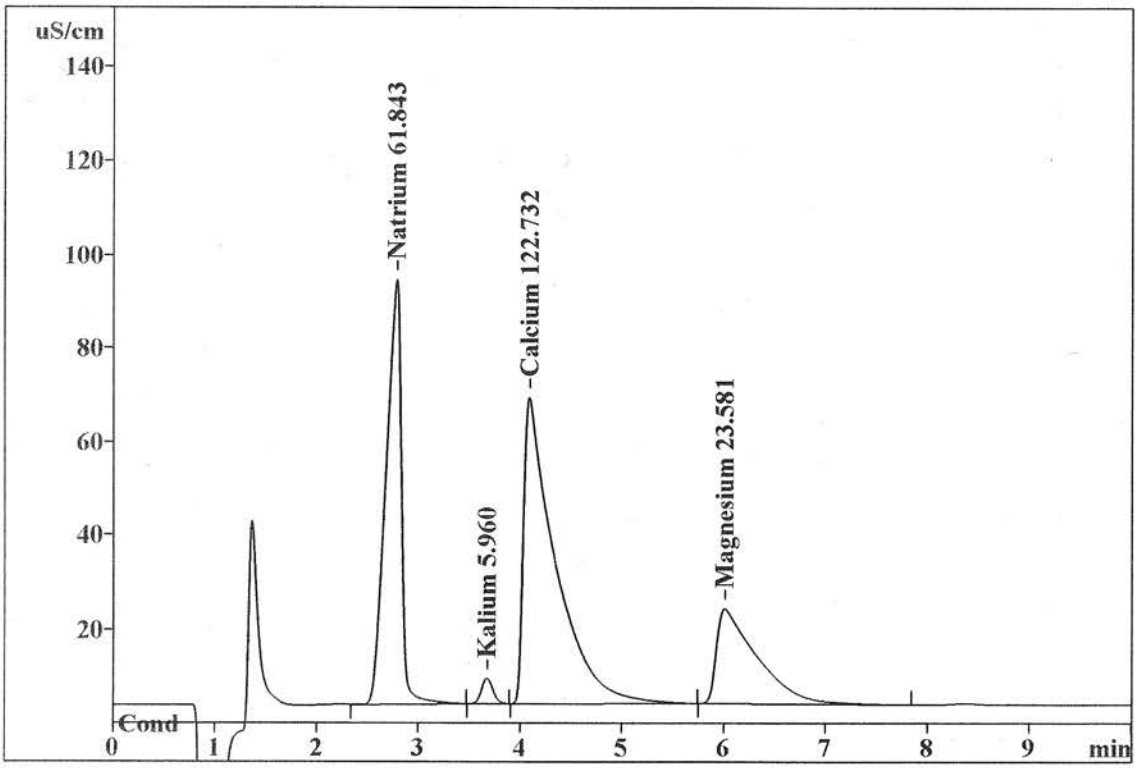
Ident: Mosel filtriert
Analyse vom: 19/07/2016 10:36:50
Datei: _2016-07-19_ gespeichert: 19/07/2016 08:46:49
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1470

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.1 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.79	954.126	1592	61.843	Natrium
3.68	43.069	4922	5.960	Kalium
4.09	1418.457	805	122.732	Calcium
6.01	564.781	1055	23.581	Magnesium
10.01	2980.433	2093	214.116	

Gedruckt am: 19/07/2016 10:23:16
Gedruckt von: Wasserlabor

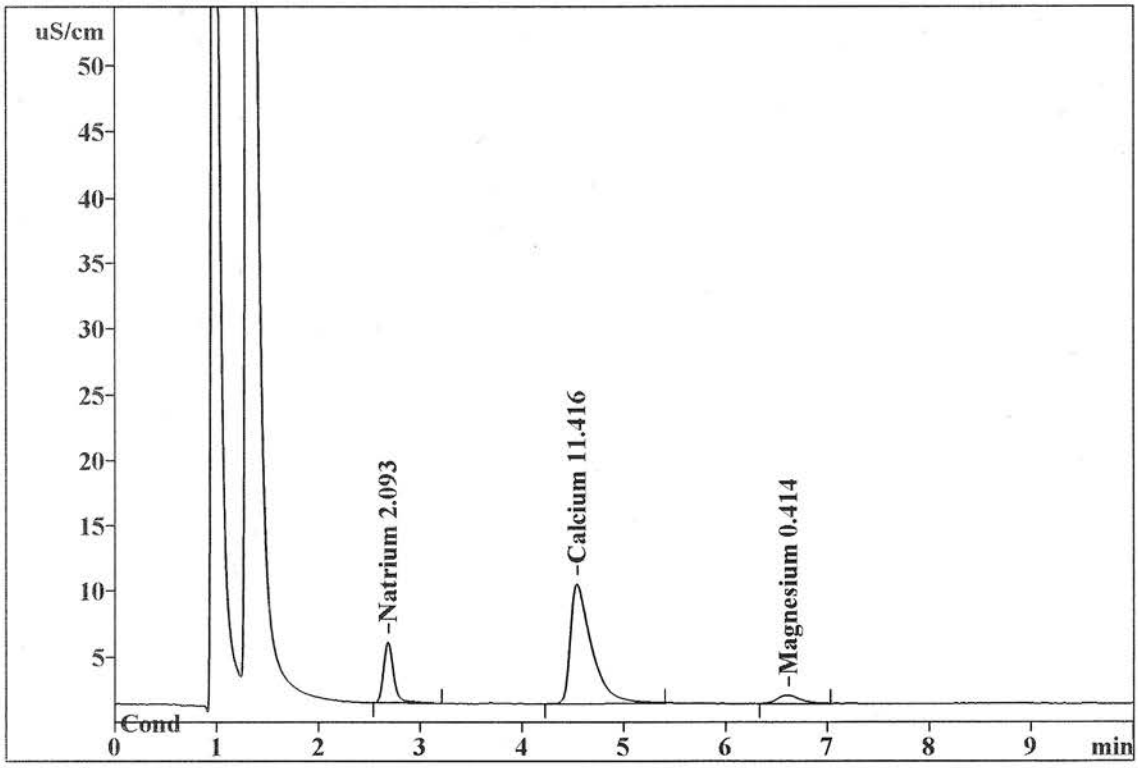
Ident: Rainwater (pond)
Analyse vom: 19/07/2016 10:03:59
Datei: _2016-07-19_ gespeichert: 19/07/2016 08:13:58
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1467

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.1 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.69	32.284	3391	2.093	Natrium
4.54	131.944	2221	11.416	Calcium
6.61	9.920	4033	0.414	Magnesium
10.01	174.148	3215	13.923	

Gedruckt am: 19/07/2016 10:28:37
Gedruckt von: Wasserlabor

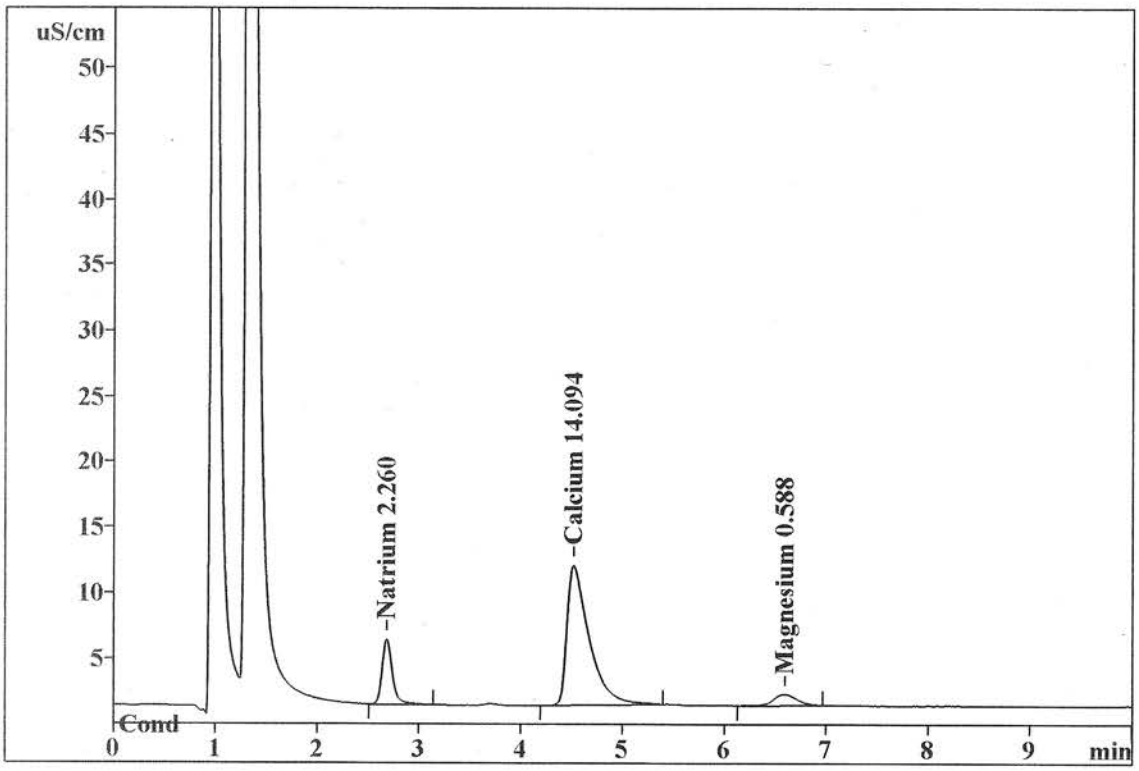
Ident: Rainwater (pond) filtriert
Analyse vom: 19/07/2016 10:14:43
Datei: _2016-07-19_ gespeichert: 19/07/2016 08:24:42
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1468

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.2 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.69	34.866	3356	2.260	Natrium
4.52	162.892	1991	14.094	Calcium
6.59	14.074	3749	0.588	Magnesium
10.01	211.832	3032	16.942	

Gedruckt am: 19/07/2016 09:55:53
Gedruckt von: Wasserlabor

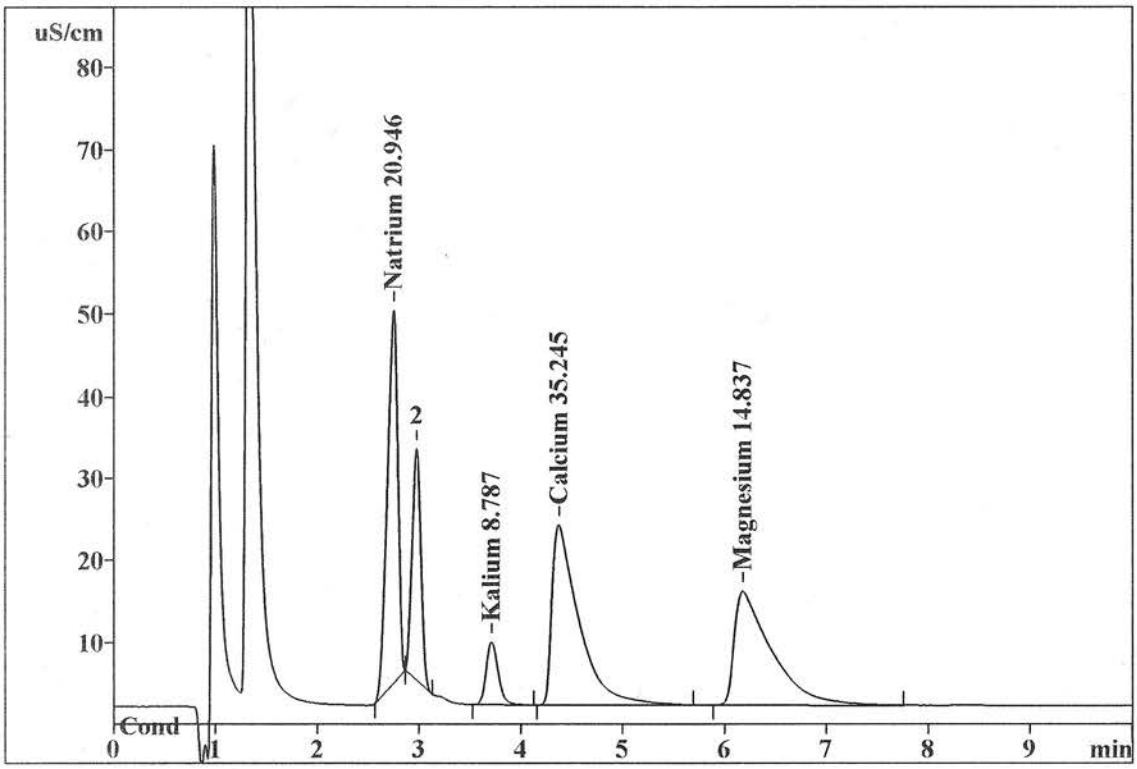
Ident: Kläranlage Ablauf
Analyse vom: 19/07/2016 09:42:30
Datei: _2016-07-19_ gespeichert: 19/07/2016 07:52:29
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1465

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.1 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.75	323.149	3377	20.946	Natrium
2.98	168.494	5657	0.000	
3.71	63.499	4620	8.787	Kalium
4.37	407.333	1256	35.245	Calcium
6.18	355.362	1325	14.837	Magnesium

Gedruckt am: 19/07/2016 10:07:40
Gedruckt von: Wasserlabor

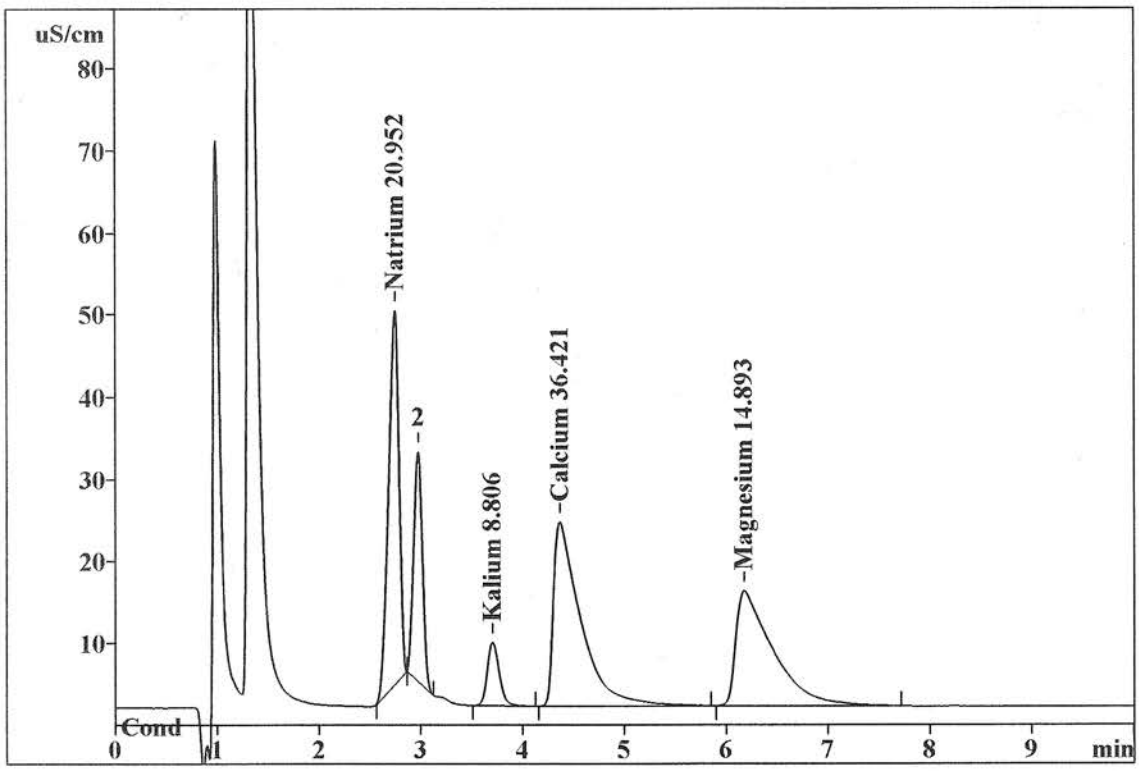
Ident: Kläranlage Ablauf filtriert
Analyse vom: 19/07/2016 09:53:12
Datei: _2016-07-19_ gespeichert: 19/07/2016 08:03:11
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1466

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.1 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.75	323.247	3379	20.952	Natrium
2.98	167.232	5670	0.000	
3.71	63.641	4596	8.806	Kalium
4.37	420.930	1232	36.421	Calcium
6.18	356.692	1337	14.893	Magnesium

Gedruckt am: 19/07/2016 09:36:06
Gedruckt von: Wasserlabor

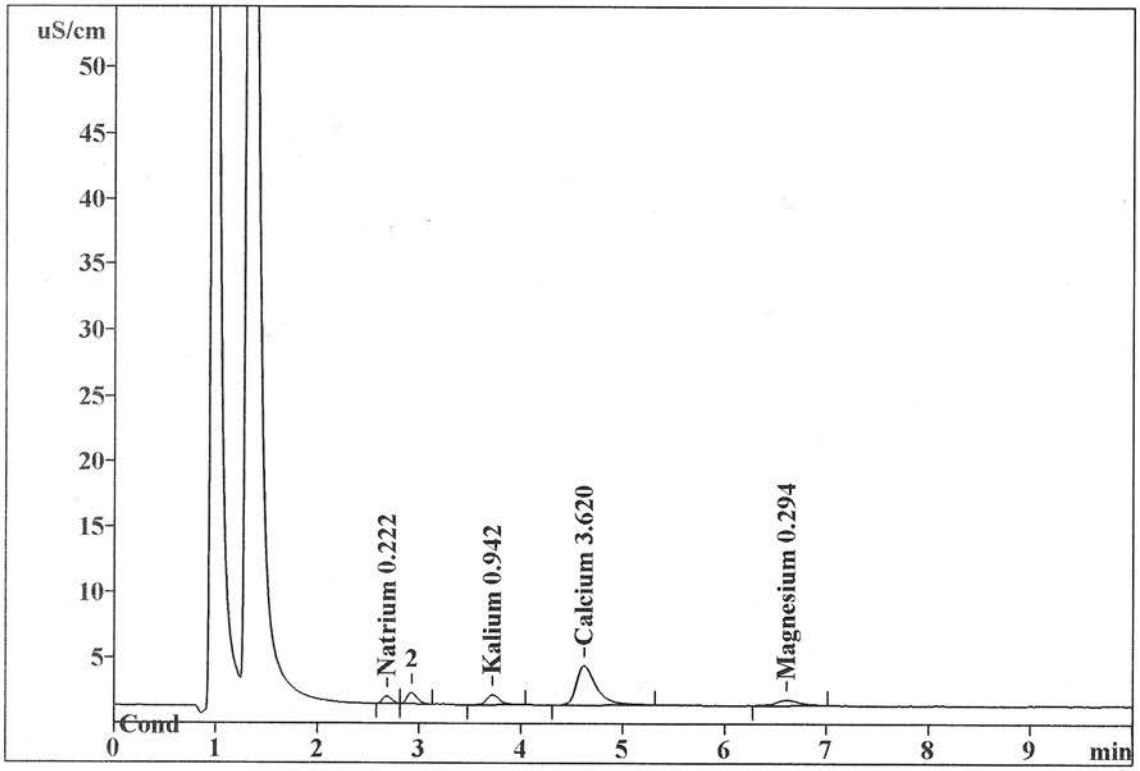
Ident: Rainwater (ton)
Analyse vom: 19/07/2016 09:20:47
Datei: _2016-07-19_ gespeichert: 19/07/2016 07:30:46
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 29/06/2016 1
Benutzer: Wasserlabor
Analysennummer: 1463

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.2 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.68	3.421	4322	0.222	Natrium
2.93	5.605	4182	0.000	
3.72	6.805	3810	0.942	Kalium
4.62	41.835	2536	3.620	Calcium
6.61	7.040	3566	0.294	Magnesium

Gedruckt am: 19/07/2016 09:44:42
Gedruckt von: Wasserlabor

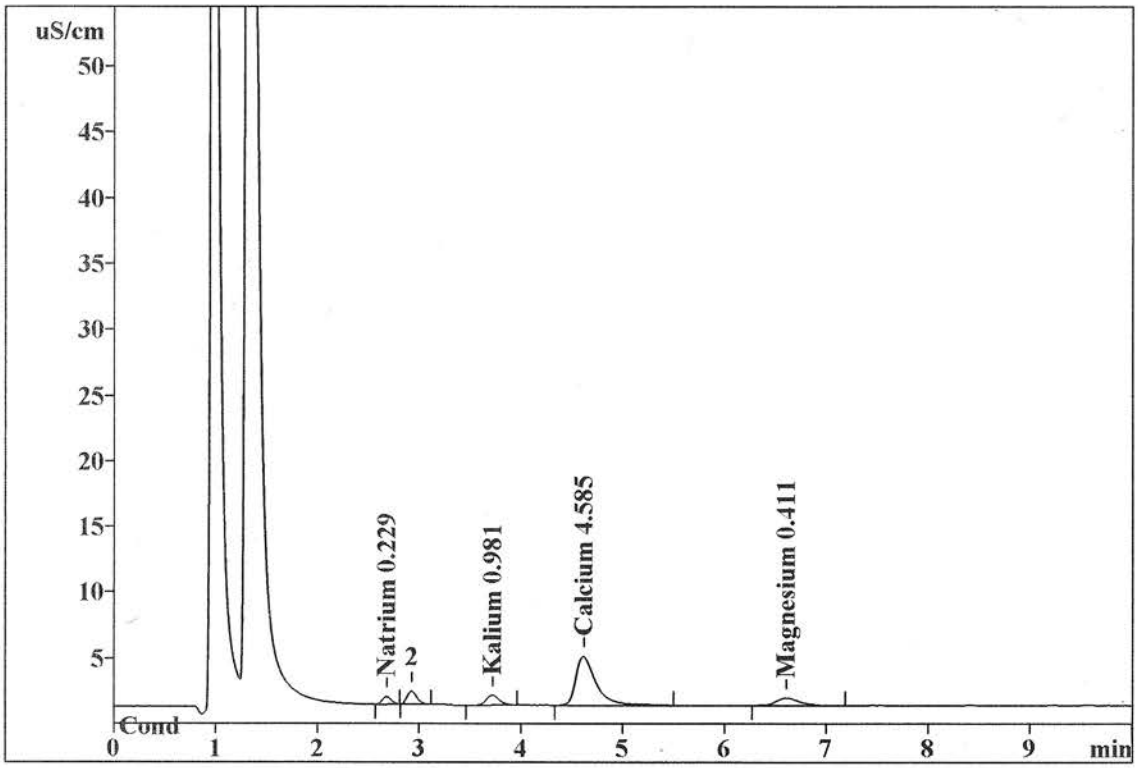
Ident: Rainwater (ton) filtriert
Analyse vom: 19/07/2016 09:31:39
Datei: _2016-07-19_ gespeichert: 19/07/2016 07:41:38
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 19/07/2016 0
Benutzer: Wasserlabor
Analysennummer: 1464

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.2 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.68	3.531	4364	0.229	Natrium
2.93	6.740	4363	0.000	
3.72	7.086	3791	0.981	Kalium
4.62	52.993	2441	4.585	Calcium
6.61	9.848	3683	0.411	Magnesium

Gedruckt am: 19/07/2016 09:13:05
Gedruckt von: Wasserlabor

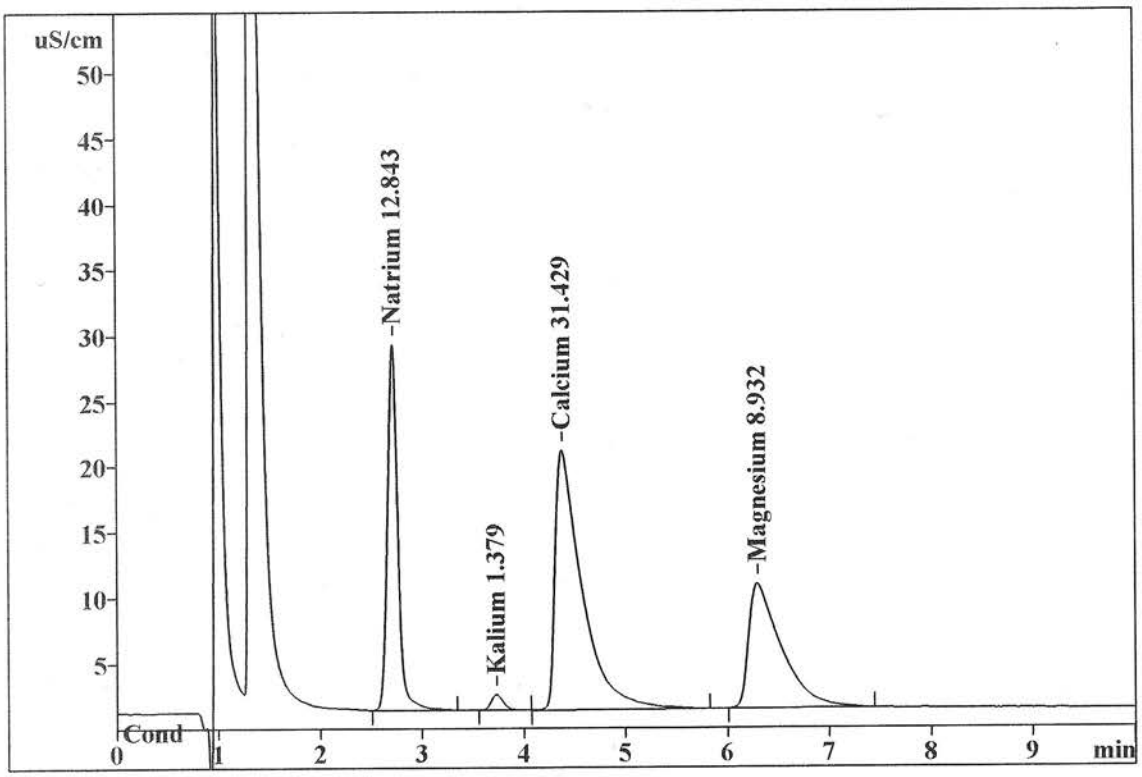
Ident: Brunnenwasser (WELL)
Analyse vom: 19/07/2016 08:58:48
Datei: _2016-07-19_ gespeichert: 19/07/2016 07:08:47
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 29/06/2016 1
Benutzer: Wasserlabor
Analysennummer: 1461

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.2 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.72	198.143	3318	12.843	Natrium
3.73	9.968	4501	1.379	Kalium
4.38	363.238	1290	31.429	Calcium
6.30	213.933	1791	8.932	Magnesium
10.01	785.281	2725	54.584	

Gedruckt am: 19/07/2016 09:22:41
Gedruckt von: Wasserlabor

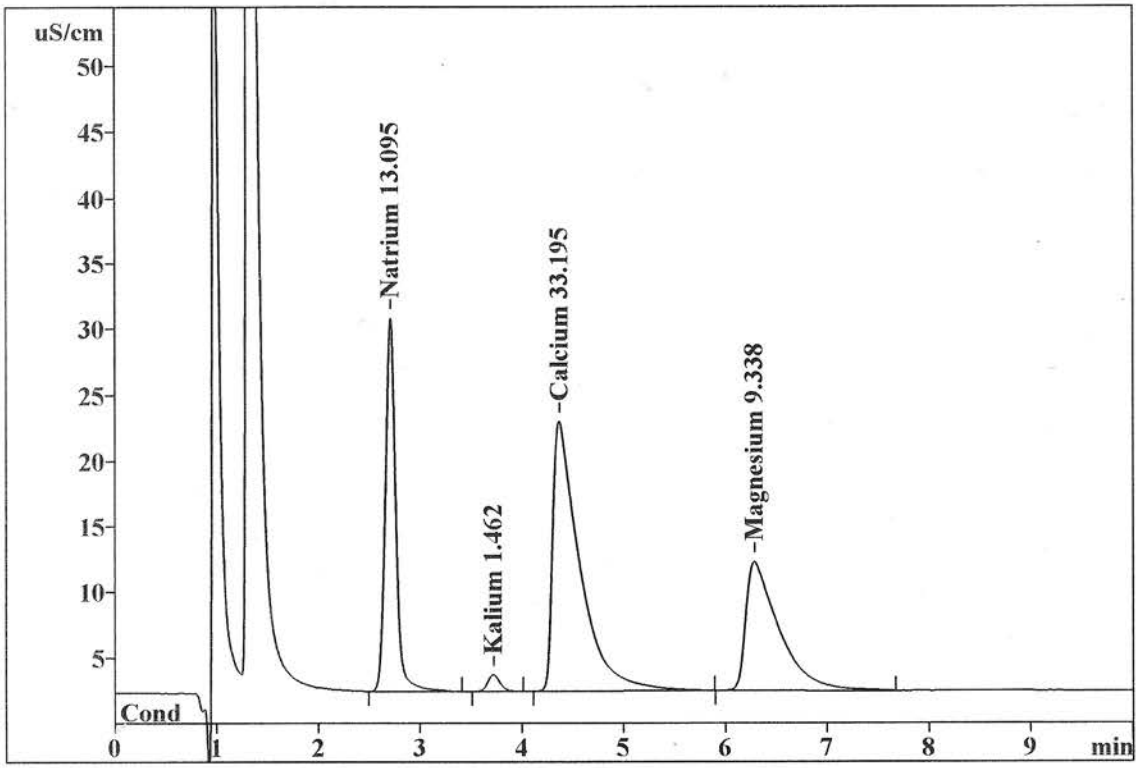
Ident: Brunnenwasser (Filtriert)
Analyse vom: 19/07/2016 09:09:38
Datei: _2016-07-19_ gespeichert: 19/07/2016 07:19:38
Modified!
Methode: Kation C4_Trinkwasser2016 gespeichert: 29/06/2016 1
Benutzer: Wasserlabor
Analysennummer: 1462

PROBE Info 1:
Info 2:
Probengefässnummer: 1
Injektionsvolumen: 20.0 µl
Verdünnung: 1.00
Einwaage: 1.0000

SAEULE: IC Column Metrosep C 4
Abmessung: 4.0 x 100 mm
Seriennummer: 6.1050.410
Korngrösse: 5.0 µm

ELUENT A: 2 mmol/L Nitric acid / 2 mmol/L Dipicolinic acid
B:
C:
Fluss: 0.90 mL/min
Temperatur: 20.0°C
Druck: 7.2 MPa

CHROMATOGRAMM



PEAKTABELLE
Quantifizierungs-Methode: Custom

Retention min	Fläche uS/cm*sec	TP	Konz. mg/L	Name
2.72	202.036	3291	13.095	Natrium
3.72	10.564	4571	1.462	Kalium
4.37	383.648	1246	33.195	Calcium
6.29	223.645	1723	9.338	Magnesium
10.01	819.894	2708	57.090	