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MASTER THESIS

Assessing the performance and handling of three filter designs for water treatment in rural households in Nepal

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Abstract

Household water filtration represents a promising method to improve drinking water quality at the point-of-use. In Nepal, the use of ceramic filters with insufficient performance and a high sensitivity to inadequate operation and maintenance (OM) practices calls for an intervention with high quality water filters and improved household trainings.

This study assessed three filter designs and their handling. The first design was a two bucket filter system with a gravity-driven membrane (GDM) from Germany. Likewise, the second filter design consisted of a raw water and storage bucket and was equipped with a locally produced ceramic candle filter with silver impregnation (MCC filter). The third assessed filter was a hollow-fiber filter produced by Sawyer Products, Inc. and did not include a storage unit. After the distribution of 66 filters to households living in a remote area in Western Nepal and training the local people in the filter's use, microbial water analyses of the raw water and the filtrate were conducted in the laboratory and in the field. A semi-structured questionnaire was carried out with the filter users to assess the influence of handling practices on the performance of the filter.

In the laboratory, all three filter designs significantly improved the water quality. Log removal values (LRVs) for total coliforms of 4.48 (Sawyer), 4.32 (MCC) and 2.17 (GDM) were observed. In the field, 91 % (GDM), 95 % (MCC) and 91 % (Sawyer) of the samples contained 0 CFU/100 mL (*E. coli*). However, recontamination in the storage of the MCC (23 %) and particularly the GDM filters (41 %) was observed. Hence, less recontamination was observed for the MCC filter where colloidal silver diffuses from the MCC candles into the storage. Based on the logistic regression model, handling aspects did not represent a reliable explanation for the different filter performances and recontamination in the storage. Yet, prevalent cleaning practices (e.g. hands, cloths and raw water) could have an influence on the water quality after longer time of filter operation.

The high performance, availability of local supply-chains, cost-effectiveness and the reduction in recontamination makes the MCC filter suitable for the local context. Trainings on adequate OM and the regular replacement of the candles may be crucial to ensure continuous improvement of the water quality. Furthermore, future studies on the long-term performance of the MCC candles is necessary.

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AAS	**A**tomic **A**bsorption **S**pectrometry
Eawag	Swiss Federal Institute of Aquatic Science and Technology
EC	*E. coli*
E. coli	*Escherichia coli*
ETC	*Enterococci*
CI	**C**onfidence **I**nterval
CFU	**C**olony **F**orming **U**nit
CHF	Swiss franc
CGI	**C**orrugated **G**alvanised **I**ron
Filtered I	Filter discharge pipe (sampling)
Filtered II	Tap of the storage bucket (sampling)
GDM	**G**ravity **D**riven **M**embrane
HDI	**H**uman **D**evelopment **I**ndex
Helvetas	HELVETAS Swiss intercooperation Nepal
HH	**H**ouse**h**old
HIS	**H**ealth **I**mpact **S**tudy
HWI	**H**andwashing **I**ndex
HWTS	**H**ousehold **W**ater **T**reatment and Safe **S**torage
LRV	**L**og **R**emoval **V**alue
MAD	**M**edian **A**bsolute **D**eviation
Mdn	**M**edian
MCC	**M**adhyapur **C**lay **C**rafts
NGO	**N**on-**G**overnmental **O**rganization **C**rafts
NR	**N**epalese **R**upee
OM	**O**peration and **M**aintenance
OR	**O**dds **R**atio
PCA	**P**rincipal **C**omponent **A**nalysis
POU	**P**oint-**o**f-**U**se
PUC	**P**oint-**o**f-**C**ollection
SDG	**S**ustainable **D**evelopment **G**oal
SODIS	**So**lar Water **Dis**infection
TC	**T**otal **C**oliforms
TI	**T**oilet **I**ndex
UN	**U**nited **N**ations
UNICEF	**U**nited **N**ations **C**hildren's **F**und
WASH	**Wa**ter, **S**anitation and **H**ygiene
WHO	**W**orld **H**ealth **O**rganization
WI	**W**ealth **I**ndex

Chapter 1

Introduction

1.1 The WASH concept and its impact on public health

Today, still 844 million people lack the access to basic drinking water services [87] and 80 % of this group lives in rural areas [88]. Around the world, over 2 billion people consume drinking water with faecal contamination [84]. In addition, according to the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) of the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), globally 2.3 billion people lack basic sanitation. Furthermore, 47 % of people in least developed countries (LDCs) do not have any hand washing facilities [88]. The WHO estimates a 502,000 diarrhoeal deaths per year due to unsafe drinking water and a total amount of 842,000 diarrhoeal deaths which can be attributed to inadequate Water, Sanitation and Hygiene (WASH) [74]. This accounts for 58 % of global diarrhoeal deaths and 1.5 % of the total disease burden [74]. Globally, diarrhoea remains a major cause of death particularly among children below the age of five and can be traced back to unsafe water and unsafe sanitation in 72 % and 56 %, respectively [2].

With the aim to globally improve the WASH situation the United Nations (UN) launched the Millennium Development Goal (MDG) Target 7.C: "Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation". Whereas according to the JMP by 2015 91 % of the population used improved drinking water, the objective on sanitation infrastructure was not achieved as still 2.4 billion lack facilities [86]. Within the framework of the new development agenda of the UN, the Sustainable Development Goal (SDG) 6 addresses WASH in particularly two subgoals: "By 2030, achieve universal and equitable access to safe and affordable drinking water for all" (SDG 6.1) and "By 2030, achieve access to adequate and equitable sanitation and hygiene for all [...]" (SDG 6.2) [87, p. 2].

Due to the overlap of the three WASH aspects, it is crucial to establish comprehensive WASH interventions in order to improve the public health. A meta-analysis by Wolf et al. [76] provides evidence for the reduction of diarrhoeal morbidity on account of WASH interventions in low- and middle-income countries (LMICs). Moreover, a recent systematic review suggests an association of such interventions with non-diarrhoeal morbidity [21]. Furthermore, preliminary reviews of WASH interventions have emphasised the importance of enhancing the household drinking water quality at the point-of-use (POU) [65]. In a systematic review including 50 studies from LMICs (84,000 participants) Clasen et al. [10] demonstrated that particularly water treatment methods at the household level lead to a reduction in diarrhoeal events. Yet, the fact that household water treatment and safe storage (HWTS) accounts for a reduction in diarrhoea of 30-40 % is quite disputed [62]. Experts criticized that the reporting bias in unblinded studies might account for a part of the measured impact [26, 62].

1.2 WASH situation in Nepal

Pursuant to the MDG assessment report by JMP the MDG 7.C. on drinking water was met due to improved drinking water sources in over 90 % [86, 68]. Among the households without improved water source only 14 % used appropriate household treatment methods [68]. Microbial analyses of the water quality of households with improved water sources have however revealed that at the source there is contamination of *E. coli* in 71 % of the samples [68]. Notably, fecal contamination occurred in 82 % of the households. Despite improvements in drinking water infrastructure, the enhancement of microbial water quality remains a challenge [68].

The first insights from the recent comprehensive Health Impact Study (HIS) by Meierhofer [41] support the findings obtained by UNICEF. Among the 1427 evaluated households in Mid- and Far-Western Nepal, 94 % of the samples at the point-of-collection (POC) showed fecal contamination [41]. 64 % of these water samples contained more than eleven *E. coli* per 100 mL which resulted in a medium risk according to the WHO risk classification of *E. Coli* contamination in drinking water [41]. Notably, the microbial water quality tests revealed that in 70 % there is an increase in contamination at the point-of-use (POU). In general, the WASH situation in the study area in Western Nepal was critical [41]. While most of the households had their own latrines, only 40 % had their own handwashing station of which a fraction ($\approx$ 30%) was equipped with soap. Moreover, the study showed that 16.5 % of the children had diarrhoea in the last seven days [41]. The multivariate logistic regression revealed that there was an association with factors such as a floor made of mud, handwashing after toilet and personal hygiene [41]. In the study area 55.7 % of the children were diagnosed with parasitic infections. Additionally, undernutrition was reported in 55 % of the children and 64 % of the children had clinical signs of nutritional deficiencies [41]. Factors including low personal hygiene of caregiver and child, better hygiene in the latrine and poor water quality at the source are associated with the observed nutritional deficiencies [41].

1.3 Households water treatment methods

If the feasibility or reliability of a centralised piped water supply system is not given, HWTS represents an efficient strategy to improve the drinking water quality at the POU [6, 79, 84]. Additionally, compared to centralised water treatment, HWTS can be more effective regarding the improvement of the water quality and economical aspects [11]. Besides the main objective of HWTS to provide safe drinking water in an economical and sustainable way, HWTS methods are required to be socially accepted and simple in operation and maintenance [79]. In fact, the performance of HWTS methods is extremely sensitive to inadequate operation and maintenance (OM) practices [6]. Therefore, efficient training and education is crucial [53, 42]. In addition, to ensure health gains associated with HWTS methods, correct, consistent and sustained use, referred to as adherence is a prerequisite [6]. A quantitative microbial risk model by Brown and Clasen [6] revealed that a reduction in adherence from 100 % to 90 % results in a decline in health gains of up to 96 %. Recurring expenses, a high user burden and the need of a considerable behavioral change may increase the likelihood of non-adherence [6, 31]. A field study in Rwanda including a membrane filter revealed a continued use of 86 % of the distributed filters after 12-24 months [31]. Besides the simple operation, and the integrated storage, additional support on OM and repair as well as repeated behaviour change messaging were reasons for the high reported adherence [31].

Provided that effective HWTS technologies are operated correctly, these systems have the potential to significantly improve the drinking water quality and reduce the diarrhoeal burden [36, 65, 10, 84]. World Health Organization (WHO) [84] reported a reduction in diarrhoeal diseases up to 61 % for households with such technologies. Based on the principle of disinfection by solar radiation, solar water disinfection (SODIS) is one of these methods. By means of SODIS contaminated water is disinfected in a plastic bottle within 6 h at direct exposure of sunlight [36, 40]. Based on the meta-analyses of Clasen et al. [10], the use of SODIS leads to a reduction of diarrhoea by around a third. Other HTWS methods include the disinfection by boiling or chlorination which have also shown to reduce the risk for diarrhoea by around 25 % [10]. Moreover, different HWTS technologies are based on the principle of filtration. Various studies on consumer preferences indicated that among HWTS technologies household filters are favoured [55] and are also highly accepted in Nepal [70]. Additionally, a higher adherence was shown for household filtration systems compared to other HWTS methods [84]. Based on the principle of size exclusion, various filtration technologies and products were invented to remove colloids, pathogens and suspended solids. For filtration at the POU evidence suggests a diarrhoeal risk reduction of about 50 % [10]. A recent meta-analysis by Wolf et al. [76] revealed that as a result of an integrated safe storage there is a risk reducion of 61 % for diarrhoeal diseases compared to filters without safe storage. Household filtration systems have demonstrated different advantages and disadvantages during efforts of providing safe drinking water at the POU. With regard to the above mentioned criticism on the reporting bias of non-blinded studies, the mentioned values for the reduction in diarrhoea could be biased as Clasen et al. [10] reports a lack of blinding in 80 % of the included studies. The analysis adjusted for non-blinding reveals a smaller but significant effect of chlorination and filtration systems and a non-significant effect of SODIS [10].

1.4 Households filtration systems and their challenges

As a promising HWTS method, different household filtration systems have been invented to reduce the diarrhoeal burden particularly in LMICs by means of improved drinking water quality. Currently, technologies used at the POU are mainly biosand, ceramic and membrane filters.

Biosand filters are adapted from slow sand filters and consist of a concrete or plastic container filled with sand [66, 26]. In this sand column which is covered by a biofilm layer (*Schmutzdecke)*, pathogens and suspended particles are removed by biological and physical processes [26, 66, 65, 16]. Filter design aspects such as the filter depth and the type of sand have shown to be crucial influencing factors when it comes to the removal of bacteria and viruses [57]. A modified design including iron-coated sand has shown to achieve removal values above 2 log for *E. coli* [1]. Globally, a reduction in diarrhoeal illnesses related to biosand filters was demonstrated [57].

In the last 30 years ceramic filters have gained worldwide importance as a low-cost HWTS and represent a very promising POU water treatment technology [5, 53, 30]. Both an improvement of the drinking water quality at the POU and an associated reduction in diarrhoeal events have been shown by various studies [9, 39]. While ceramic filters may efficiently remove bacteria and protozoa, there is a limited effectiveness against viruses [84, 35, 71]. The fired clay in the form of a pot or a candle serves as the porous media that filters the drinking water. Saw dust is used to create the porosity hence an increased percentage of saw dust leads to higher average pore size, a higher porosity and higher hydraulic conductivity [30]. Consequently, this increases the flow rate and may have a negative effect on the performance [30, 84]. These factors related to the production quality have a large influence on the performance [56, 46, 84]. A quality management in local factories is therefore crucial [46].

A recent study conducted in Nepal has revealed that the locally produced ceramic filters improve the water quality only in 40% of the cases [42]. This was due to a generally low performance of the ceramic filters and importantly because of inadequate filter operation and maintenance practices [42]. It is proposed that as a result of low flow rates cleaning practices including extensive brushing resulting in an abrasion of the ceramic layers, were common in the households [42]. This study accentuates the importance of handling aspects as a precondition for the efficient operation of a household filtration system.

Various studies provide support for the fact that the performance of a ceramic filter is increased by additional disinfection using colloidal silver [30, 34, 67]. The silver nanoparticles ($AgNO_3$, diameter: 10–100 nm) are incorporated into the clay candle or a solution including colloidal silver applied on the inside and outside surface of the candle [30, 67]. As a result, the formation of a biofilm is inhibited [64]. Moreover, Meierhofer et al. [43] showed that the presence of silver in the storage container is associated with a reduction in recontamination risks and a decrease in regrowth of both *E. coli* and total coliforms. The silver concentrations leaching into the effluent water depend on the water chemistry, numerous product characteristics and the operation period of the candle [43, 30]. According to the experiments of Kallman et al. [30] the highest amount of colloidal silver is released during the first 12 hours and a slightly lower concentration was observed after then months of usage. Despite the advantageous effect of silver for water treatment, the potential ecotoxicological implications have to be considered. For instance, ionic silver (Ag^+) released from silver nanoparticles may cause oxidative stress and disrupt cellular processes [50]. Therefore, a drinking water limit of 0.10 mgL^{-1} was set by the WHO [83]. This value is based on the no observable adverse effect level (NOAEL) of 10 g for humans as a cumulative dose over 70 years [83]. However, taking into account the fluid requirements and the lower body weight of children as well as other potential silver uptake [37], for small children drinking water should have a maximal silver concentration of 25 μgL^{-1} [43]. This calculation from Meierhofer et al. [43] is based on the tolerable daily intake value of silver of 2.5 μgkg^{-1} of body weight per day [24].

Membrane filtration constitutes a pressure- or vacuum-driven separation procedure through a semi-permeable membrane [23]. The filtration properties of the selective barrier are determined by the pore size [23]. While micro and ultra filtration is characterised by pore sizes between 0.1 - 0.2 μm and 0.01 - 0.05 μm to remove fine particles, nano filtration features smaller pore sizes (0.001 μm) and allows for the separation of solutes [23]. For water treatment ultra filtration has gained significant interest due to the high removal rates of pathogens. Depending on the pore size, membrane filters are effective against bacteria, protozoa as well as viruses [85, 35]. Gravity-driven membrane (GDM) filtration includes membranes with pore sizes between 20-40 nm that filter water at very low pressures of 10-150 mbar [54]. The GDM technology allows for water filtration without pumping, backflushing or cleaning over an operation time of five to eight years [12]. Due to the accumulation of particles on the surface of the membrane, a biofilm is formed which leads to the emergence of cavities. The water then flows through this porous film in a stable flux [12, 54]. The integrity of the membrane, the pore size, membrane fouling, seals and pipe connections are key parameters that determine the efficiency of a membrane filtration product [85]. Although market prices of membranes have decreased, the financial aspect for particularly decentralised systems, poses an obstacle for households in developing countries [56].

Hollow fibers as a different type of membrane are widely used for applications in medicine and represent another HWTS method [61]. The semi-permeable fibers are stacked in a cartage which allows for water filtration using gravity. Laboratory tests have demonstrated a log removal of six for bacteria (e.g. *Klebsiella terrigena*) and removal values of five log for protozoa [27]. Lindquist et al. [38] demonstrated significantly improved water quality in households and a reduction in diarrhoeal events after an intervention in Honduras using the filtration system Sawyer PointONE^{TM} (Sawyer Products, Inc., Safety Harbor, Florida, USA). In contrast, findings of a recent study in South Sudan revealed that fouling of the hollow fiber membrane associated with highly contaminated influent water and inadequate handling of the filter has led to a reduced performance in only a few months [25]. Hence, the backflushing of the hollow fibers using a syringe has shown to be crucial to ensure a consistent performance.

As demonstrated above, the different household filtration systems have the potential to significantly improve the drinking water quality [84]. In a recent evaluation of different HWTS products, membrane filters performed better than ceramic filters [84]. However, other factors such as social aspects including the acceptance of the product and challenges regarding the OM may impact the efficiency of HWTS. As these factors are highly dependent upon the local context, they have to be investigated in order to ensure the promotion of safe water.

1.5 Study background and aim

This Master thesis is embedded in the comprehensive Health Impact Study (HIS) "Evaluation of the impact of water quality and hygiene interventions on the health status of children in the project area of Helvetas WARM-P Project in Nepal". Previous investigations within the collaboration between HELVETAS Swiss Intercooperation Nepal and Eawag, the Swiss Federal Institute of Aquatic Science and Technology have shown significant improvements in hygiene and sanitation after a WASH education campaign in the project area in Western Nepal. However, due to high recontamination rates between the point-of-collection (POC) and the POU the objective of the HIS is an impact assessment of enhanced water quality infrastructure coupled with effective training's at the household level. During the cross-sectional study in March and May 2018 baseline data on WASH aspects of all 1427 participating households was collected in the study area in Mid- and Far-Western Nepal where previously no water treatment interventions were carried out. Within the scope of HIS in four areas the following interventions are implemented: (I) installation of chlorination system in the water supply scheme, (II) household hygiene education, (III) distribution of high quality households filtration systems including training on adequate OM, (IV) control area without intervention. This study is focused on intervention III. Due to the insufficient performance of locally produced candle filters, this study aims to determine the household water filtration system that will be implemented within the framework of the HIS intervention. Therefore, the main objective is the assessment of three different household filter designs: a GDM filter, a candle filter with silver impregnation (MCC filter) and a hollow-fiber filter (Sawyer filter). Furthermore, due to the potential influence of inadequate filter OM on the water quality, this study takes into account handling aspects of the different filter designs.

1.6 Research questions

This study aims to assess the performance and the handling of three different water filter designs to determine the most suitable household filtration system in the current local context of the study area in Western Nepal. To this end, this study seeks to address the following research questions:

1. How do the GDM, MCC and Sawyer filters perform on improving microbiological water quality in the laboratory?
2. How do the GDM, MCC and Sawyer filter perform on improving microbiological water quality when used by rural households in Nepal?
3. Handling aspects of the three filter designs:
   (a) Can adequate filter operation and maintenance be established by appropriate user's training?
   (b) Can design reduce recontamination that can be caused by inadequate handling?
4. Which filter type shows the highest acceptance and is the most favourable in the current local context?

Chapter 2

Material and Methods

In section 2.1 the study design and context is elucidated and a brief introduction to the study area (section 2.2) of this research project provided. Then, information on the participating households and the questionnaire is given in section 2.3. The filter types used in this study and its distribution in the field is described in section 2.4. To assess the performance of the three filter types, experiments under laboratory conditions were performed as described in section 2.5. Additionally, the performance of the 66 distributed water filters was evaluated in households (section 2.6). Information on the data analysis is provided in section 2.7.

A detailed overview of the experiments conducted in the laboratory of HELVETAS Swiss Intercooperation in Surkhet, the Swiss Federal Institute of Aquatic Science and Technology (Eawag) and in the field in Nepal, is provided in Table 2.1. The outcome variables and the respective section in Materials and Methods is indicated.

TABLE 2.1: Experiments conducted within the scope of this research project. The filter type, the outcome variable and the respective section in Materials and Methods is indicated.

Experiment	Outcome variable	Section
Laboratory (Helvetas / Eawag)		
Air flow resistance (AFR) of MCC candles	AFR [mmhg]	2.5.1
Flow rate of MCC candles	Q [mLh^{-1}]	2.5.1
Filter performance test (all filters)	LRV [1] *E. coli*, total coliforms (filtered I [2])	2.5.2
Brushing experiment I - filter performance (MCC)	LRV E. coli, TC [3] (filtered I)	2.5.3
Brushing experiment I - flow rate (MCC)	Q [mLh^{-1}]	2.5.3
Brushing experiment II - filter performance (MCC)	LRV *Enterococci* (filtered I, filtered II [4])	2.5.3
Brushing experiment II - silver diffusion (MCC)	C_{silver} [μgL^{-1}] (filtered I, filtered II)	2.5.3
Brushing experiment II - disinfection in storage (MCC)	Δ *Enterococci* (CFU [5] /100 mL)	2.5.3
Field (Nepal)		
Filter performance test (all filters)	LRV *E. coli*, TC (filtered I, filtered II)	2.6
Recontamination in the storage (MCC, GDM)	Δ *E. coli*, TC (CFU/100 mL)	2.6

[1] Log_{10} of pathogen concentration [CFU/100 mL] of influent divided by pathogen concentration [CFU/100 mL] of effluent water
[2] Sample at the filter discharge pipe
[3] Total coliforms
[4] Sample at the tap of the storage
[5] Colony-forming unit

2.1 Study design and context

As stated in the Introduction, the overarching framework of this study is the Health Impact Study (HIS) with the goal to assess the impact of water quality interventions in the rural study area in Mid- and Far-Western Nepal. To assess the performance of the three selected filter types a randomised experimental design was conducted in the study area in Nepal. Each of three filter types, the GDM, MCC and Sawyer filter was distributed to 22 households and the users were trained on adequate operation and maintenance (OM) practices. The households were revisited after approximately one month to test the water quality of the raw water, at the discharge pipe of the filter and at the tap of the storage of the GDM and MCC filter. Furthermore, an interview with questions on general demographics, filter operation and maintenance and general water, sanitation and hygiene (WASH) conditions in the household was conducted. By means of an experimental setup in the field laboratory of HELVETAS Swiss Intercooperation in Surkhet, Nepal, the filter performance was assessed. Additionally, a follow-up experiment was conducted at Eawag, Dübendorf, Switzerland. The generally used indicator for faecal contamination, *Escherichia coli* (*E. coli*) was used to evaluate the filters [13, 82]. Additionally, the gram-negative bacteria total coliforms were used as a second indicator [13].

The distribution and installation of the filters as well as the training was carried out between the 29th January and the 2nd February 2019. We then proceeded with the data collection in the field from the 21st February to the 7th March 2019.

2.2 Study area

The Federal Democratic Republic of Nepal is a landlocked country in South Asia and is bordered by India and China. Nepal's diverse geography can be divided into three belts from South to North: the Terai, the tropical region in the Gangetic Plain, the Pahad, the hilly area and the Himal, the mountain region with its highest altitudes in the world. According to the World Bank the population of Nepal was over 29.3 million in 2017 [78]. 81 % of people have reported to live in rural areas [77]. In 2017, the Human Development Index (HDI) of Nepal has reached 0.57 which corresponds to the rank 149 of 189 assessed countries and territories [69]. Importantly, whereas the HDI measures the achievement in the average human development in a country, the Inequality-adjusted HDI includes inequalities within the country. Considering the discount due to inequalities the value of 0.57 falls to 0.43 (-25.6%) [69]. Furthermore, gender-based inequalities are represented in the Gender Inequality Index (GII) where Nepal reaches a value of 0.48, ranking it 118 out of 160 countries [69].

According to Minstry of Foreign Affairs [44] there are then different religions of which Hinduism is the most abundant (81.3 %). Furthermore, there are 123 spoken languages in Nepal and 126 caste/ethnic groups [44]. Hence, a social hierarchy ranks people into different castes with Brahmin, Chhetri, Newari and Thakuri in the highest caste, followed by Janajati (middle) and Dalit in the lowest caste [3, 63]. Despite the fact that the system was abolished using a constitutional amendment, discrimination based on the social status, particularly against the Dalit community, is prevalent [63].

FIGURE 2.1: Map of the study area in Western Nepal showing the provinces (color grading), districts within the provinces and a map extract from Surkhet district. Designed using data from Wikimedia Commons distributors [75] and OpenStreetMap contributors [51].

The Surkhet district as part of the Karnali Province is located approximately 370 km west of the capital, Kathmandu (Fig. 2.1). Our study area, referred to as Surkhet B, is located around 30 km outside of Birendranagar, the capital of Karnali Province (bold frame in Fig. 2.1). The village along the Bheri river belongs to the Lekhbeshi municipality. Compared to villages in the hilly area of Nepal, the topography of the study area is relatively flat. On the hill above the village water is collected in reservoirs and a piped water system provides water in the morning and the evening, respectively. However, as mentioned above, recent water quality tests in 1427 households have revealed that over 95 % of the samples at the POU were contaminated with *E. coli* [41]. While a critical WASH situation in the study area was reported, a high share of children had parasitic infections and showed clinical signs of nutritional deficiencies [41]. Regarding the socio-economic characteristics of the study area, the recent study by Meierhofer [41] revealed that 70 % of the respondents spent less than CHF 137.00 (15.000 NRs) per month. Half of the 1427 investigated households had electricity and wood was mainly used for cooking [41]. Over 80 % of the floors were made from mud and painted with cow dung. While 20 % had a high and 16 % a low socio-economic status, 64 % of the respondents had a middle socio-economic status in the study area Surkhet B [41].

2.3 Participating households and questionnaire

2.3.1 Selection of the households

Prior to the actual distribution of the water filters the participating households were selected together with the local authorities. Potential participants had to be outside of the recently installed chlorination scheme in the catchment areas of the piped water supply scheme. First, during a meeting in Surkhet B the aim of the study and the filter designs were presented to the local User's Committee which is responsible for the water scheme. Additionally, during the meeting the intended distribution process was discussed with Helvetas and the local community. In order to ensure a randomised distribution of the filter types among all households (Fig. 2.2), the lottery method was chosen. To this end, the head of the households was attending the meeting on our distribution day (28.01.2019). All participants were informed about the study purpose and then the member of the household payed NRs. 1000 and took a lottery ticket (numbers 1-3). Based on these numbers the water filters were handed out. The GDM modules were not distributed at this point as they had to be activated first.

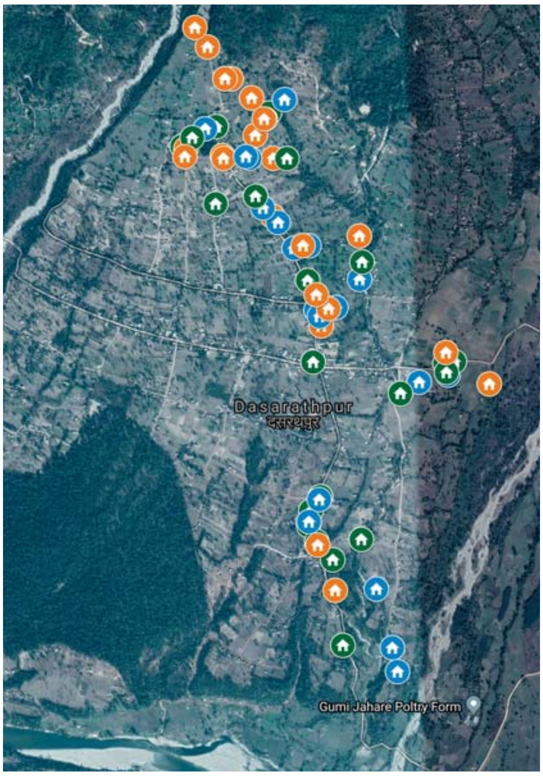


FIGURE 2.2: Selected households in Surkhet B. Indicated in blue are GDM, in orange MCC and in green Sawyer households [22].

2.3.2 Ethical considerations

This study was approved by the Ethical Review Committee of Eawag. To ensure transparency, the participants were informed about the goal and the approach of the study. Before the study informed consent forms were signed by the participant. As an alternative for illiterate participants fingerprints were used. Household members below the age of 16 were not allowed to be part of the study. Prior to the study meetings with the Lekhparsa Drinking Water supply and sanitation User's Institution, the User's Committee of the water scheme and local NGO staff were held to inform about the aim of the study. Additionally, the procedures of the research project including the selection of the households and the distribution of the filters and prices were discussed in detail.

2.3.3 Household questionnaire

To collect information on the households and the filter handling practices a household questionnaire was composed and translated into Nepalese. The survey consisted of 100 questions dived into four categories: A - Household information, B - Wealth index, C - Water handling and hygiene, D - Filter Design, E - Observation through the interviewer. The questions related to wealth aspects were based on the report DHS Comparative Reports No. 6 by Rutstein [60]. As the design and the handling of the water filter varied, not all of the questions were applicable for all filter types. To gather the necessary information dichotomous questions (Yes / No), multiple-choice questions, questions with a likert-skale and some open-end questions were used. The entire survey can be found in the Appendix A (section A.1).

The household questionnaire was set up using the software Open Data Kit (ODK; (University of Washington, Seattle, USA) and the data collection was carried out using the tablet Samsung Galaxy Note A3 (Samsung Group, Seoul, South Korea).

2.4 Water filter types and distribution of the water filters

2.4.1 Selection of filter types and properties of filter products

To ensure improved water quality at the POU the three following water filters were selected for the assessment to subsequently facilitate a large-scale distribution of one of the filter designs within the scope of the HIS.

GDM filter

In a project by Sandec in Uganda membrane filters have been successfully used to provide safe drinking water. In local water kiosks large gravity driven membrane (GDM) filters (MICRODYN-NADIR Biocell 25, Wiesbaden, Germany) were installed [12]. For this study the same technology in a different design was chosen for water purification on the level of the households. The applied filter module CUBE Mini Module (FM 045) is from the MARTIN Membrane Systems AG (Berlin, Germany). It is an ultrafiltration membrane with an area of 0.45m^2 (150 kDalton, 35 nm pore size). Whereas the GDM module was imported all other components were obtained from the local market in Kathmandu. The design included two plastic buckets (32 L) and a tap. The Fig. 2.3 shows the GDM filter design and the membrane module which was attached on the sides of the upper bucket. The filter module costs CHF 30.00 and the additional components (buckets, bolts, nuts, seal rings and a cord) were around CHF 20.00.

(A) (B)

FIGURE 2.3: GDM filter design in one of the households (A) and the membrane module in the upper bucket of the filter (B).

MCC filter

Similar to the widely distributed ceramic filters, is the candle filter produced by the local manufacturer Madhyapur Clay Craft (MCC) in Bhakthapur. Importantly, in an additional production step the candle is impregnated with colloidal silver. Due to the anti-microbial characteristics and the strong adhesion to clay ceramic, there is an increased use of colloidal silver in ceramic filter production [89]. According to the manufacturer of the MCC candles, the method used for the impregnation of the MCC candles is dipping in a solution including colloidal silver. The product used in this study was suggested by HELVETAS Swiss Intercooperation Nepal and was also subject to pretests in the laboratory in Surkhet. The assembly of the water filter is simple and the local distributor provides all the necessary parts. The filter design includes one clay candle, a raw water tank (5 L) and a clean water tank (5 L) with a tap. The design used in this study is shown in Fig. 2.4 The filter including all parts is available on the national market for approximately CHF 13.00 (1400 NRs) and a replacement candle costs CHF 1.70 (190 NRs).

(A) (B)

FIGURE 2.4: Candle filter from MCC Bhakthapur (A) and the impregnated clay candle in the upper bucket of the filter (B).

Sawyer filter

The third water filter assessed is a fibre membrane filter produced by Sawyer Products, Inc. (Safety Harbor, Florida, USA). The Sawyer PointONE^{TM} used in this study contains hollow fiber tubes (diamter 1mm) with a pore size of 0.1 μm [61]. The Sawyer PointONE^{TM} is widely used in developing countries. The design (Fig. 2.5) included a plastic bucket (22 L; Bagmati Plastic Industries Pvt. Ltd, Kathmandu, Nepal) with a price of CHF 3.50 (380 NRs). The Sawyer PointONE is available on the national market and costs CHF 45.00 (5000 NRs).

2.4.2 Assembly of water filters, training and user's manual

During the distribution phase, each of the households was visited to install the filters and to give instructions on the OM of the respective filter design. Furthermore, the GPS data, the head of the family, the filter number was noted, the informed consent forms were signed by the participant and a photo was taken from the household.

To facilitate the on-site assembly of the GDM and Sawyer filter the necessary preparations such as drilling of holes were made in the Office of Helvetas in Surkhet. Furthermore, for each of the filter designs an illustrative manual on the OM of the

(A) (B)

FIGURE 2.5: Sawyer filter design (A) including the Sawyer PointONE (B).

filter type was developed and printed (Fig. 2.6). Please refer to Appendix B for the Manuals in English and Nepalese.

The activation of the GDM modules was performed in the evening before the distribution of the modules. They were soaked in a 500 ppm NaOCl solution for three hours and then rinsed to avoid remaining chlorine. The solution was prepared using a locally available household bleach solution (5.25 % Sodium hypochlorite (NaOCl)). Overnight the modules were kept in the water.

Whereas the MCC filter can be easily assembled without any additional tools, the GDM filter assembly is a more complex process including numerous components and tools. To avoid microbial contamination in the storage containers of the GDM and MCC filters, they were disinfected using chlorine tablets. Prior to the operation start of the filter, the training concerning the OM practices (incl. manuals) of each filter type was conducted in Nepalese.

FIGURE 2.6: Manual with OM aspects in Nepalese on a MCC filter in the field.

2.5 Filter performance under laboratory conditions

To compare the performance of the three filter designs, water quality tests were performed in the field laboratory of Helvetas in Surkhet. The laboratory setup consisted of three GDM filters (GDM Lab 1-3), 12 MCC filters (MCC Lab 1-12) and three Sawyer filters (SAWYER Lab 1-3). The filters MCC Lab 1-6 are analogous to the filters distributed in the field (section 2.4) while MCC Lab 7-12 were part of a second production batch. To investigate the influence of brushing events with different brush types on the filter performance and the diffusion of silver, an additional follow-up study was carried out at Eawag (section 2.5.3).

2.5.1 Air flow resistance and flow rate of MCC candles

According to Helvetas there is an absence of effective quality management in the production of locally produced ceramic filters. The flow rate of the ceramic filter candles serves as an indicator for the quality control [46]. During a visit staff from the Geberit AG have addressed the issue of quality management and suggested to measure the air flow resistance (AFR) of filter candles [46]. In their unpublished report it has been shown that the AFR of the ceramic candles correlates with the flow rates [46].

To assess the AFR [mmhg] of the MCC candles used in this study, an adapted blood pressure measurement device was used (Fig. 2.7). From the 33 tested candles six were selected for the laboratory tests. To investigate the potential influence of AFR on the performance, two candles with low, middle and high AFR values were selected. Then the candles were put into operation and the flow rates Q [mLh^{-1}] were measured. The raw water bucket was filled with 5 L of water and the volume of filtrate quantified after one hour. The procedure was repeated three times. Due to highly variable flow rates and extremely low values of the first batch which was distributed in the field, a second match of candles was ordered and also assessed in the lab in Surkhet.

FIGURE 2.7: Adapted blood pressure measurement device to assess the air flow resistance of the MCC candles.

2.5.2 Sampling and analysis of the water quality

To evaluate the performance of the GDM, MCC and Sawyer filter, the water quality of the raw water and the filtrate at the filter discharge pipe was tested. The raw water for the filter tests was collected from a small stream in the South of Birendranagar, Nepal. Before the experiment the raw water containers were emptied. From the collected river water a 10 mL sample was taken for water quality analysis using a syringe. Subsequently, the filter containers were filled with the raw water. After 15 minutes a 100 mL sample was taken from the filtered water and filled into a sterile Whirl-Pak® bag (Nasco, Fort Atkinson, USA). The sample from the GDM filter and the MCC filter were taken directly from the filter discharge pipe (filtered I) rather than the storage. In the case of the MCC filter the sampling was performed using a modified bucket as shown in Fig. 2.8.

(A) (B)

FIGURE 2.8: Installation used for the sampling of the filtrate (A) and sampling at the filter discharge pipe (filtered I) using a Whirl-Pak (B).

All water samples were immediately processed using a filtration kit (DelAgua, Marlborough, Wiltshire, UK), sterile membrane filters (pore size: 0.45 μm, ⌀: 47 mm) and Compact Dry EC plates (Nissui Pharmaceuticals, Tokyo, Japan). After passing the sample through the sterile membrane filter, it was placed on a moistened Compact Dry EC plate. To wet the Compact Dry EC plates, sterile water was used which was boiled every morning, filled into a baby bottle and subsequently boiled again. The tweezers were sterilised using a lighter. The disinfection of the DelAgua filtration device was performed as follows: 2 mL of methanol were added to the lower cup and burned. Once the methanol was almost completely burnt the filtration head was placed over the sample cup. The disinfection took place for ten minutes. Each sample was labelled with the sample ID, the time and the date. Subsequent to the processing of the water sample the plate was placed in the solar-powered incubator (Eawag, Dübendorf, Switzerland) and incubated for 24 hours at 35 $\pm$ 2 $^\circ$. To ensure consistent quality of the procedure a duplicate of every 10th sample was taken. Additionally, every day one negative control using sterilized water was processed.

After the incubation of 24 h the colony forming units (CFU) of *E. coli* and total coliform per 100 mL were counted. If colonies were very numerous, the CFU's were counted manually using the Promega Colony Counter for iOS (Promega Corporation, Madison, Wisconsin, USA) as shown in Fig. 2.9. The counts were recorded in the note book as well as on the plate using a permanent marker.

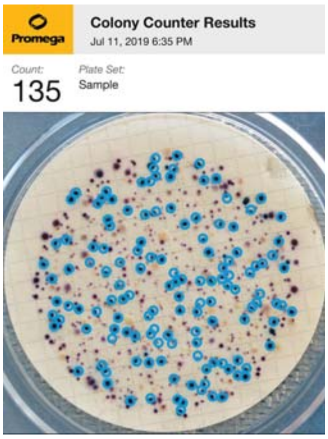


FIGURE 2.9: Sample plate with both CFU/100 mL of *E. coli* and total coliforms. Here *E. coli* were counted using the Promega Colony Counter.

2.5.3 Filter performance and durability test of MCC candles

A recent study revealed that extensive or frequent brushing of the ceramic filter candle might be a common practice to increase the flow rates [42]. It was suggested that this physical damage of the ceramic layers may lead to a reduced filter performance [42]. As mentioned above, the effectiveness of the MCC candles is enhanced by the colloidal silver coating on the filter candles. To investigate the influence of brushing, the candles on wearing off this silver layer and therewith possibly reducing the filter's performance, two experiments were performed.

Brushing experiment I

The first experiment was carried out in the field lab in Surkhet with four MCC candles. Two candles from the first and two candles from the second production batch with relatively low AFR values were selected. The water quality tests were performed as described in section 2.5.2 and repeated three times. Additionally, the flow rate of each candle was measured as described in section 2.5.1. Subsequently, the MCC candles were extensively brushed using a steel brush and then the performance was assessed. After three iterations of this procedure, the flow rate measurements were repeated.

Brushing experiment II including silver measurements

In the laboratory at Eawag (Dübendorf, Switzerland) an additional experiment including soft, middle (mid) and hard brush types was conducted (Fig. 2.10). Two candles were used per brush type and one was used as the control. First the initial performance of the candles and the silver concentration of the filtrate was analysed three times. Subsequently, with each brush type two MCC candles were consistently brushed for one minute and the system flushed over night. Then the buckets were filled again with spiked water and the microbial analysis and the sampling for the silver measurement was performed again (filtered I). After ≈ 3-4 hours the storage container was shaken and again samples for the microbial analysis and the silver measurements were taken (filtered II). The whole procedure was repeated three times.

The analysis was performed using tap water spiked with *Enterococci*. The powder of one tablet Bioflorin (Sanofi-Aventis (Suisse) SA, Vernie, Switzerland) was added to a laboratory glass bottle (1 L) and mixed with 1 L tap water (not cholorinated). From this stock solution 20 mL were added to 4 L of tap water using a pipette. Before filling the filter a 1 mL sample was taken for water quality analysis of the raw water. This raw water sample was diluted with tap water (1:9) and subsequently 1 mL was pipetted directly onto a Compact Dry ETC plate (Nissui Pharmaceuticals, Tokyo, Japan). Then the sample from the filter discharge pipe was taken and analysed as described in section 2.5.2. Due to uncertainties concerning the amount of CFU/100 mL of filtered water and a maximal detection limit of 300 CFU/100 mL a sample of 1 mL and a sample of 100 mL were taken and analysed in accordance with section 2.5.2. To moisturise the ETC dry plate NANOpure water (Thermo Scientific Barnstead NANOpure Water Purification System, Waltham, USA) was used. The plates were then incubated for 24 h at 37 °C. To analyse the diffusion of silver from the candle into the stored water a 10 mL water sample was taken from the filter discharge pipe, mixed with 100 μL of nitric acid (65%) and stored in a tube at 4°C.

To quantify the dissolution of silver atomic absorption spectrometry (AAS) was used. In the case of high silver concentrations, a repeated measurement was carried out after the automatic dilution of the sample.

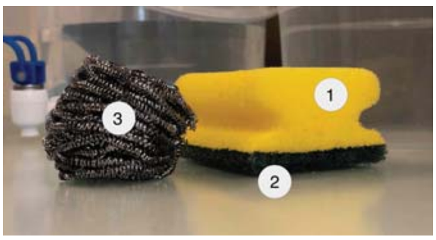


FIGURE 2.10: Different brush types: (1) soft, (2) middle and (3) hard brush

2.6 Data collection in the field

At each household, in the first step the buckets of the water filters and the drinking water container used by the households were emptied. Then a household member was asked to fill the water container at the tap. In a second step from this container a 100 mL water sample was taken for water quality analysis and filled into Whirl-Pak® bag (Nasco, Fort Atkinson, USA) and subsequently, the raw water bucket of the filter device was filled using the collected raw water. In a few Sawyer households no transport container was used as the bucket can be easily filled directly at the tap. To ensure a representative water sample in these cases, the sample for water quality analysis was taken after letting the tap run for 30 seconds. In the third step, a 100 mL water sample was taken directly after the filtering process from the filter discharge pipe and filled into a Whirl-Pak®. Due to the low flow rates of the MCC candles this sample was taken using the sampling bucket depicted in Fig. 2.8. As the GDM filter and the MCC filter design included a storage which could be subject to recontamination, in the forth step an additional 100 mL water sample was taken from the tap of the safe water bucket and filled into a Whirl-Pak®.

All water samples were directly processed at the household using a filtration kit (DelAgua, Marlborough, Wiltshire, UK) as described in 2.5.2 and illustrated in Fig. 2.11. Each sample was labelled with the sample ID, the time and the date. At lunch time and in the evening the plates were placed in a solar-powered incubator (Eawag, Dübendorf, CH) and incubated for 24 hours at 35 ± 2 °C. To ensure a consistent electricity supply for the incubator a solar panel and a car battery were installed at the study site. Analogous to the lab experiments every 10^{th} water sample was duplicated to ensure a consistent processing. After the incubation of 24 hours the colonies were counted in the field as described in section 2.5.2.

(A) (B)

FIGURE 2.11: Field laboratory setting including the DelAgua filtration kits, Compact Dry EC plates, sterile membrane filters (A) and filtration of a water sample collected using a Whirl-Pak® (B).

2.7 Data analysis

The data from the water quality tests and the questionnaire was analysed in Excel 16 (Microsoft Corporation, Redmond, Washington, USA), SPSS 25 (IBM, Armonk, New York, USA) and RStudio 1.2 (Rstudio, Inc., Boston, Massachusetts, USA). More detailed information on the statistical analysis and the calculation of the log removal values (LRV), the compliance rate, indicator for recontamination and the applied indices is provided in the following sections.

2.7.1 Statistical analysis

The assessment of the normality was performed graphically and numerically using the Shapiro–Wilk test. Whereas, as part of the descriptive statistics such as the mean $\pm$ standard deviation were calculated for normally distributed data, the median (Mdn) and median absolute deviation (MAD) were computed for data violating the normality assumption. Statistical hypotheses testing was conducted using t-tests for data following normal distribution. In the case of a violation of normality, for bivariate analyses Wilcoxon rank-sum tests were performed. To test differences between several independent groups violating the assumption of normal distribution, the non-parametric Kruskal-Wallis test was conducted. Subsequently, a non-parametric *post hoc* test analogous to the Wilcoxon rank-sum test was carried out to compare the different groups as suggested by Field et al. [18].

For further analyses the water quality data was categorised in accordance with the *E. coli* classification of the World Health Organisation (WHO) [80]. The CFU/100 mL of total coliforms were categorised analogously.

TABLE 2.2: *E. coli* classification by the World Health Organization (WHO) [80].

CFU/100 mL	Classification
0	In conformity with WHO guidelines
1 - 10	Low risk
11 - 100	Intermediate risk
101 - 1000	High risk
>1000	Very high risk

2.7.2 Compliance rate, log removal value (LRV) and recontamination

To assess the impact of our training on OM practices a compliance rate was composed which is based on the information retrieved after one month of filter operation. It included handling aspects which were both part of the training session during the distribution and queried in the survey. The composition of the variables included in the compliance rate depended on the filter type. All aspects are presented in Table 2.3. The instructed handling practice always represents 1. Therefore, some variables were re-coded or their scale adjusted to ensure that 1 is always the appropriate answer which matches the instruction from the training and the OM manual. The performance indicator of each filter type was calculated in accordance with formula 2.1. The number of households in compliance with the variable i was divided by the total amount of households (N = 22 if not specifically indicated). Subsequently, the average of the n quotients was calculated and multiplied by 100 (equation 2.1).

$$\% \text{ Compliance Rate} = \frac{\sum_{i=1}^{n}\left(\frac{\text{Number of HH in compliance (Variable i)}}{\text{Total number of HH (Variable i)}}\right)}{n} \times (100) \qquad (2.1)$$

The log removal value (LRV) as a measure for the filter performance was calculated using the $\log_{10}$ of the influent divided by the effluent CFU/100 mL of *E. coli*, total coliforms and *Enterococci* in the case of the brushing experiment II. The $\log_{10}$ will be referred to as log.

To quantify potential recontamination, re-growth or additional disinfection in the storage container, the difference between CFU/100 mL at the filter discharge pipe (filterd I) and the CFU/100 mL at the tap of the storage (filtered II) was calculated and expressed as Δ *E.coli*, Δ *Enterococci* and Δ total coliforms, respectively.

TABLE 2.3: Variables *i* included the compliance performance indicator for each of the filter types (N = 22). The number *n* of variables per filter type is indicated. In the coding, 1 represents the instructed handling practice.

Filter Type	Variable i	Coding (1 = instructed handling practice)
	Clean filter	0 = cleaning, 1 = no cleaning
GDM (n = 3)	Cleaning membrane module	0 = cleaning, 1 = no cleaning
	Top bucket removed	0 = removed, 1 = not removed
	Clean filter	0 = no cleaning, 1 = cleaning
	Clean frequency candle	0 = no cleaning, 1 = cleaning every week
MCC (n = 5)	Clean materials: raw water	0 = raw water, 1 = no raw water
	Clean materials: boiling water	0 = no boiling water, 1 = boiling water
	Clean materials: brush	0 = no brush, 1 = intended brush
	Clean filter	0 = no cleaning, 1 = cleaning
Sawyer (n = 3)	Clean frequency backflush	0 = no backflushing, 1 = backflushing
	Backflush water (N = 9)	0 = use of raw water, 1 = use of filtered water

2.7.3 Wealth, handwashing and toilet index

In order to aggregate the information on wealth and hygiene aspects, principal component analysis (PCA) was used [73, 19]. By means of this mathematical model variables are reduced to uncorrelated variables or more specifically principle components [17]. As not all factors may be retained in the analysis, there are various criteria to exclude factors of less statistical importance [17]. In accordance with Kaiser [29] all factors with values below 0.5 in the anti-image correlation matrix were excluded and the analysis repeated. Then, using a method described by Cattell [8] which includes a so-called scree plot, the factors with high eigenvalues were selected. Also based on the Kaiser's Criterion all factors with eigenvalues above 1 were retained [28]. As defined by Krishnan [33] from the factor scores, the Non-Standardized Index (NSI) was calculated using the equation 2.2. The subsequent standardisation was based on equation 2.3 [33]. Overall, three indices were composed: a wealth (WI), handwashing (HWI) and a toilet (TI) index.

$$NSI = \sum_{i=1}^{n} \left(\frac{\text{Variance explained by factor i score}}{\text{Total variance explained}} \right) \times (\text{factor i score}) \tag{2.2}$$

$$SI = \frac{NSI - \text{Min } NSI}{\text{Max } NSI - \text{Min } NSI} \times 100 \tag{2.3}$$

2.7.4 Logistic regression models

To investigate the influence of social parameters, WASH conditions and handling aspects on the performance of the water filters, two logistic models were generated in accordance with Field [17]. Based on evidence from the literature and bivariate analyses with the target variables and the explanatory variables, potentially relevant parameters for the models were identified. While the GDM and MCC filters had similar design characteristics and therefore equivalent handling practices, the Sawyer filter had different properties and handling aspects. For example there was no storage that could be subject to recontamination. Therefore, in both models only data from GDM and MCC households were incorporated.

For the first two logistic regression models the variables Δ *E.coli* and Δ total coliforms as a measure for recontamination were selected as the dependent variables. For this, binary variables were formed with uncontaminated (0 = 0 CFU/100 mL) and contaminated (1 = > 0 CFU/100 mL). Then the binary logistic model was carried out. To assess the impact of household factors on the LRV for *E. coli* and total coliforms the LRVs were divided into three categories: III = $\geq$ 4 log, II = $\geq$ 3 log, I = < 2 log [81]. Subsequently, with the outcome variable and the household factors a ordinal regression model was computed. The statistical significance was tested using the Wald test. In addition to the p-value, the odds ratio (OR), the 95 % Confidence interval (CI), the estimated logit coefficient (B) and its standard error (S.E.) were reported.

Chapter 3

Results

The findings of this thesis are presented in five subsections. In the first section (3.1) insights on the demographics, wealth and WASH aspects in the rural study area in Western Nepal are provided. The results from the laboratory filter tests are presented in section 3.2 while the results from the performance tests in the field are elucidated in section 3.3. In section 3.4 the findings from the survey on the handling aspects is presented and finally, the acceptance of the three filter designs addressed (section 3.5).

3.1 Demographics, wealth and WASH aspects

3.1.1 Socio-demographic characteristics

Around 85 % of the respondent were female and the participants had an average age of 36 $\pm$ 13 years and were between 17 and 70 years old. In the majority of the households (62 %) lived four or five people and in 47 % of the households lived children below the age of ten. About 35 % of the respondents belonged to the lower Dalit caste. In our study area 20 % can neither read or write. While almost 14 % had no educational background, a high share of the respondents (42 %) had access to education until secondary school. 65 % of the women did not have an employment and quarter of the men worked in agriculture. About the same amount of men had a foreign employment. A detailed overview of the socio-demographic characteristics of the households in the study area is in the Appendix of this document (Table B.5).

3.1.2 Socio-economic characteristics

The typical household in this study in Surkhet B (Fig. 3.1) spent between 10,000 - 19,999 Nepali Rupees (CHF 90.00 - 180.00[1]), had a mobile phone (83 %) and access to electricity (86 %). Additionally, almost half of the households had a television. For cooking the families almost exclusively used wood (97%). In Fig. 3.1 a typical kitchen is shown in proximity to animals. The house with between three and five rooms (62 %) was made from stones and mud (62%), has corrugated galvanised iron (CGI) sheets on the roof (49 %) and a floor made from earth (71 %). 67 % of

[1] Exchange rate: 1 CHF = 111.73 NPR [15]

the household owned less than 10 kattha of land which is equivalent to less than 0.84 acres. While this represented an average household for example every third household spent less than 10.000 Nepali Rupees (≈ CHF 90.00[1]). Some did not have access to electricity and ten percent stated to own none of the items we included in the survey. The detailed compilation of the socio-economic characteristics of the 66 households is found in the Appendix B (Table B.6).

(A) (B)

FIGURE 3.1: Household with a fireplace to cook outside, a washing station, walls build from stones and mud, CGI sheets on the roof (A) and kitchen in proximity to animals (B).

3.1.3 Drinking water: infrastructure and knowledge

Among the 66 surveyed households almost 90 % had piped water in the house or the yard. Yet, the majority of respondents (58 %) considered their drinking water to be very risky or a bit risky. While 97 % of the households knew water disinfection by boiling, also 94 % of the respondents knew the principle of filtration. Previously, 94 % of the households boiled water to disinfect it. Additionally, every 5th household used filtration with a cloth. Other applied methods were SODIS (9 %) and chlorination (8 %). In the households women were mainly responsible for the household water treatment (wife: 71 %, daughter: 21 %). Around 20 % of the households have used a water filtration system before which were almost exclusively ceramic filters. Whereas high acquisition costs (20 %) were mentioned as an obstacle, the major reason for not having used water filters in the past, is the lack of knowledge (60 %). This includes unawareness about the need of water treatment and also missing knowledge about water filters. In addition, as a reason, the absence of a local market system was mentioned by 9 % of the respondents. Additional data on drinking water and household water treatment is found in Table B.4 in the Appendix B.

3.1.4 Wealth, handwashing and toilet index

Using principal component analysis (section 2.7.3) the wealth index (WI) was calculated to assess the socio-economic status of the individual households. Within our study area there is large diversification of wealth indices (Fig. 3.2). The largest share of households reach a WI between 20 - 40, classified as low (Mdn = 35.25, MAD = 20.49).

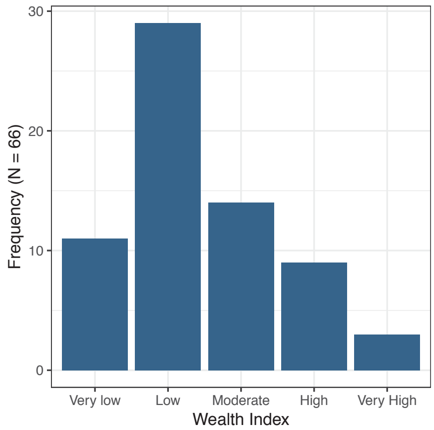
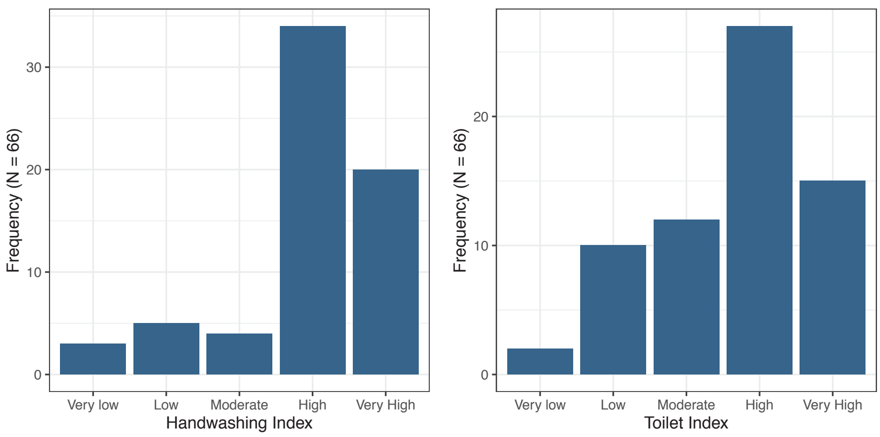


FIGURE 3.2: Wealth index (WI) classified from very low to very high

Fig. 3.3 shows the frequencies of the handwashing index (HWI) and the toilet index (TI) among the 66 participating households. With a median HWI of 76.27 (MAD = 13.00) most of the households were in the category high. Likewise, the majority of the households exhibited a TI between 60 - 80 (Mdn = 73.00, MAD = 18.22) and are therefore also classified as high. Based on the spearman correlation test, the variables HWI and TI are uncorrelated (r_s = 0.056, p = 0.653). Furthermore, neither between the WI and HWI (r_s = 0.139, p = 0.265), nor between the WI and TI (r_s = 0.179, p = 0.150) a significant correlation was observed. The variables included in the indices are presented in the Appendix B (section B.1).



(A) (B)

FIGURE 3.3: Handwashing index (HWI) and toilet index (TI) classified from very low to very high.

3.2 Filter performance under laboratory conditions

3.2.1 Flow rate and air flow resistance of MCC candles

According to section 2.5.1 the air flow resistance (AFR) and flow rate Q of the MCC candles were evaluated. The measurement of the AFR of the 33 candles of the first production batch (MCC 1) resulted in values of 51.4 ± 11.4 mmhg. The average AFR of the 26 candles from the second production batch (MCC 2) was 44.4 ± 8.9 mmhg. As shown in Fig. 3.4 the AFR values from MCC 2 (laboratory candles) were slightly less diversified. The flow rate of the lab candles from the first production batch range between 240 mLh^{-1} and 1480 mLh^{-1} (Fig. 3.4). The lab candles from the second production batch have flow rates between 420 mLh^{-1} and 1200 mLh^{-1}. The relationship between the AFR values and the flow rates determined by the Spearman correlation test is significant (r_s = -0.970, $p < 2.2\times10^{-16}$).

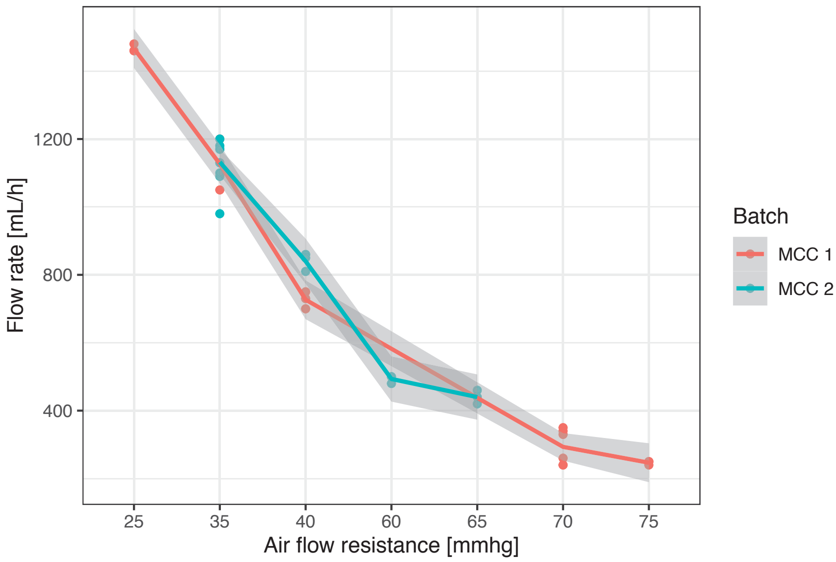
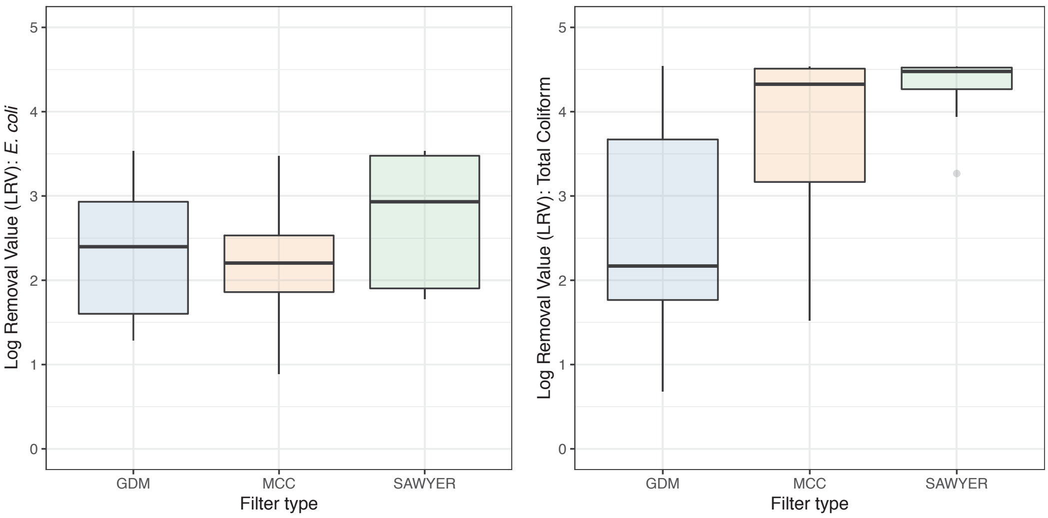


FIGURE 3.4: Flow rate Q and air flow resistance (AFR) of MCC candles. The two assessed production batches MCC 1 (N = 6) and MCC 2 (N = 6) and the confidence interval are indicated.

3.2.2 Comparison of log removal values (LRV)

The performance of the GDM, MCC and Sawyer filter was assessed in the field laboratory in Surkhet (section 2.5). Included in these experiments were 3 GDM, 12 MCC and 3 Sawyer filters. Due to highly variable concentrations of *E. coli* and total coliforms in the river that served as a water source for the experiments, the contamination of the influent water was not constant. Influent concentrations of *E. coli* ranged between 400 - 1,800 CFU/100 mL for the first four iterations and between 20 and 210 CFU/100 mL for the fifth, sixth and seventh iteration of the performance test. Counts of total coliforms were observed up to 18,000 CFU/100 mL.



(A) (B)

FIGURE 3.5: Log removal values (LRV) calculated using the CFU/100 mL of *E. coli* (A) and total coliform (B) of influent and effluent of the filter types GDM (N = 21), MCC (N = 54) and Sawyer (N = 21). The median as well as the lower and upper quantiles and error lines are shown.

Fig. 3.5 shows the log removal of *E. coli* and total coliforms. In the laboratory LRVs of 2.93 (MAD = 0.81) for *E. coli* and 4.48 (MAD = 0.07) for total coliforms were observed for the Sawyer filters. The MCC filters reached LRVs of 2.20 (MAD = 0.49) and 4.32 (MAD = 0.31) for *E. coli* and total coliform, respectively. A similar removal rate of *E. coli* revealed the tests of the GDM filter (Mdn = 2.40, MAD = 1.14). For total coliforms LRVs of 2.17 (MAD 1.14) were observed. The Kurskal-Wallis rank sum test showed a significant difference between the $\log_{10}$ reduction of *E. coli* of the observed groups (($\tilde{\chi}^2(2) = 8.263$, p = 0.016). Whereas the comparison of the mean ranks between the filter designs shows a significant difference between the LRVs of the MCC filter and the Sawyer filter, no other difference was observed between the groups (Table 3.1). There was a statistically significant difference between the LRVs for total coliforms and the different filter types ($\tilde{\chi}^2(2) = 19.794$, $p = 5.031 \times 10^{-5}$). The statistic comparison of the mean ranks between the three groups demonstrates a significant difference between the LRVs of the GDM filter compared to the LRVs of the

MCC and Sawyer filters. The critical difference between the LRVs of the MCC and Sawyer filters was higher than the observed difference hence there is no significant difference.

The correlation tests furthermore highlighted that there was no significant relationship between the LRVs for *E. coli* and total coliforms and the flow rates of the MCC candles (r_s = -0.198, p = 0.247; r_s = -0.186, p = 0.276).

TABLE 3.1: *Post-hoc* test after Kruskal-Wallis test for LRVs of *E. coli* and total coliforms among the three filter types, p = 0.05.

Bacteria type	Compared groups	Observed difference	Critical difference	Difference
LRVs *E. coli*	GDM-MCC	8.065	17.150	False
	GDM-Sawyer	12.357	20.581	False
	MCC-Sawyer	20.422	17.150	True
LRVs total coliforms	GDM-MCC	22.272	17.150	True
	GDM-Sawyer	37.857	20.581	True
	MCC-Sawyer	15.585	17.150	False

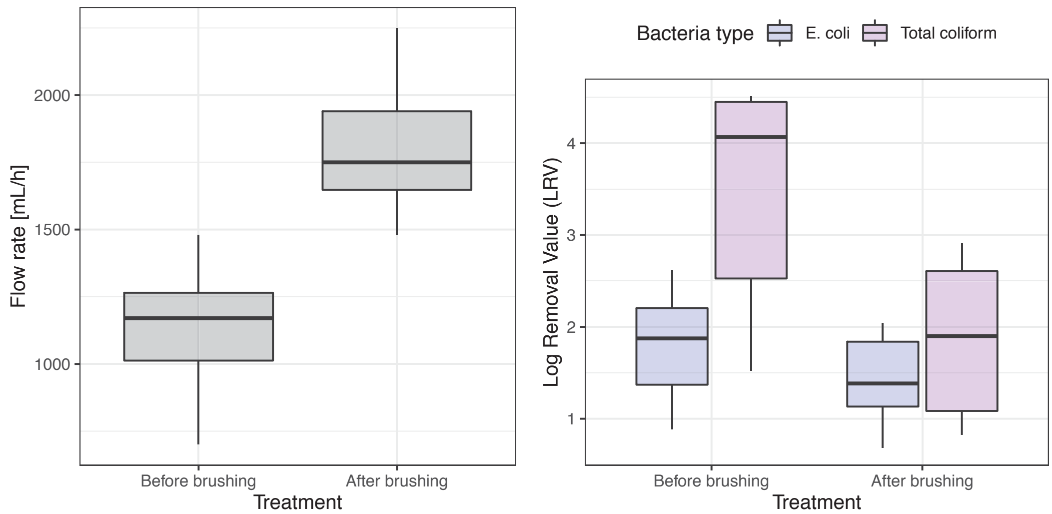
3.2.3 Filter performance and durability test of MCC candles

To assess the effect of extensively brushing the MCC candles, durability tests were performed in the field laboratory in Surkhet and at Eawag (section 2.5.3). Illustrations of the treated and untreated candles are shown in the Appendix B (Fig. B.1).

Brushing experiment I

The three intensive brushing events using a steel brush led to an abrasion of approximately 0.5 cm in diameter. The reduction in the thickness of the ceramic layer has led to an increase in the average flow rates (Fig. 3.6). On average the untreated candles had a lower flow rate (1128 ± 276.51 mLh^{-1}) than the brushed candles (1808 ± 268.97 mLh^{-1}). The difference tested with the Wilcoxon rank-sum test, was significant ($Z = 20.929$, $p = 3.282 \times 10^{-10}$) and represented a large effect $r = 0.988$.

Fig. 3.6 indicates a decrease in the LRVs for *E. coli* and total coliforms before and after the brushing events. Furthermore, the Wilcoxon rank-sum test showed that there was a significant difference ($Z = -3.182$, $p = 0.006$) between the LRVs for total coliforms of the MCC candles before (Mdn = 4.07, MAD = 0.66) and after the brushing events (Mdn = 1.90, MAD = 1.14). In accordance with the Cohen's classification the effect was large ($r = -0.918$). The log removal of *E. coli* before (1.79 ± 0.55) and after (1.43 ± 0.45) the treatment did not significantly differ, $Z = -2.067$, $p = 0.063$, $r = 0.529$.)



(A) (B)

FIGURE 3.6: Flow rate Q [mLh^{-1}] (A) and LRVs (B) of MCC candles for both *E. Coli* and total coliform before (N = 24) and after (N = 24) the brushing event.

Brushing experiment II including silver measurements

To investigate the influence of brushing practices on the performance and the diffusion of colloidal silver, a follow-up experiment was conducted (section 2.5.3).

The spiked raw water used for this experiment contained 370,000 CFU/100 mL of *Enterococci* (MAD = 16,300). Fig. 3.7 depicts the initial LRVs of the MCC candles and the LRVs after each brushing event (Brush 1-3) measured at the filter discharge pipe (filtered I). The performance tests of the seven candles before any brushing resulted in a median LRV of 2.87 (filtered I, MAD = 0.77). When calculating the LRV using the water quality of the raw water sample and the sample of the tap of the storage (filtered II), significantly higher (Z = -2.866, p = 0.004, r = -0.766) median values of 3.56 log (MAD = 0.432) were observed. The silver (Ag) concentrations determined by means of AAS were 32.96 μgL^{-1} (MAD = 3.53 μgL^{-1}) and 36.52 μgL^{-1} (MAD = 15.54 μgL^{-1}) for filtered I and filtered II, respectively.

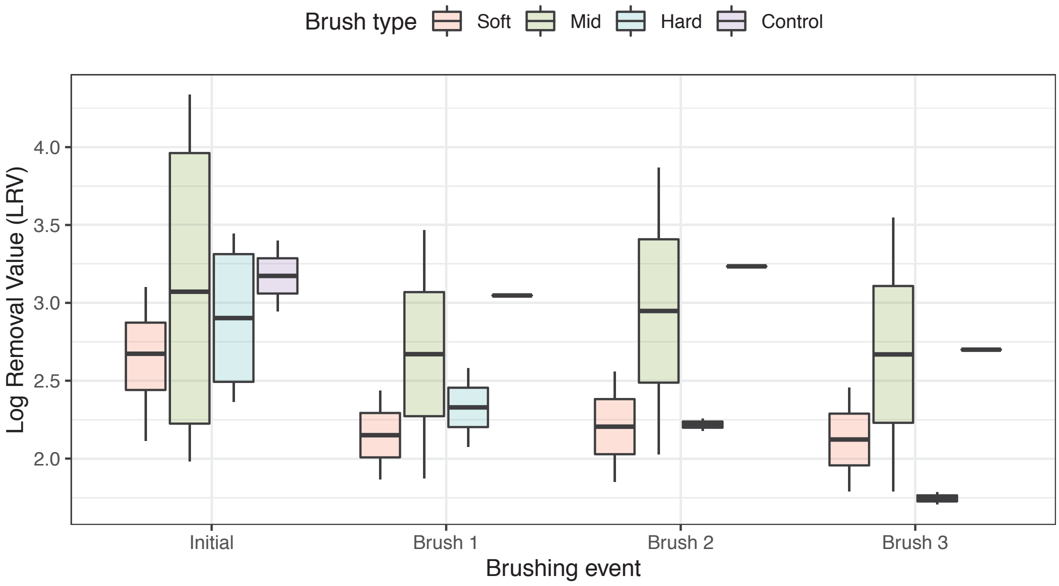


FIGURE 3.7: Influence of brushing events with a soft (N = 2) , middle (N = 2) and hard (N = 2) brush on the LRV's (filtered I) of the MCC candles. The control (N = 1) an the initial LRVs (N = 4 per brush type) are shown.

To analyse the differences in LRVs after the brushing events of the different groups, a Kruskal-Wallis test was performed. The test revealed no significant difference in the LRVs of candles that were treated with soft, mid and hard brushes. However, the comparison between brushed candles and not brushed candles indicated significant differences. The Wilcoxon rank-sum test was performed for each brush type: soft brush: Z = -2.207, p = 0.027, r = -0.698; mid brush: Z = -2.335, p = 0.020, r = -0.738, hard brush: Z = -1.970, p = 0.049, r = -0.623). Comparing the LRVs of the control (Brush 1-3) with the initial values, a similar trend is shown but there was no significant difference (Z = -1.863, p = 0.063, r = -0.589).

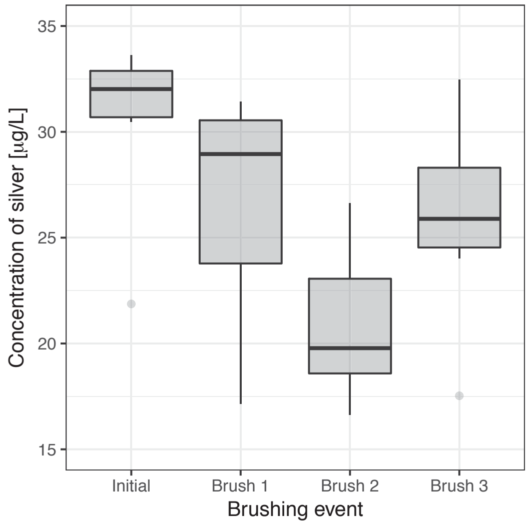


FIGURE 3.8: Initial (N = 14) diffusion of colloidal silver [μgL^{-1}] and after each of the brushing events (N = 7).

Directly after the commissioning of the filter candles silver concentrations between 38 μgL^{-1} and 87 μgL^{-1} were measured in the filter storage bucket. These measurements were excluded from the analyses. Fig. 3.8 depicts a slight decrease of the silver concentrations over the course of time. The Kruskal-Wallis test revealed no significant difference in the silver concentration of candles that were treated with soft, mid and hard brushes. However, the comparison between brushed candles and not brushed candles indicated significant differences. A significant difference was observed for the soft (Z = -2.66, p = 0.008, r = -0.940), mid (Z = -2.66, p = 0.008, r = -0.940) and hard brush (Z = -2.66, p = 0.008, r = -0.940) but not the control (Z = -1.534, p = 0.125, r = -0.686). Compared to initial the silver concentrations, after the brushing of the candles, the silver concentrations of the combined groups were significantly lower (Z = -6.598, p = 4.17×10^{-11}, r = -1.247).

Median silver concentrations (Brush 1, Brush 2, Brush 3) of 25.04 μgL^{-1} (MAD = 6.72 μgL^{-1}) were measured at the filter discharge pipe. Slightly lower values were observed at the tap of the storage (Mdn = 23.81 μgL^{-1}, MAD = 3.50 μgL^{-1}). There was no correlation between the silver concentrations in the effluent water (filtered I) and the LRVs of the filters (r_s = 0.4891, p = 0.489). However, there was a significant correlation between the Ag concentration and the Δ *Enterococci*, the additional disinfection in the storage (r_s = -0.668, p < 0.001).

3.3 Filter performance in the field

3.3.1 Comparison of log removal values (LRV)

Using the described procedures (section 2.6) the performance of 22 GDM, MCC and Sawyer filters was analysed in Surkhet B. The log removal value (LRV) was then calculated using the concentrations of *E. coli* and total coliforms from the influent and effluent water (section 2.7.2).

There was a large variability in the contamination of the influent water source. The concentration of *E. coli* ranged from 0 to over 700 CFU/100 mL with a median of 4.50 (MAD = 5.19). The median of the total coliform counts was 187.5 (MAD = 77.84) and they ranged from 0 to over 2000 CFU/100 mL. Fig. 3.9 shows the LRVs of all filters if samples were taken at the filter discharge pipe directly (filtered I) and at the tap of the storage (filtered II). The median of the log removal of *E. coli* was 0.94 (MAD = 0.70), 0.95 (MAD = 0.52) and 0.95 (MAD = 0.77) for the GDM, MCC and Sawyer filter, respectively. A slightly lower median LRV for *E. coli* of 0.62 (MAD = 1.00) and 0.84 (MAD = 80) was observed after the storage at the tap of the GDM and MCC filter. Substantially higher LRVs for total coliforms than *E. coli* were observed: 2.50 (MAD = 0.48) for the GDM, 2.50 for the MCC (MAD = 0.44) and 2.48 (MAD = 0.26) for the Sawyer filter. As depicted in Fig. 3.10 the GDM exhibited particularly lower LRVs at the tap of storage (Mdn = 1.15, MAD = 0.77). In contrary, this was not observed for LRVs of the MCC filter after the storage. The observed median was 2.49 (MAD = 0.28). All results are characterised by large variabilities in LRVs. Furthermore, the highest LRVs were observed at the highest initial pathogen concentrations.

Between the LRVs for *E. coli* (filtered I) no significant differences among the three groups ($\tilde{\chi}^2(2) = 1.153$, p = 0.562) were found. Likewise, the LRVs for total coliforms (filtered I) were not significantly affected by the filter type ($\tilde{\chi}^2(2) = 0.794$, p = 0.672). Additionally, no significant differences between the LRVs for *E. coli* were observed at the tap (filtered II). However, there is a statistically significant difference between the LRVs for total coliforms among the three filter types ($\tilde{\chi}^2(2) = 13.096$, p = 0.001). The statistic comparison (Table 3.2) of the mean ranks between the three groups shows a significant difference between the LRVs (filtered II) of total coliforms of the GDM filter compared to the LRVs of the MCC and Sawyer filters.

TABLE 3.2: *Post-hoc* test after Kruskal-Wallis test for LRVs (filtered II) for *E. coli* and total coliforms among the three filter types, p = 0.05.

	Bacteria type	Compared groups	Observed difference	Critical difference	Difference
Filtered II	LRVs *E. coli*	GDM-MCC	7.341	13.856	False
		GDM-Sawyer	8.477	13.856	False
		MCC-Sawyer	1.136	13.856	False
	LRVs total coliforms	GDM-MCC	19.409	13.856	True
		GDM-Sawyer	16.523	13.856	True
		MCC-Sawyer	2.886	13.856	False

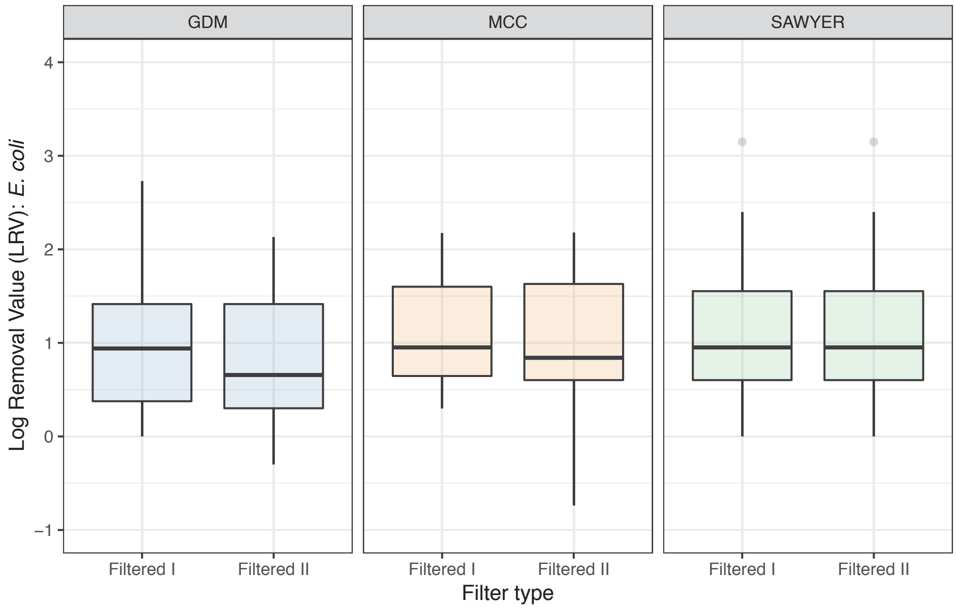


FIGURE 3.9: Log removal values (LRVs) for *E. coli* of filtered I (N = 22) and filtered II (N = 22) for each of the filter types. For the Sawyer filter: filtered I = filtered II. The median as well as the lower and upper quantiles and error lines are shown.

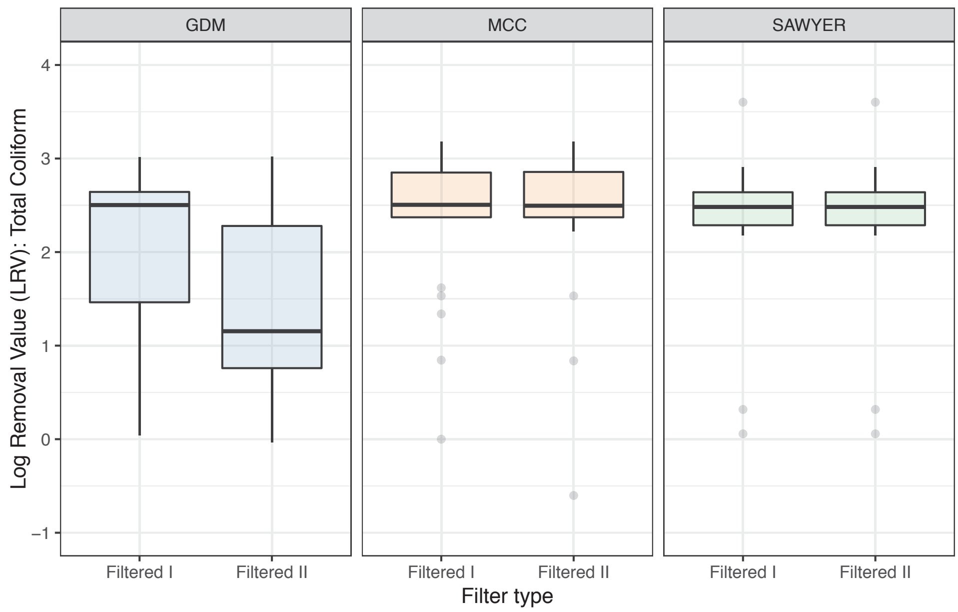


FIGURE 3.10: Log removal values (LRVs) for total coliforms of filtered I (N = 22) and filtered II (N = 22) for each of the filter types. For the Sawyer filter: filtered I = filtered II. The median as well as the lower and upper quantiles and error lines are shown.

3.3.2 Comparison of water quality using the classification by WHO

To evaluate the performance of the filters using the LRVs, the water quality of the raw water, a sample from the filter discharge pipe (filtered I) and a sample from the tap of the storage (filtered II) was assessed. For the user the most important performance value of a water filter is the pathogen concentration at the POU. Therefore, the water quality (filtered II) was categorised in accordance with the *E. coli* classification of the WHO (section 2.7.1). As shown in Fig. 3.11 95 % of all raw water samples were within the categories low risk, intermediate risk or high risk. After the filtering process, referred to as filtered I in Fig. 3.11, 91%, 95% and 91% from the GDM, MCC and Sawyer samples were in conformity with WHO guidelines. The remaining samples exhibited numbers between 1 - 3 CFU/100 mL and were therefore in the low risk category. At filtered II, subsequent to the filtering and the storing, 68 %, 77% and 91 % of the samples from the GDM, MCC and Sawyer filter exhibited *E. coli* counts below one and were therefore in conformity with WHO guidelines. In the case of the Sawyer filter, filtered I and filtered II is equal, as the filter design does not include any storage. At the tap, 32 % of the samples from the GDM filters and 23 % of the samples from MCC filters showed contamination of *E. coli*. The increase in samples classified as low, intermediate and high risk during the period of storage indicates recontamination of re-growth of bacteria in the storage vessel.

Similar to the classification of the *E. coli* counts CFU/100 mL of total coliforms were categorised (section 2.7.1) as depicted in Fig. 3.12. 89 % of all raw water samples contained more than 100 CFU/100 mL and a large fraction (46 %) within the orange category (101 - 1000 CFU/100 mL), exhibited numbers of total coliforms above 400 CFU/100 mL. The efficient filtration processes resulted in 0 CFU/100 mL in 55 %, 86 % and 72 % for the GDM, MCC and Sawyer filter, respectively. Yet, from Fig. 3.12 we note that recontamination or re-growth during storage seems to be present, particularly in the case of the GDM filter. Further results with respect to recontamination are provided in section 3.3.3.

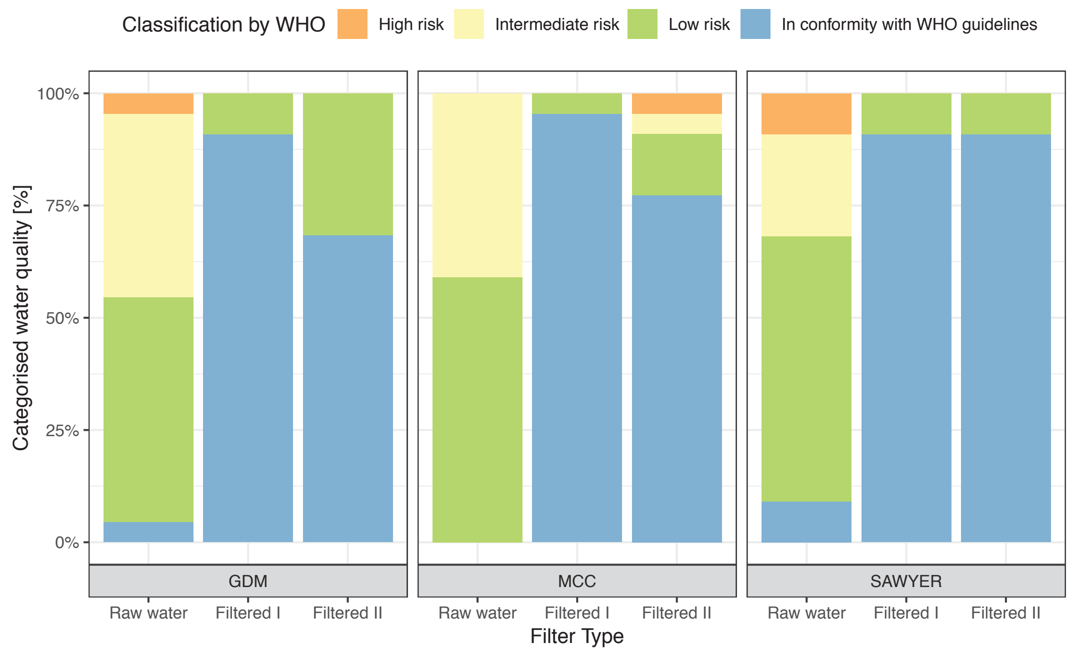


FIGURE 3.11: Water quality (*E. coli*) of raw water (N = 22), filtered I (N = 22) and filtered II (N = 22) of the three filter designs. For the Sawyer filter: filtered I = filtered II. The categories are in accordance with the classification of WHO [80].

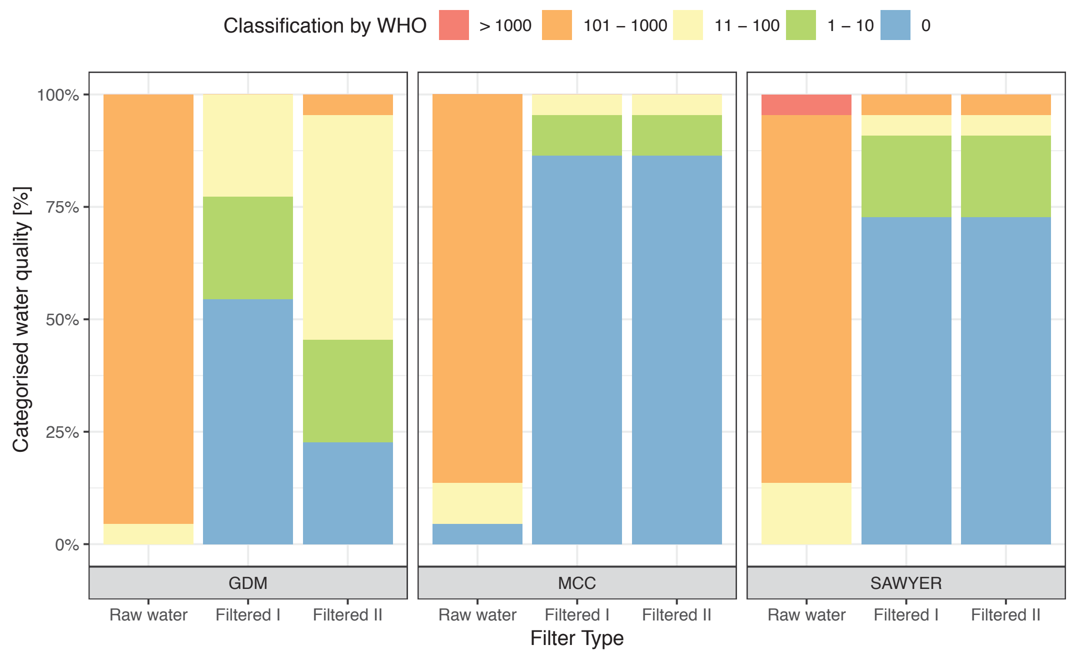


FIGURE 3.12: Water quality (total coliforms) of raw water(N = 22), filtered I (N = 22) and filtered II (N = 22) of the three filter designs. For the Sawyer filter: filtered I = filtered II. The categories are in accordance with the classification of WHO [80].

3.3.3 Recontamination

As shown in previous studies recontamination or microbial re-growth may pose a problem for household filter designs including GDM and ceramic filters [43, 49, 54]. The recontamination was measured as Δ *E. coli* and Δ total coliforms between the filter discharge pipe and the tap of the storage (section 2.7.2). Fig. 3.13 shows samples from a GDM filter with high contamination of *E. coli* (> 250 CFU/100 mL) and total coliforms (> 150 CFU/100 mL) in the raw water and no growth on the plate from the sample directly after filtering. The sample from the tap exhibits both recontamination of *E. coli* and total coliforms (2 and $\approx$ 50 CFU/100 mL).

FIGURE 3.13: EC plates from the raw water, filtered I and filtered II (left to right) from a GDM filter with recontamination or regrowth in the storage.

In the field, in 32 % of the filters or more specifically in 9 of 22 GDM and 5 of 22 MCC filters recontamination of *E. coli* was observed. Furthermore, an increased amount of total coliforms was also observed in water samples of 3 MCC filters. For GDM filters *E. coli* recontamination ranged between 1 and 35 CFU/100 mL (Mdn = 3, MAD = 1.48) and between 2 and 59 CFU/100 mL for total coliforms (Mdn = 13, MAD = 16.31). Samples of the MCC filters exhibited recontamination values between 1 and 114 CFU/100 mL (Mdn = 1, MAD = 0) and between 1 and 57 CFU/100 mL (Mdn = 2, MAD = 1.48) for *E. coli* and total coliforms, respectively. The samples from the GDM filters (15 of 22) were significantly more contaminated ($Z = -2.757$, $p = 0.006$, $r = -0.416$) with total coliforms than the samples from the MCC filters. A significant relationship between the filter type and the recontamination was not observed for *E. coli* ($Z = -1.544$, $p = 0.123$, -0.233). Further Spearman correlation tests have shown that there was no significant correlation between the *E. coli* and total coliforms counts directly after filtering and Δ *E. coli* and Δ total coliforms ($Z = 1776.6$, $p = 0.989$; $Z = 1521.4$, $p = 0.532$).

Regarding the Sawyer filter recontamination may also pose a risk for users who store the drinking water in containers before the consumption. Only two households assert to use an additional storage, namely a jerrycan and a Gagris. Latter is usually used to transport water from the water source. In both vessels recontamination of *E. coli* and total coliforms was observed.

3.4 Handling of the water filters and compliance with user's training

As mentioned in section 2.4 after the onsite installation of the filters, users were trained and manuals on the appropriate OM were handed out. The results on handling aspects and whether the households have complied with the training, are presented in the following subsections.

3.4.1 Handling of the three filter designs

Table 3.4 shows OM aspects of the GDM, MCC and Sawyer households. All households stated to use the distributed filter as their main drinking water source. However, 3 MCC households and 5 Sawyer households claimed to consume water from another source. MCC households used additional tap water due to the insufficient amount provided by the MCC filter. While 3 Sawyer households used another candle filter, two MCC households boiled water to disinfect it.

Whereas the majority of GDM and Sawyer households filled their water filter twice per week, 68 % of MCC users stated to fill it once per day. 66 % of all households used a steel jug for their drinking water. Furthermore, plastic bottles and cups are widely used. Only three households claimed to use an additional storage container for their drinking water. Generally, the MCC filter was cleaned more frequently than the other two filter designs. With respect to the cleaning of the filter parts, almost all participants cleaned the inside and the outside of the steel buckets, mostly once per week. This cleaning practice was less prevalent in GDM and Sawyer households. The backflushing of the Sawyer filter was not carried out by the majority of the users. Additionally, over 60% of the households used unfiltered water for this cleaning procedure. From the households stating to clean the candle, 80 % cleaned it every week. Most households used their hands, a brush and either raw water or boiled water to clean the MCC candle. The aggregated frequencies of cleaning materials among the 66 households for various filter parts show that hands are mostly used, followed by a brush (Table 3.3). In general, raw water is used to clean the different filter parts.

TABLE 3.3: Cleaning materials used by the 66 households to clean the filter parts tap, lower bucket (inside and outside), lid, upper bucket (inside and outside).

Material used for cleaning	Number (N = 396 [1])	%
Raw water	159	40.2
Boiled water	35	8.8
Hands	193	48.7
Soft cloth	15	3.8
Brush	110	27.8
Soap	18	4.5

[1] Response count of the 66 participating households on the cleaning materials used for six filter parts

TABLE 3.4: Handling aspects of the GDM, MCC and Sawyer filter mentioned by the households included in this study. Unless otherwise indicated: N = 22 per filter type.

	Filter type					
	GDM		**MCC**		**Sawyer**	
Variable (N = 22 if not indicated)	**Number**	**%**	**Number**	**%**	**Number**	**%**
Main drinking water source						
Distributed filter	22	100	22	100	22	100
Other source	0	0.0	3	13.6	5	22.7
Frequency of filling						
Once per day	7	31.8	15	68.2	4	18.2
Every second day	0	0.0	0	0.0	1	4.5
About twice per week	12	54.5	6	27.3	13	59.1
Once per week	1	4.5	1	4.5	2	9.1
Less than once per week	2	9.1	0	0.0	2	9.1
Safe water container						
Additional storage	0	0.0	1	4.5	2	9.1
Cup	7	31.8	5	22.7	5	22.7
Jug	17	77.3	13	59.1	14	63.6
Pan	0	0.0	0	0.0	1	4.5
Bottle	8	36.4	4	18.2	6	27.3
Other	2	9.1	1	4.5	1	4.5
Cleaning frequency						
Every day	0	0.0	0	0.0	3	13.6
Once per week	8	36.4	17	77.3	5	22.7
Every two weeks	2	9.1	5	22.7	4	18.2
Never	12	54.5	0	0.0	10	45.5
Filter cleaning process						
Outside of upper bucket	9	40.9	20	90.9	12	54.5
Inside of upper bucket	6	27.3	22	100.0	12	54.5
Lid upper bucket	10	45.5	22	100.0	7	31.8
Outside of lower bucket	9	40.9	19	86.4	0	0.0
Inside of lower bucket	7	31.8	21	95.5	0	0.0
Candle	0	0.0	1	4.5	0	0.0
Tap of the filter	5	22.7	13	59.1	0	0.0
Frequency of backflushing[1]						
Every day					2	9.1
Once per week					4	18.2
Every two weeks					3	13.6
Less than once per month					13	59.1
Backflush water[1] **(N = 9)**						
Filtered Water					3	33.3
Unfiltered water					6	66.7
Cleaning frequency lower bucket						
Once per week	5	22.7	18	81.8		
Every two weeks	2	9.1	3	13.6		
Cleaning frequency candle[2]						
Once per week			14	63.6		
Every two weeks			3	13.6		
Cleaning material candle[2] **(N = 17)**						
Raw water			9	52.9		
Boiled water			8	47.1		
Hands			17	100.0		
Brush			17	100.0		
Soap			1	5.9		

[1] Only applicable for Sawyer filter
[2] Only applicable for MCC filter

3.4.2 Compliance with user's training

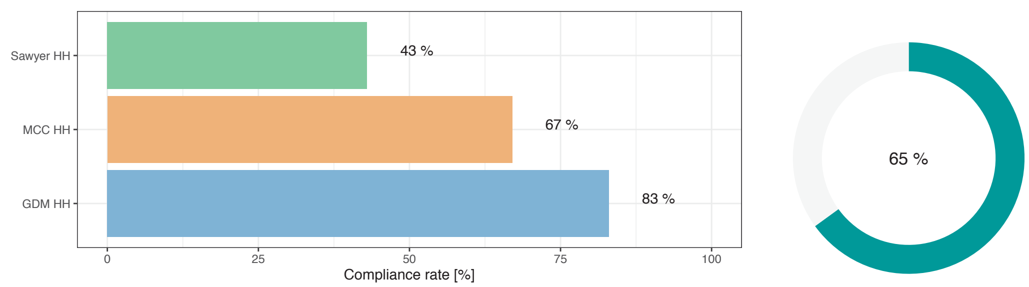
To assess the compliance of the households with the user's training, a performance indicator was calculated (section 2.7.2). All variables including the frequencies and the coding used for the composition of the compliance rate are listed in Table 3.5. In the coding 1 corresponds to the instructions whereas 0 represents the inadequate handling practice.

As instructed none of the households cleaned the membrane module of the GDM filter but the majority cleaned other parts of the filter. Regarding the MCC filter, over 60 % of the households cleaned the candle every week. However, only 8 out of 22 households used boiling water as instructed. Most striking is the fact that only 40 % of the households carried out the backwashing of the Sawyer filter (9 % every day) and among these households only a third used filtered water for the procedure.

The lowest compliance rate was observed for Sawyer households (43 %) and the highest for GDM households (83 %) (Fig. 3.14). The OM practices of the MCC households complied with the training in 67 % of the investigated households. The average compliance rate among all 66 households was 65 % (Fig. 3.14).

TABLE 3.5: Variables included in the compliance performance indicator for each of the filter types (N = 22). In the coding, 1 represents the instructed handling practice.

Filter Type	Variable (N = 22 if not indicated)	Number	%	Coding
GDM	Clean filter	12	54.5	0 = cleaning, 1 = no cleaning
	Cleaning membrane module	22	100.0	0 = cleaning, 1 = no cleaning
	Top bucket removed	21	95.5	0 = removed, 1 = not removed
MCC	Clean filter	22	100.0	0 = no cleaning, 1 = cleaning
	Clean frequency candle	14	63.6	0 = no cleaning, 1 = cleaning every week
	Clean materials: raw water	13	59.1	0 = raw water, 1 = no raw water
	Clean materials: boiling water	8	36.4	0 = no boiling water, 1 = boiling water
	Clean materials: brush	17	77.3	0 = no brush, 1 = intended brush
Sawyer	Clean filter	12	54.5	0 = no cleaning, 1 = cleaning
	Clean frequency backflush	9	40.9	0 = no backflushing, 1 = backflushing
	Backflush water (N = 9)	3	33.3	0 = use of raw water, 1 = use of filtered water



(A) (B)

FIGURE 3.14: Compliance rates of the GDM, MCC and Sawyer households (A) and average compliance rate among all 66 households (B).

3.4.3 Influence of handling aspects on the water quality

The impact of household factors on the recontamination (Δ *E. coli* and Δ total coliforms) and on the LRVs for *E. coli* and total coliforms was identified (section 2.7.4). Because of the large differences between the filter designs and the corresponding handling aspects only the two similar filter designs, the GDM and MCC filter were included in the model. Bivariate analyses including the household factors led to some unexpected results which should be interpreted with caution. For instance, there was a significant correlation between Δ total coliforms and the variable indicating whether the users cleaned the filter or not (r_s = 18866, p = 0.0289).

The binary logistic regression model for the predictor variables wealth index (WI), handwashing index (HWI) and toilet index (TI), cleaning of the lower bucket, cleaning of the tap and the outcome variable Δ *E. coli* of recontamination as explained above was statistically significant ($\tilde{\chi}^2(5) = 11.378$, p = 0.044). According to the Nagelkerkele R^2 the model explains 32 % of the variance. The results of the model are presented in Table 3.6. The model suggests that an increase in the wealth index and the cleaning rates of the tap lead to a decrease in recontamination of the filtered water. Additionally, there is a tendency to lower recontamination in households with no cleaning of the lower bucket and with a lower toilet index. The same model for the outcome variable Δ total coliforms was not significant ($\tilde{\chi}^2(5) = 4.241$, p = 0.515). The ordinal regression model including household factors and the categorized outcome variable LRV for total coliforms was also not statistically significant.

As mentioned above, in 14 cases recontamination of *E. coli* was observed of which nine were GDM and five MCC filters. Handling practices of these 14 cases indicate potential reasons for the observed recontamination. In various cases user's cleaned the inside of the storage container with raw water, their hands or a brush. Details on the handling practices of the 14 recontaminated samples are found in the Appendix B (Table B.7).

TABLE 3.6: Binary logistic regression model of household factors on the outcome variable Δ*E.coli*

					95% CI	
	B	**S.E.**	**p**	**OR**	**Lower**	**Upper**
Wealth index	-.056	.028	.043	.946	.896	.998
Handwashing index	.007	.016	.672	1.007	.975	1.040
Toilet index	.042	.025	.095	1.043	.993	1.096
Cleaning of lower bucket	2.093	1.232	.089	8.106	.724	90.700
Cleaning of tap	-3.270	1.348	.015	.038	.003	.534
Constant	-2.104	2.060	.307	.122		

3.5 Acceptance of the assessed filter designs

In general as shown in Fig. 3.15 the respondents liked the randomly assigned filter design. The most frequently mentioned positve aspect was the fact that the filters supply safe water (44 %). 30 % the GDM, 14 % of the MCC and 14 % of the Sawyer households particularly liked the filter designs. 23 % of the GDM households furthermore appreciated the large storage volume included in the filter's design. Two of the MCC and three of the Sawyer households declared not to like the filter type. Various aspects constitute a reason for the slightly lower acceptance of the MCC and Sawyer filter. The most frequently mentioned aspect was the low flow rate of the MCC filter (Fig. 3.16). In addition to the flow rate, the storage volume (5 L) was considered to be insufficient by two households. Regarding the Sawyer filter's design, the plastic lid, the general filter operation and the absence of a storage were not appreciated by the users. Additionally, for both the GDM and Sawyer filter concerns regarding the durability and the quality of the plastic buckets were mentioned.

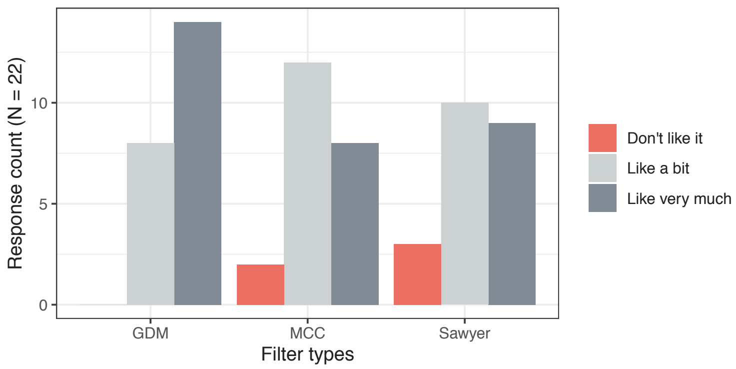


FIGURE 3.15: "How much do you like to use the filter?" Answers of the 66 participating GDM, MCC and Sawyer households (N = 22 per filter type).

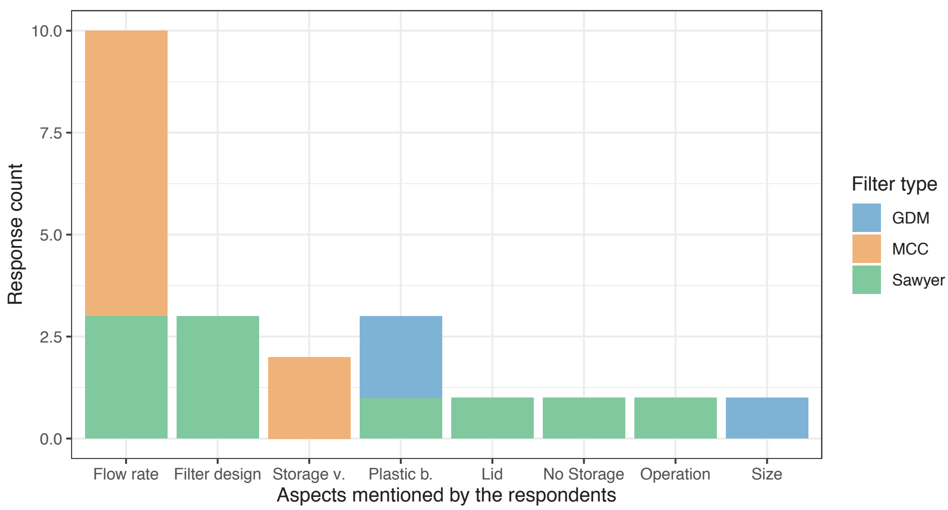


FIGURE 3.16: Negative aspects of the filter designs (N = 22) mentioned by the 66 users (multiple answers possible).

Chapter 4

Discussion

The discussion is focused on our four main research questions, starting with the performance of the three selected household water filters (section 4.1). In section 4.2 the performance in the field setting will be further discussed and key findings on the user's training and the handling of the water filters elucidated (section 4.3). Then social and economical aspects are made subject of discussion to address the last research question (section 4.4).

4.1 Performance of the assessed filter designs

In conformity with the classification of the WHO a water treatment product with very high removal of bacteria reaches a 4 log reduction [81]. A high removal is achieved when a product demonstrates a LRV of at least 3 log. In the lab setting in Surkhet, Nepal, the median of the LRV for *E. coli* of all filter types were below 3 log. With a log removal of total coliforms above 4 log, the MCC and Sawyer filter achieved a significantly higher removal than the GDM filter. This difference but also the large variability among the performance values of the GDM filter, is a very striking result emerging from the data. First, it is crucial to note the difference between the LRVs for *E. coli* and total coliforms among all three filter types. The concentrations of *E. coli* in the raw water were substantially lower than the concentrations of total coliforms which leads to lower maximum LRVs that can be achieved for *E. coli*. Hence, the fact that the concentrations between *E. coli* and total coliforms in the influent water partially differed 2-3 orders of magnitude, explains the observed differences in the log removal of *E. coli* and total coliforms [54]. In addition to different bacterial concentrations in the raw water other factors may have influenced LRVs. Firstly, in the relatively simple design of the GDM Filter, the raw water is filtered through the CUBE Mini Module (FM 045) ultra filtration membrane and is discharged through a pipe into the storage bucket. The water is filtered until a certain threshold of the transmembrane pressure is reached which in our case was at a very low water level. This results in a risk of membrane damage induced by drying out of the membrane surface [54]. Pursuant to the model assuming 30°C and 40 % humidity by Peter-Varbanets [54] complete drying out is expected after three days if the filter module is not protected by a cage. The drying process is expected to be considerably decelerated in the scenario of a raw water bucket with a lid as used in this study. Additionally, the GDM modules used for this investigation, were different than in the study of Peter-Varbanets [54]. However, as the manufacturer of CUBE Mini Module (FM 045) cannot rule out the potential damage of the membrane due to drying out, this aspect has to be considered and may have contributed to the large diversification of LRVs among the GDM filters. Secondly, the observed variabilities in the performance could result from quality differences from the membrane modules. For instance, due to leaking pipe connections within the membrane module [84].

Employees of Helvetas and Geberit AG raised concerns regarding the quality standard of locally produced ceramic filter candles due to a lack of quality assurance [46]. It is proposed that some of the variability in LRVs of the MCC filters is due to unstandardised production. In contrast with the estimations of Müller and Baggenstos [46] the evidence we found points to a significant correlation between the AFR and the flow rates of the MCC candles. However, contrary to our expectations, we did not find any correlation between the flow rate and the LRVs for *E. coli* and total coliforms. This might be due to the added disinfection of colloidal silver. The variability in LRVs of the MCC filters could also be a consequence of the silver application technique used by the manufacturer. The candles are dipped in a colloidal silver solution which does not allow for a control of the applied amount [67]. In fact, a study by Oyanedel-Craver and Smith [52] has revealed that not the application technique but the applied quantity of silver per candle is important for the efficiency.

The water quality data was collected in the early stage of the life cycle of the filters hence no statement can be made about the impact of the flow rate on the filter performance in filters that had been used for an extended period of time. Nevertheless, assuming the disinfection capacity by the colloidal silver is reduced due to the diffusion of the silver layer over time, differences in the filter performance, which relate to the flow rate, potentially emerge. This hypothesis was confirmed by the results of the brushing experiment in the field where an increase in the flow rates and a decrease in the LRVs were reported. Whereas low flow did not enhance microbial disinfection, low flow rates led to dissatisfaction of the users. Consequently, as observed in the field, this may impact the consistent use of the filter and therewith result in the consumption of untreated water. Additionally, previous observations have revealed, that low flow rates of ceramic filter candles resulted in extensive brushing of the candles [42]. Meierhofer et al. [42] suggested that this manipulation of the filter candle leads to a loss in filter performance. According to our observations in Surkhet, the local MCC candles were substantially more robust than the imported ceramic filter candles. However, the intense abrasion using a steel brush caused both a significant increase in the flow rates (+ 62 %) and a significant decrease in the LRVs of the tested candles. Notably, the abrasion caused in this experiment is not comparable to any cleaning practice observed in the field. A significant decrease in LRVs was also observed during our follow-up experiment using three different brush types compared to candles before they were brushed. Contrary to our expectation, no statistically significant differences in LRVs were observed between the three distinctive brushing treatments. The apparent slight decrease in the LRVs after the first brushing event points towards a link between this first cleaning practice and the performance. We hypothesise that the removal of the outer silver layer leads to this slight decrease which does not necessarily imply a bad performance of the filter. In fact, as the control and previous observations in the field lab showed similar patterns after the operation start, we suggest that the brushing may accelerate the abrasion of the outer layer but is not exclusively responsible for it. Clearly, considering the findings from the previous brushing experiment including the substantial abrasion of the ceramic layer, the brush type and the intensity are suggested to have an influence on the filter performance. With regard to the silver measurements, no significant influence of the brush types on the silver concentration was observed. We propose that other factors such as the water chemistry have a larger impact [43]. Furthermore, the variability in silver concentrations between the candles could be influenced by the silver application technique. As mentioned above, dipping the candles in a colloidal silvers solution does not allow for a control of the applied amount of silver per candle [67]. With values reaching 87 μgL^{-1}, initial silver concentrations were below the 0.1 mgL^{-1} level which is tolerated for drinking water by the World Health Organization (WHO) [83]. Yet, these concentrations were above the level of 25 μgL^{-1} suggested for small children [43]. After the first two filtration cycles the effluent silver concentrations were in the suggested range.

To conclude the first research question, clearly all filter types led to a significant improvement of the water quality. Generally, the observed LRVs are in line with previous performance tests of the GDM, MCC and Sawyer filters [56, 34, 27]. We argue that slightly lower values for the Sawyer filter in the literature can be traced back to variabilites in influent pathogen concentrations. Above all, the Sawyer filter achieves the highest performance and highest consistency of LRVs.

4.2 Performance of the three filter designs in the field

The performance of all three filter designs was substantially lower in the field than in the laboratory. However, this is the consequence of the above mentioned effect of influent pathogen concentrations on the LRVs. The maximal LRV that could be achieved with a concentration of 4.5 CFU/100 mL (Mdn *E. coli*) is 0.95 and 2.57 for total coliforms (Mdn = 187.5). Despite the fact that these values are rather low, a 0.95 log is still equivalent to a removal of 99.7 %. The classification of the water quality according to the WHO emphasises the clear improvement of the drinking water. Whereas 95 % of the raw water samples were categorised as a low, intermediate or high risk, over 90 % of all samples directly after filtration were in conformity with WHO guidelines. However, the conspicuous aspect to emerge from the performance data of the three filter designs is the lower log removal measured at the tap of the storage of the GDM and MCC filter. Particularly, the LRVs of total coliforms from the GDM filter were significantly lower. This decrease in the performance of *E. coli* and total coliform removal implies reconamination or re-growth in the storage. Unfortunately, recontamination and re-growth in the storage of household filters is a well-known issue [54, 20, 32, 43]. Whereas re-growth may play a role, the missing correlation between the water quality of the filtrate and the recontamination suggests that recontamination is the prevalent mechanism. In fact, there was significantly more recontamination of total coliforms in the storage of the GDM than the MCC filter. This lends support to previous research where total coliforms were susceptible to diffused silver [43]. A similar pattern was observed in a previous study in Bolivia where GDM filters and ceramic filters with colloidal silver were assessed [54]. As indicated by Meierhofer et al. [43] and Peter-Varbanets [54], the dissolution of the colloidal silver provides a protection for the filtered water during storage. Our experimental data indicating a significant correlation between the silver concentration and the removed CFU/100 mL, further substantiates these previous findings. Yet, while a study by van der Laan et al. [72] points towards an efficient disinfection of *E. coli* , an efficient removal of viruses was not observed [72]. Hence, other important pathogens might by less vulnerable to silver [72].

As demonstrated by Kunwar et al. [34] over the first six months the performance of the ceramic filter candles with the colloidal silver decreased by two percent. Additionally, we propose that the amount of silver leaching into storage is a function of time [72, 58] hence recontamination could play a more important role after some time of usage. An investigation on impregnated candle filters by Kallman et al. [30] revealed a steady diffusion over the first few months and slightly lower diffusion rates after then months of operation [30]. At this point in time this aspect of the MCC filters is largely unknown.

The safe storage of drinking water at the household level is a critical and very crucial aspect for HWTS systems. Regarding the Sawyer filter recontamination in the storage technically does not pose a risk. However, in the event of additional storage vessels, this risk is expected to be higher than for storage buckets included in the filter design [76]. Contrary to our expectations, only two households claimed to use an additional storage. Due to the fact that the households used large drinking vessels (67 % steel jugs, 33 % plastic bottles) and that the Sawyer filter can provide large volumes of water due to the high flow rate, it is plausible that households do not use large storage containers. Regardless of the filter type and the storage, recontamination may occur in the vessel used for the drinking water consumption. A field study in Bolivia has revealed that in 35 % of the households there was recontamination of the drinking water in the cup [59]. As mentioned above, in Surkhet B most of the participating households use steel jugs and plastic bottles, followed by a quarter that uses cups for the consumption of drinking water. In three investigated steel jugs both *E. coli* and total coliforms were present. This finding stresses the importance of reducing the risk of recontamination at the POU and directly before use. Due to the interlinkages of different WASH aspects a comprehensive WASH intervention including hygiene education could reduce such recontamination risks [4].

The results from the field provide an answer for our second research question. Whereas the GDM, MCC and Sawyer filter significantly improved the water quality at the POU, the lowest performance was achieved by the GDM filter. A major reason constitutes the recontamination of the filtered water in the storage container.

4.3 Filter handling aspects

The handling is an integral part of a HWTS and is a critical point when it comes to the successful treatment and storage of drinking water [43, 11]. Meierhofer et al. [42] demonstrated that inadequate OM practices of ceramic filters are common in the study area in Nepal and a short training has not resulted in significant improvements of cleaning practices. Various handling aspects that positively or negatively affect the LRV of the ceramic filter were identified [42]. Therefore, factors such as the use of boiling water to clean the buckets of the filter or the cleaning of the candle with a hard brush was incorporated in the training session of each household.

With a compliance rate of 67% for MCC households, OM instructions were put in practise with a slightly higher rate than observed by Meierhofer et al. [42] at households with candle filters. Presumably, for users of candle filters, the slight adoption of their fixed behavioural pattern posed a larger challenge than for households receiving totally new instructions. The overall compliance rate of 65 % lends support to the fact that fixed behavioral patterns are difficult to change yet, they are necessary for the adoption to HWTS and its success [45]. The compliance rates between the households varied considerably. A reasonable explanation for this difference are variabilities in the complexity and the necessary efforts of OM practices. For instance, the backflushing using the syringe required by the Sawyer filter was only carried out by approximately 40 % of the households and by 9 % every day as instructed. Presumably, OM practices with the necessity of such high frequencies are difficult to implement particularly, when there is no obvious benefit for the user. Our data revealed that highest OM compliance rates were achieved by those products that required the least OM effort. Hence, these HWTS products require less effort to obtain a behavior change towards adequate handling as mentioned by Mosler and Kraemer [45]. For example, households were asked not to clean the GDM filter module which involves no change in behaviour compared to the weekly cleaning of the MCC candle with boiling water. These findings regarding the influence of the simplicity of HWTS operation on the adherence are consistent with previous studies [76, 85].

While all households asserted to use the distributed filter as their primary drinking water source, three MCC households consumed additional tap water due to the insufficient volume of safe drinking water. A long-term investigation Cambodia including ceramic filters, revealed that low flow rates were the main reason for a decrease in adherence (correct, consistent and sustained use) [7]. Regarding the Sawyer filter, five households consumed boiled water or water from another candle filter. Brown and Clasen [6] and Enger et al. [14] emphasise the importance of adherence for the effectiveness of a HWTS intervention. Already a slight reduction in adherence leads to a decline in health gains [6]. Furthermore, Enger et al. [14] suggest, that the effectiveness of HWTS interventions is limited by adherence.

Previous studies [42, 38, 54, 56] have revealed that handling aspects have a large influence on the performance of HWTS. Considering our investigations on OM practices in the GDM, MCC and Sawyer households and the findings of previous studies, it seems likely that we observe a similar negative impact on the water quality. However, the results from the bivariate analyses and the regression models seem to imply a positive influence of some handling aspects such as the presence of cleaning, the cleaning frequency or cleaning of some filter parts. The observed effect of different cleaning aspects is largely biased due to two reasons. Firstly, the MCC households generally clean the filter more frequently than the GDM households and secondly, the MCC filters are simultaneously characterised by both, significantly lower recontamination rates and higher LRVs. Therefore, the findings suggest, that the impact of different properties of the filter designs, lead to a larger variabilities in the water quality than the impact of handling aspects. In general, the performance of the MCC filter was higher in both the lab and the field conditions. Additionally, the above mentioned diffusion of silver from the MCC candles and the associated disinfection in the safe water storage is a major reason for the lower recontamination and higher LRVs. Yet, observations in the field (not representative) could explain some of the recontamination. Raw water, hands and brushes which are potentially highly contaminated [42] were used to clean the inside of the storage bucket.

These findings provide an answer for the research question, "Can design reduce recontamination that can be caused by inadequate handling?". The diffusion of the colloidal silver into the storage, constitutes a design aspects which seems to reduce the level of recontamination from handling aspects. The higher robustness of MCC candles compared to candles imported from India additionally contributes to a smaller negative impact of brushing events on the performance as previously observed by Meierhofer et al. [42]. Moreover, manipulations or extensive brushing as previously reported, were not carried out by the MCC users during the period of this study [42].

Due to the lack of a storage container, the Sawyer filter design seems to prevent any recontamination caused by inadequate handling. However, additional storage containers pose a large risk for recontamination. Additionally, inadequate handling (no backflushing) as observed in the majority of households, may lead to a rapid decrease of the filter performance [48, 25]. Therefore, this filter design is proposed to be rather vulnerable to inadequate handling practices. In fact, studies in Honduras and South Sudan have shown that depending on the influent water quality and the operation membrane fouling may occur after a few months and may lead to an irreversible damage of the fibers [47, 25]. Hence, in this case the backflushing using clean water could be vital to guarantee a continuous performance of the filter.

4.4 Social and economical aspects

Besides the performance of a water filter, it is crucial to include social and economical aspects into decision making. In general, the filter designs were accepted by the local community. However, the lower adherence to MCC and Sawyer filters compared to GDM filters could be a consequence of dissatisfaction with the filter design [84]. There are various reasons for the slightly lower acceptance of the MCC and Sawyer filter. The decisive aspect in the case of the MCC filter is the flow rate, followed by the storage volume. These aspects were mentioned as the main reason for the consumption of additional tap water. The design of the Sawyer filter was unfamiliar to all households as it differed from the commonly used ceramic filters. A wide range of design and operational aspects of the Sawyer filter were not appreciated by the respondents. However, contrary to our expectations, the five households with the low adherence to the Sawyer filter claimed to like the filter design. Yet, they additionally consumed water treated with a previously used HWTS method.

The procurement of the MCC filter and the Sawyer filter poses less challenges as they are both available on the national market. Additionally, the necessary components for the GDM filter installation were challenging to organise, even in Kathmandu. The price of the three filter designs poses an obstacle to the local communities. While the MCC filter costs around CHF 13.00 (excluding the transport to Surkhet from Kathmandu), the GDM and Sawyer filter cost around four times more than the MCC filter. This does not include the transport costs to Surkhet from Europe or Kathmandu, respectively. Due to the different technologies the filters have varying lifespans which have to be taken into account when considering economic aspects. According to producers, GDM filters have a relatively high life expectancy ranging from 8-12 years [12]. A similar lifespan of ten years was advertised for the Sawyer PointONE filter [47] but concerns regarding membrane fouling were mentioned above which could substantially reduce the life span of this filter product. According to the manufacturer MCC filter candles should be replaced after one year. Provided that the candles are regularly replaced, the replacement of the MCC candles will result in higher maintenance costs than the running costs of the other filter types. However, considering the market price of one candle (CHF 1.70) and a yearly replacement, the total costs after 10 years will still be substantially lower than the acquisition costs of the GDM and Sawyer filter.

The integration of the presented results provides an answer for the last research question. Due to high the performance, the slightly reduced recontamination risks, the relatively high acceptance, the availability in the national market and the reasonable price, the MCC constitutes the most favourable filter design for the current local context.

4.5 Limitations

Finally, a number of weaknesses of this study have to be considered. The results obtained in Nepal are representative for the study area Surkhet B and may not be transferable to other regions. This research project was conducted in the winter time hence the water quality tests may not be representative for other seasons. The investigations of the filter performance using the measure LRV for our indicator organisms, were limited by the large variability and relatively low concentrations of pathogens in the influent water samples. The current study has only investigated the status quo after approximately one month of filter usage. Therefore, no statement can be made about the filter performance and the impact of handling aspects in the longer term. Additionally, whereas in the laboratory repeated sampling procedures and iterations of experiments were carried out, in the field households could be assessed only once. Moreover, a larger sample size for our laboratory experiments including the silver measurements and a study over a longer time period would be advantageous.

All questionnaires were conducted by the same interviewer. However, an observational bias and preconceived responses due to an interviewer bias cannot be excluded. Potentially, over-reporting of for instance, wealth indicators or cleaning frequencies could be a problem. Additionally, a potential courtesy reporting bias cannot be ruled out. For instance, due to the instructions on adequate filter handling, households potentially knew the desired answer during the questionnaire on filter handling practices. Finally, despite the fact that R^2 is low in our regression models, a higher statistical power could potentially be achieved with a larger sample size.

Chapter 5

Conclusions and Outlook

Over 800 million people lack basic drinking water services globally and more than 2 billion people consume water with faecal contamination. As a consequence, there are over half a million associated deaths highlighting that the promotion of safe drinking water remains a great challenge. HWTS and particularly household filtration systems are a promising approach to improve the water quality at the POU. With the aim to assess the impact of different WASH interventions on health, water filters will be distributed within the scope of a health impact study in Western Nepal. This research project had the key objective to determine the most suitable filter design for the current local context. Therefore, this study included the assessment of the performance and the handling aspects of a GDM filter, a ceramic candle filter with silver impregnation and a hollow-fiber filter both under laboratory conditions and in a village in Western Nepal.

The findings from this study suggest a significant improvement of the microbial drinking water quality for all assessed filter designs. While for *E. coli* the filters achieved LRVs above 2 log (>99 % removal), LRVs for total coliforms above 4 log (> 99.99% removal) were observed for the MCC and Sawyer filter. The GDM filter design exhibited significantly lower values. The observed differences between the removal of *E. coli* and total coliforms are result of different influent concentrations.

Our microbial analyses in the field, after one month of operation time, demonstrated a significantly improved water quality in the samples from the filter discharge pipe and the storage. Yet, as previously observed, recontamination in the storage of the GDM and the MCC filter is a major concern considering the fact that about 30 % of the samples were recontaminated. Significantly less contamination of total coliforms was observed in MCC filters indicating that the diffusion of colloidal silver from the candles leads to a reduction in recontamination. This finding was additionally verified by means of laboratory tests providing evidence for the significant correlation between the number of removed CFU/100 mL (*Enterococci*) and the concentration of colloidal silver. The majority of the households carried out OM practices as instructed in the individual training session. Yet, some handling aspects, namely, cleaning of the storage of the GDM and MCC filter using raw water, the hands or a cloth and no or inadequate backflushing of the Sawyer filter were observed in the households. These practices could provoke recontamination or a decrease in the filter performance. However, for the obtained data, the regression models did not demonstrate a significant reduction in performance or an increase in recontamination which can be associated with the observed handling practices. We hypothesise that this is due to the additional disinfection in the storage of the MCC filter, the generally high performance of the filters and also due to the low amount of observed recontamination and inadequate handling practices. For instance, the previously observed extensive brushing of the ceramic filter candles was not recorded during our visits. Additionally, only the excessive abrasion using a steel brush resulted in an apparent performance reduction of the generally robust MCC candles.

All three filter designs were generally accepted among the participating households. However, some negative aspects were mentioned particularly for the MCC and Sawyer filter design. As expected, a major concern was the flow rate of the MCC candle. With regard to the financial and procurement aspect, the MCC filter is the most favourable.

Aggregating the findings including the microbial performance, the handling and recontamination aspects and the social and economic components of the respective filter designs, the MCC filter from the national market is the most favourable filter design for the current local context. With regard to the low flow rates, an improved filter design with both more than one candle and a larger storage container (18L) should be considered to increase the adherence. Additionally, the OM training including manuals is an integral part and repeated monitoring and the assurance of the replacement of the candle could be essential to ensure the improvement of the water quality in the longer term. Considering our observations on recontamination in the drinking vessels and the related literature, comprehensive WASH interventions are fundamental to avoid any recontamination before the drinking water consumption. Moreover, an improved quality management for MCC candles would be crucial to ensure a consistent performance of the filter candles and a controlled diffusion of colloidal silver. The silver diffusion of the MCC candles over a longer time period and the disinfection efficiency of other microorganisms such as viruses are important issues to resolve for future studies. In consideration of the high values of silver diffusion directly after the commissioning of the MCC candles, we recommend to avoid the consumption of the water from the first two filtration cycles. Moreover, investigations are needed to determine the ecotoxicological impacts and pathways of colloidal silver particles. Future studies should be carried out in a larger sample size and target the long-term performance of the GDM, MCC and Sawyer filter in our study area, as well as the influence of handling aspects on the performance and recontamination after a longer operation period.

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Appendix A

Methods

A.1 Household Questionnaire

The entire questionnaire is attached to this document.

A.2 Informed consent form

The informed consent form is attached to this document.

A.3 OM filter manuals in English and Nepalese

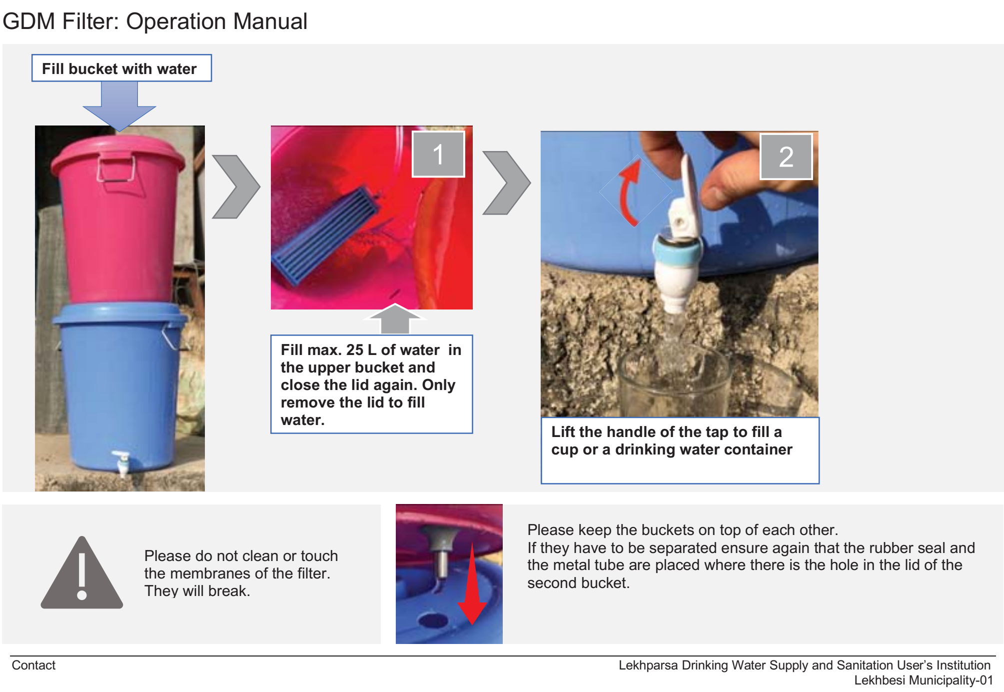

FIGURE A.1: OM manual for the GDM filter (English)

FIGURE A.2: OM manual for the GDM filter (Nepalese)

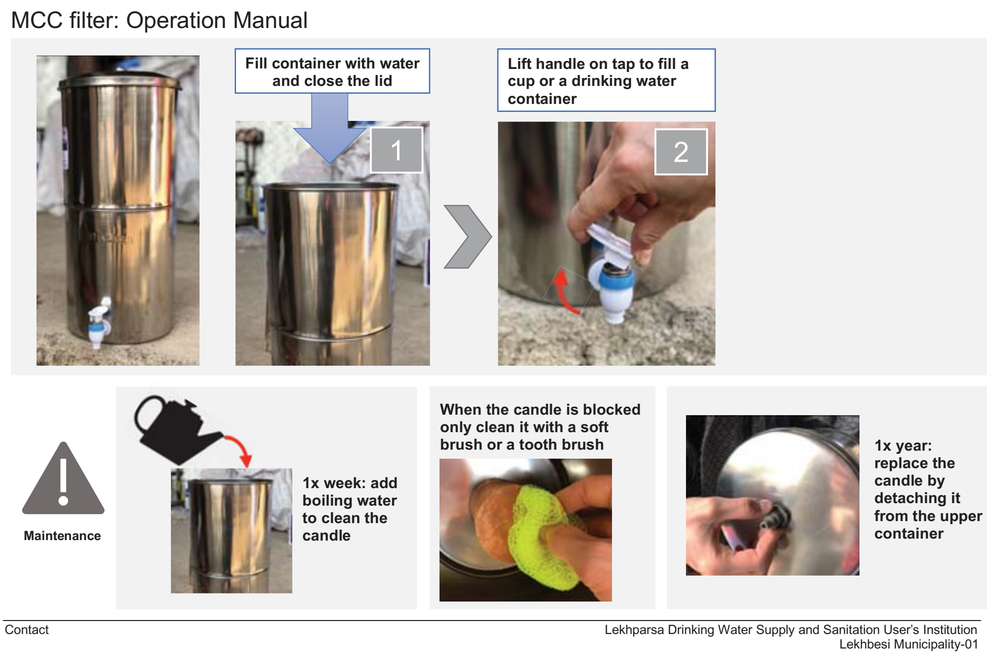

FIGURE A.3: OM manual for the MCC filter (English)

FIGURE A.4: OM manual for the MCC filter (Nepalese)

FIGURE A.5: OM manual for the Sawyer filter (English)

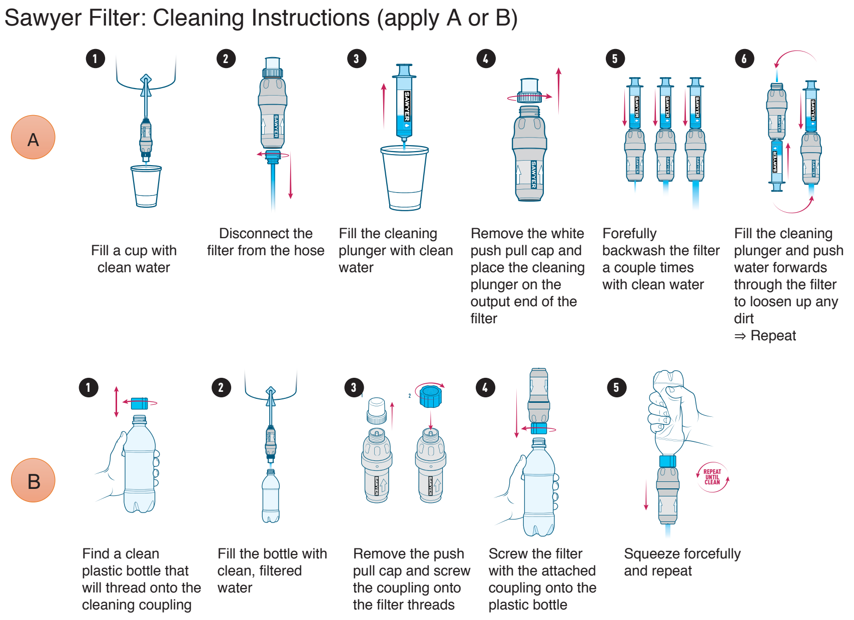

FIGURE A.6: OM manual for the Sawyer filter (Backflushing) (English)

FIGURE A.7: OM manual for the Sawyer filter (Nepalese)

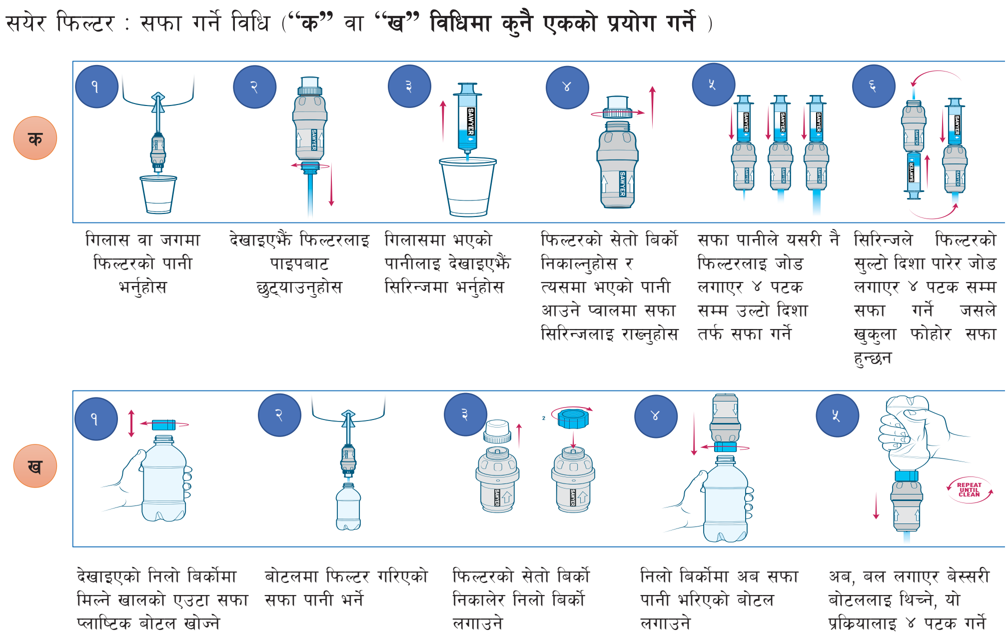

FIGURE A.8: OM manual for the Sawyer filter (Backflushing) (Nepalese)

Appendix B

Results

B.1 Variables included in the wealth, handwashing and toilet index

TABLE B.1: Variables included in the handwashing index (N = 66).

Variable (N = 66)		N	%	Coding for PCA
Handwashing with soap	≤ 3	25	37.9	0
	> 3 ≤ 6	28	42.4	1
	> 6 ≤ 9	6	9.1	2
	>9	7	10.6	3
Kind of handwashing facility	None	7	10.6	0
	Water from a bucket	42	63.6	1
	A drum with a tap	16	24.2	2
Clean handwashing facility		37	56.1	0 = not clean, 1 = clean
Handwashing facility with soap		58	87.9	0 = absent, 1 = present
Handwashing facility with water		59	89.4	0 = absent, 1 = present
Excluded[1]				
Handwashing yesterday	≤ 3	1	1.5	0
	> 3 ≤ 6	26	39.4	1
	> 6 ≤ 9	10	15.2	2
	>9	9	13.6	3

[1] Excluded due to values below 0.5 in the anti-image correlation matrix.

TABLE B.2: Variables included in the wealth index (N = 66).

Variable (N = 66)		N	%	Coding for PCA
Education of respondent	None/ Don't know	10	15.2	0
	Informal education	4	6.1	1
	Primary	18	27.3	2
	Secondary	28	42.4	3
	College and higher	6	9.1	4
Items owned by the household	TV	31	47.0	0 = absent, 1 = present
	Solar panel	19	28.8	0 = absent, 1 = present
	Motorbike	9	13.6	0 = absent, 1 = present
	Watch	9	13.6	0 = absent, 1 = present
Electricity		57	86.4	0 = absent, 1 = present
Fuel used for cooking	Wood	64	97.0	1
	Gas	38	5.8	4
	Electricity	5	7.6	5
Number of rooms	<3	16	24.2	1
	3–5	41	62.1	2
	>5	9	13.6	3
Land ownership [kattha[2]]	<= 10	44	66.7	1
	>10 $\leq$ 20	20	30.3	2
	>20 $\leq$ 30	2	3.0	3
Building material of the roof	Made from mud	0	0.0	1
	Straw	4	6.1	2
	Roof tiles/ Stone slates	17	25.8	3
	CGI Sheet	32	48.5	4
	RCC	13	19.7	5
Building material of the floor	Earth	47	71.2	1
	Cement	19	28.8	2
	Floor tiles	0	0.0	3
Excluded[1]				
Solar power		6	9.1	0 = absent, 1 = present
Own house	Rent house	3	4.5	1
	Own house	63	95.5	2
Items owned by the household	Radio	14	21.2	0 = absent, 1 = present
	Mobile phone	55	83.3	0 = absent, 1 = present
	Bicycle	3	4.5	0 = absent, 1 = present
	Car	1	1.5	0 = absent, 1 = present
	Fridge	5	7.6	0 = absent, 1 = present

[1] Excluded due to values below 0.5 in the anti-image correlation matrix.
[2] kattha = 338.63 m^2

TABLE B.3: Variables included in the toilet index (N = 66).

Variable (N = 66)		**N**	**%**	**Coding for PCA**
Kind of toilet	They use the bushes	1	1.5	0
	A shared simple pit latrine	11	16.7	1
	A shared water sealed toilet	9	13.6	2
	Household's own simple pit latrine	45	68.2	3
Condition toilet		33	50.0	0 = not clean, 1 = clean
Availability of materials	Sandals/slippers	8	12.1	0 = absent, 1 = present
	Drum with water	59	89.4	0 = absent, 1 = present
	Brush	36	54.5	0 = absent, 1 = present

B.2 Demographics, wealth and drinking water

TABLE B.4: Variables related to drinking water from the households (N = 66).

Drinking water variable (N = 66)		Number	%
Main drinking water source	Piped water in the house or yard	59	89.4
	Piped water in the village	1	1.5
	Unmanaged piped system	3	4.5
	River, Stream or Canal	0	0.0
	Lake	0	0.0
	Bottled Water	3	4.5
Safety of drinking water	Very safe	2	3.0
	Quite safe	16	24.2
	Neither safe nor risky	10	15.2
	A bit risky	17	25.8
	Very risky	21	31.8
Known water treatment methods [1]	Boiling	64	97.0
	Filtration with a cloth	20	30.3
	Flocculation and sedimentation	0	0.0
	Chlorination	7	10.6
	Sodis	7	10.6
	Use of Filter	62	93.9
	Other	5	7.6
Used water treatment methods [1]	Boiling	62	93.9
	Filtration with a cloth	18	27.3
	Chlorination	5	7.6
	Sodis	6	9.1
	Use of Filter	64	97.0
Responsible person for water treatment [1]	Wife	47	71.2
	Husband	3	4.5
	Daughter	14	21.2
	Son	3	4.5
	Other	3	4.5
Previous filter	Ceramic candle filter	13	19.7
	Sand filter	1	1.5
Previously no filter: reason [1]	Financial reasons	9	20.0
	Lack of knowledge	27	60.0
	Logistical reasons	4	8.9
	Missing trend	3	6.7
	Other treatment method	2	4.4

[1] Question with multiple possible answers.

TABLE B.5: Socio-demographic characteristics of the households included in this study (N = 66)

Socio-demographic variable (N = 66)		Number	%
Gender of participant	Female	56	84.8
	Male	10	15.2
Age group	16-25	15	22.7
	26-35	26	39.4
	36-45	12	18.2
	46-55	7	10.6
	56-65	5	7.6
	>65	1	1.5
Number of people in the household	2	3	4.5
	3	3	4.5
	4	20	30.3
	5	21	31.8
	6	9	13.6
	7	4	6.1
	8	4	6.1
	>8	2	3.0
Number of children in the household	0	31	47.0
	1	17	25.8
	2	14	21.2
	3	3	4.5
	4	1	1.5
Ethnicity	Dalit	23	34.8
	Janajati	33	50.0
	Brahmin, Chhetri, Thakuri	10	15.2
Literacy	Can neither read or write	13	19.7
	Can both read or write	53	80.3
Education of respondent	Informal education	4	6.1
	Primary	18	27.3
	Secondary	28	42.4
	College and higher	6	9.1
	None/ Don't know	10	15.2
Employment of head of household	Agriculture	17	25.8
	Small business	9	13.6
	Other independent work	3	4.5
	Daily laborer	7	10.6
	Employed	1	1.5
	Government service	3	4.5
	Retired with pension	1	1.5
	Foreign employment	16	24.2
	None	9	13.6
Employment of spouse	Agriculture	1	1.5
	Small business	2	3.1
	Other independent work	3	4.6
	Daily laborer	4	6.2
	Employed	2	3.1
	Government service	6	9.2
	Foreign employment	5	7.7
	None	42	64.6

TABLE B.6: Socio-economic characteristics of the households included in this study (N = 66)

Socio-economic variable (N = 66)		Number	%
Expenditure per month	<10000	19	29.2
	10000-19999	33	50.8
	20000-29999	8	12.3
	30000-40000	5	7.7
Items owned by the household [1]	Radio	14	21.2
	TV	31	47.0
	Solar panel	19	28.8
	Mobile phone	55	83.3
	Bicycle	3	4.5
	Motorbike	9	13.6
	Car	1	1.5
	Fridge	5	7.6
	Watch	9	13.6
	None of this	6	9.1
Electricity		57	86.4
Solar power		6	9.1
Fuel used for cooking [1]	Wood	64	97.0
	Gas	38	5.8
	Electricity	5	7.6
Number of rooms	<3	16	24.2
	3–5	41	62.1
	>5	9	13.6
Land ownership [kattha[2]]	$\leq$ 10	44	66.7
	>10 $\leq$ 20	20	30.3
	>20 $\leq$ 30	2	3.0
Building material of the walls	Stone with mud	41	62.1
	Stone with cement	12	18.2
	Brick with cement	13	19.7
	Cement	0	0.0
Building material of the roof	Made from mud	0	0.0
	Straw	4	6.1
	Roof tiles/ Stone slates	17	25.8
	CGI Sheet	32	48.5
	Roller-compacted concrete	13	19.7
Building material of the floor	Earth	47	71.2
	Cement	19	28.8
	Floor tiles	0	0.0

[1] Question with multiple possible answers.
[2] kattha = 338.63 m^2

B.3 Brushing experiment I and II

(A) (B)

FIGURE B.1: MCC candle before (A) and after (B) the treatment using a steel brush.

(A) (B) (C) (D)

FIGURE B.2: Dimension of abrasion after three brushing events using a soft (A), mid (B) and hard (C) brush. D is the control.

B.4 Handling of water filters

TABLE B.7: Observations regarding handling practices of households with recontaminated samples. The variables Δ *E. coli* (EC), Δ total coliforms, whether HH cleaned the filter, the outside of the storage bucket, the inside of the storage bucket, the materials used for the cleaning and uncovering the storage bucket are indicated.

HH ID	Δ EC	Δ TC	Clean	Clean out	Clean storage	Clean mat. storage	Storage lid
GDM_03	3	19					
GDM_09	35	50					x
GDM_10	2	18					
GDM_13	1	36	x	x			
GDM_14	12	59					
GDM_15	2	53	x	x			
GDM_17	4	31	x	x			
GDM_19	12	2					
GDM_22	3	0	x	x	x	Raw water, hands	
MCC_03	1	0	x	x	x	Hands	
MCC_10	1	0	x	x	x	Raw water, hands, brush	
MCC_11	114	1	x	x	x	Hands, Brush	
MCC_14	12	2	x	x	x	Hands, Brush	
MCC_17	1	57	x	x	x	Raw water, hands, brush	

Household Questionnaire

All the information you provide is confidential and your name will not be disclosed anywhere. The results will be treated anonymously. Participation in this study is voluntary. You don't have to take part if you don't want to. You don't have to answer any question you don't want to, and you can stop the interview at any time. If you decide not to participate there will not be any negative consequences.
Do you have any questions? Do you agree to participate in this study?
If you have any further questions you can contact Madan Bhatta from Helvetas. The phone number of the Helvetas office in Surkhet is: 083521092 / 083521093

Administer informed consent. If subject agrees to participate, proceed to questionnaire

- ◯ Yes
- ◯ No

beginning

Name of interviewer

- ◯ Neerima Thapa
- ◯ Akina Shrestha

Enter the household ID (HHID)
Copy that Household ID in your notebook in case you need to take notes

____

Type of filter received

- ◯ MCC_Filter
- ◯ GDM_Filter
- ◯ Sawyer_Filter
- ◯ Filter Market Surkhet
- ◯ Other (specify)

A - Household Information

A-Household information

Name of person interviewed

____

Name of the head of the household

____

Have you been part of the Baseline Study?

- ◯ Yes
- ◯ No

What is the gender of the respondent?
Please indicate without notifying the respondent

- ◯ Male
- ◯ Female

What is the age of the respondent?
Enter number / if unknown: approximate the age: ."60-70"

____

What is your mobile phone number?
Enter mobile phone number / Enter 999 if no mobile phone

____

How many people in TOTAL, including you, live in your household?
Including respondent

____

How many children are 0 to 10 years in this household?
Enter number

____

How many children are below the age of 5?
Enter number

____

Are you able to read or write?

- ◯ Can neither read or write
- ◯ Can read only
- ◯ Can both read or write

What is the highest education level you have completed?
Do not read out - select one answer given by respondent

- ◯ Informal education
- ◯ Primary
- ◯ Secondary
- ◯ College and higher
- ◯ None/ Don't know

What is the occupation of the head of the household?
Do not read out - select one answer (main occupation)

- ◯ Agriculture
- ◯ Small business
- ◯ Other independent work
- ◯ Daily laborer
- ◯ Employed
- ◯ Government service
- ◯ Retired with pension
- ◯ Foreign employment
- ◯ None

What is the occupation of the spouse of the household head?
Do not read out - select one answer (main occupation)

- ◯ Agriculture
- ◯ Small business
- ◯ Other independent work
- ◯ Daily laborer
- ◯ Employed
- ◯ Government service
- ◯ Retired with pension
- ◯ Foreign employment
- ◯ None
- ◯ No spouse (=single or widow)

What is the ethnicity of this household?
Do not read out - select one answer given by respondent

- ◯ Dalit
- ◯ Janajati
- ◯ Bramihin, Chhetr, Thakuri
- ◯ Other

Specify other ethnicity

____

B - Wealth index

B - Wealth index

About how much does your household spend PER MONTH on regular expenses (regular expenses = food, transport, clothing, and school fees) ?
Insert number in NPR per month

____

Does anyone from your household own/ have any of these items?
Read out all options

- ☐ Radio
- ☐ TV
- ☐ Solar panel
- ☐ Mobile phone
- ☐ Bicycle
- ☐ Motorbike
- ☐ Car
- ☐ Fridge
- ☐ Watch
- ☐ None of this

Does the household have an electricity connection?
Connection to an electrical grid

- ◯ Yes
- ◯ No

Does the household have solar panels?

- ◯ Yes
- ◯ No

What kind of fuel do you use mainly for cooking?

Do not read out - select one answer (main fuel used)

- ☐ Wood
- ☐ Charcoal
- ☐ Kerosene
- ☐ Gas
- ☐ Electricity

Are you the owner of your house?

- ◯ Own house
- ◯ Rent house

How many rooms does your house have?

______

How much land does your family own?

Enter area owned by the household in Ropanis
If no area is owned enter "0"
If don't know enter "999"

______

C - Water handling and hygiene

C-Water handling and hygiene

Which water source do you currently use as MAIN drinking water source?

Do not read out

- ◯ Piped water in the house or yard
- ◯ Piped water in the village
- ◯ Rainwater harvesting
- ◯ Open source (dug well, pond, spring)
- ◯ Protected source (well, spring)
- ◯ Unmanaged piped system
- ◯ River, Stream or Canal
- ◯ Lake
- ◯ Bottled Water

Do you currently also use other water sources for drinking?

- ◯ Yes
- ◯ No

Which other water sources for drinking water do you currently use?

Do not read out - select all answers given by respondent

- ☐ Piped water in the house or yard
- ☐ Piped water in the village
- ☐ Rainwater harvesting
- ☐ Open source (dug well, pond, spring)
- ☐ Protected source (well, spring)
- ☐ Unmanaged piped system
- ☐ River, Stream or Canal
- ☐ Lake
- ☐ Bottled Water

How safe do you think your main drinking water source is for drinking?

Do not read out

- ◯ Very safe
- ◯ Quite safe
- ◯ Neither safe nor risky
- ◯ A bit risky
- ◯ Very risky

Which methods for water treatment do you know?

Do not read out

- ☐ Boiling
- ☐ Filtration with a cloth
- ☐ Flocculation and sedimentation
- ☐ Chlorination
- ☐ Sodis
- ☐ Use of Filter
- ☐ Other (specify)
- ☐ Do not know any

Please specify other:

____

Which of these methods for water treatment do you use?

- ☐ Boiling
- ☐ Filtration with a cloth
- ☐ Flocculation and sedimentation
- ☐ Chlorination
- ☐ Sodis
- ☐ Use of Filter
- ☐ Other (specify)
- ☐ Don't use any

Who in your family is mainly responsible for water treatment?

- ☐ Wife
- ☐ Husband
- ☐ Daughter
- ☐ Son
- ☐ Other

Have you been using any water filtration system in your household before?

- ◯ Yes
- ◯ No

What kind of water filter have you been using?

____

Why have you previously not been using a water filter?

____

Do you fill your water filter every day?

- ◯ Yes
- ◯ No

How often do you fill your water filter per day?

____

How often do you fill your water filter?

- ◯ Every second day
- ◯ About twice per week
- ◯ Once per week
- ◯ Less than once per week

Besides the storage vessel provided by the filter – do you use an extra storage for the filtered water?

- ◯ Direct Use
- ◯ Storage

Where do you put the filtered water?

- [ ] Cup
- [ ] Jug
- [ ] Pan
- [ ] Bottle
- [ ] Other (specify)

Please specify other:

____

Where do you store the filtered water?

____

Did anyone remove the upper bucket of the filter?

- ○ Yes
- ○ No

If yes, how often within 48 hours?

____

Do you clean your water filter?

- ○ Yes
- ○ No

How often do you clean your water filter?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

Which parts of the filter do you clean?

- [ ] Outside of upper bucket
- [ ] Inside of upper bucket
- [ ] Lid upper bucket
- [ ] Outside of lower bucket
- [ ] Inside of lower bucket
- [ ] Candle
- [ ] Membrane Filter
- [ ] Tap of the filter

How often do you backflush the membrane filter?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

Which water did you use for the backflushing?

- ○ Filtered Water
- ○ Unfiltered water

How often do you clean the outside of the upper bucket?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

What kind of materials do you use to clean the outside of the upper bucket?

- raw water
- boiled water
- hands
- soft cloth
- rough cloth
- brush
- soap
- chlorine
- ash
- earth

How often do you clean the inside of the upper bucket?

- Every day
- Every second day
- Once per week
- Every two weeks
- Once per month
- Less than once per month

What kind of materials do you use to clean the inside of the upper bucket?

- raw water
- boiled water
- hands
- soft cloth
- rough cloth
- brush
- soap
- chlorine
- ash
- earth

How often do you clean the lid of the upper bucket?

- Every day
- Every second day
- Once per week
- Every two weeks
- Once per month
- Less than once per month

What kind of materials do you use to clean the lid of the upper bucket?

- raw water
- boiled water
- hands
- soft cloth
- rough cloth
- brush
- soap
- chlorine
- ash
- earth

How often do you clean the outside of the lower bucket?

- Every day
- Every second day
- Once per week
- Every two weeks
- Once per month
- Less than once per month

What kind of materials do you use to clean the outside of the lower bucket?

- ☐ raw water
- ☐ boiled water
- ☐ hands
- ☐ soft cloth
- ☐ rough cloth
- ☐ brush
- ☐ soap
- ☐ chlorine
- ☐ ash
- ☐ earth

How often do you clean the inside of the lower bucket?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

What kind of materials do you use to clean the inside of the lower bucket?

- ☐ raw water
- ☐ boiled water
- ☐ hands
- ☐ soft cloth
- ☐ rough cloth
- ☐ brush
- ☐ soap
- ☐ chlorine
- ☐ ash
- ☐ earth

How often do you clean the candle?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

What kind of materials do you use to clean the candle?

- ☐ raw water
- ☐ boiled water
- ☐ hands
- ☐ soft cloth
- ☐ rough cloth
- ☐ brush
- ☐ soap
- ☐ chlorine
- ☐ ash
- ☐ earth

How often do you clean the membrane filter?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

What kind of materials do you use to clean the membrane filter?

- [ ] raw water
- [ ] boiled water
- [ ] hands
- [ ] soft cloth
- [ ] rough cloth
- [ ] brush
- [ ] soap
- [ ] chlorine
- [ ] ash
- [ ] earth

How often do you clean the tap of the filter?

- ○ Every day
- ○ Every second day
- ○ Once per week
- ○ Every two weeks
- ○ Once per month
- ○ Less than once per month

What kind of materials do you use to clean the tap of the filter?

- [ ] raw water
- [ ] boiled water
- [ ] hands
- [ ] soft cloth
- [ ] rough cloth
- [ ] brush
- [ ] soap
- [ ] chlorine
- [ ] ash
- [ ] earth

YESTERDAY, can you tell me how many times you washed your hands?

Enter the number of times the respondent washed hands yesterday.
If zero, enter "0"
If don't know, enter "999"

____

When you washed your hands yesterday, how often did you use soap or ash?

____

Where do members of your family usually go for defaecation?

Do not read out, if answer unclear give options

- ○ They use the bushes
- ○ A shared simple pit latrine
- ○ A shared water sealed toilet
- ○ Household's own simple pit latrine
- ○ Household's own water sealed toilet

Do you keep the animal safe inside your house over night ?

- ○ Yes
- ○ No

D - Filter Design

D - Filter Design

How much do you like to use this filter?

- ○ I like it very much
- ○ I like it a bit
- ○ I do not like it

What do you like about this filter?

____

What do you not like about this filter?

____

E - Observation through the interviewer (your own observation)

E - Observation through the interviewer (your own observation)

What type of walls does the main house have?

- ◯ Wood planks
- ◯ Corrugated iron
- ◯ Stone with mud
- ◯ Stone with cement
- ◯ Brick with cement
- ◯ Cement

What type of roof does the main house have?

- ◯ Made from mud
- ◯ Straw
- ◯ Roof tiles/ Stone slates
- ◯ CGI Sheet
- ◯ RCC

What type of floor does the main house have?

- ◯ Earth
- ◯ Cement
- ◯ Floor tiles

» Condition of water transport container

In which condition is the container used for water transport?

Is the water transport container clean?

- ◯ Yes
- ◯ No

Does the water transport container have a lid?

- ◯ Yes
- ◯ No

Is the water transport container broken?

- ◯ Yes
- ◯ No

» Condition of water filter

In which condition is the water filter?

Is the water filter clean?

- ◯ Yes
- ◯ No

Is the water filter broken?

- ◯ Yes
- ◯ No

What kind of damages does the water filter have?

____

What kind of toilet does the HH have on the compound?

- ◯ No latrine
- ◯ Pit latrine
- ◯ Ventilated improved latrine
- ◯ Water-sealed latrine

» Condition of the toilet

In which condition is the toilet?

Is the toilet clean?

There are no visible traces of faeces and dirt in the toilet

- ◯ Yes
- ◯ No

Are these material available?

- ☐ Sandals/slippers
- ☐ Drum with water
- ☐ Brush
- ☐ None of these

What kind of handwashing facilities does the HH have?

- ○ None
- ○ They pour out water from a bucket
- ○ A drum with a tap

» Condition of handwashing facilities

In which conditions are the hand washing facilities?

Are the handwashing facilities in good condition?
Handwashing station is operational and not broken

- ○ Yes
- ○ No

Are the handwashing facilities clean?
Handwashing station has shows no signs of dirt

- ○ Yes
- ○ No

Is soap available?

- ○ Yes
- ○ No

Is water available?

- ○ Yes
- ○ No

Is animal dung laying around the house?

- ○ Yes
- ○ No

Is there dry rack to dry your utensils and dishes after washing?

- ○ Yes
- ○ No

Is there a significant number of flies in the kitchen (more than 10)?
if more than 10, type yes

- ○ Yes
- ○ No

****Please record any additional information here or in your notebook**

____

****Take GPS point of household location**
Go outside of the house, turn on the GPS button on the tablet and do not forget to switch it off afterward!

Breite (x.y °) ____

Länge (x.y °) ____

Höhe (m) ____

Präzision (m) ____

Thank you for answering these questions!
This is the end of the interview.
Ask how far it is

Informed consent form

सूचित सहमति फारम

Introduction
परिचय

Hello, my name is .... and I am working Helvetas Swiss Intercooperation and for the Eawag, the Swiss Federal Institute of Aquatic Science and Technology.

नमस्ते, मेरो नाम .... हो । म Eawag, the Swiss Federal Institute of Aquatic Science and Technology को लागि Helvetas Swiss Intercooperation मा काम गर्दैछु।

Background information
पृष्ठभूमि जानकारी

We are conducting a research study to evaluate to efficiency and use of different water filters.
हामी विभिन्न पानी फिल्टरहरूको प्रयोगको मूल्यांकन गर्न अनुसन्धान सञ्चालन गर्दैछौं।
The water filters are being used to treat drinking water at household level.
पानीको फिल्टर घरको स्तरमा पिउने पानीको उपचार गर्न प्रयोग गरिँदैछ।
Your participation in this study will help us to improve the drinking water quality in your community.
यस अध्ययनमा तपाईंको सहभागिताले हामीलाई तपाईंको समुदायमा पिउने पानीको गुणस्तर सुधार गर्न मद्दत गर्नेछ।

What the participant would be asked to do
सहभागीकर्ताले के गर्न आग्रह गरिनेछ

You have the opportunity to purchase a high quality water filter for a reduced price.
तपाईंसँग कम मूल्यको उच्च गुणस्तरको फिल्टर खरीद गर्ने अवसर प्राप्त हुनेछ।
We will provide you a training on how to operate and maintain the filter.
हामी तपाईंलाई तपाईंको पिउने पानीको फिल्टर कसरी सञ्चालन र जतन गर्ने बारे प्रशिक्षण प्रदान गर्नेछौं।
After some weeks we would like to visit you again to take some water samples from the filter to test its performance.
केहि हप्ता पछि हामी फिल्टर बाट केहि पानीको नमूनाहरू परीक्षण गर्न पुन: भ्रमण गर्न गर्नेछौं।
In addition, we would like to make an interview with you on general household information, water handling in the household and hygiene.
यसबाहेक, हामी तपाईंसँग सामान्य घरको जानकारी, स्वच्छता र पानी सम्बन्धित व्यवहार हरुमा एक अन्तर्वाता पनि गर्न चाहन्छौं।
The interview will take approximately half an hour of your time.
अन्तर्वाताले तपाईंको आधी घण्टा जती समय लिनेछ।

Risks and benefits of being in the study
अध्ययनमा हुने जोखिम र फाइदाहरू

There are no known risks to participating in this study. यस अध्ययनमा सहभागी हुन कुनै ज्ञात जोखिमहरू छैनन्।
You will have to opportunity to purchase a high quality water filter at reduced cost.
तपाईंले कम लागत मा एक उच्च गुणस्तरवाला पानीको फिल्टर खरीद गर्न अवसर प्राप्त गर्नु हुनेछ।

Confidentiality गोप्यता

All the information you provide is confidential and your name will not be disclosed anywhere. The results will be treated anonymously.

तपाईंले प्रदान गर्नुभएको सबै जानकारी गोपनीय हुनेछ र तपाईंको नाम कहीं पनि खुलासा हुनेछैन। परिणामहरू गुमनाम रूपमा राखिनेछ।

Voluntariness स्वैच्छिकता

Participation in this study is voluntary. यस अध्ययनमा सहभागिता स्वैच्छिक छ।
You don't have to take part if you don't want to.
यदि तपाईं चाहानुहुन्न भने भाग लिनु पर्नेछैन।
You don't have to answer any question you don't want to, and you can stop the interview at any time.
तपाईलाई कुनै पनि प्रश्नको जवाफ दिन मन छैन भने तपाईं कुनै पनि समय अन्तर्वाता रोक्न सक्नुहुन्छ।
If you decide not to participate there will not be any negative consequences.
यदि तपाईं सहभागी हुनु चाहानुहुन्न भने तपाईलाई त्यहाँ कुनै पनि नकारात्मक नतीजाहरू हुने छैनन्।

Feedback/Dissemination प्रतिक्रिया / प्रसार

Do you have any questions? Do you agree to participate in this study?
के तपाईंसँग कुनै प्रश्नहरु छन्? के तपाइँ यस अध्ययनमा सहभागी सक्नुहुन्छ?
You have been informed about this study's purpose, procedures, possible benefits and risks. तपाईंलाई यस अध्ययनको उद्देश्य, प्रक्रियाहरू, सम्भावित फाइदा र जोखिमहरूको बारेमा सूचित गरिएको छ।

By signing this consent form, you are agreeing to participate in the interview. यस सहमति फारममा हस्ताक्षर गरेर तपाईंले यस अध्ययनमा भाग लिन सहमत जनाउनुहुनेछ।

If you desire a copy of this consent form, you may request one and we will provide it.
यदि तपाईं यस सहमति फारमको प्रतिलिपि चाहानुहुन्छ भने हामी प्रदान गर्न सक्नेछौ।
You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time.
तपाईंले साइन गर्नु भन्दा पहिले तपाईंलाई प्रश्न सोध्ने मौका दिइएको छ र तपाईंलाई भनिएको छ कि तपाईं कुनैपनि समयमा अन्य प्रश्न सोध्न सक्नुहुनेछ।
You voluntarily agree to participate in this study.
तपाईं स्वैच्छिक रूपमा यो अध्ययनमा भाग लिन सहमत हुनुहुन्छ।

Contact and Questions सम्पर्क र प्रश्नहरू

The researcher(s) conducting this study are mentioned below. यो अध्ययन सञ्चालन गर्ने शोधकर्ताहरू तल उल्लेख गरिएको छ।
You may ask any questions you have now. तपाईसँग कुनै प्रश्नहरू छ भने सोध्न सक्नुहुन्छ।
If you have any questions later, you may contact them at: यदि तपाइँसँग कुनै प्रश्नहरू छन् भने, तपाईंले निम्नहरूलाई सम्पर्क गर्न सक्नुहुन्छ:
Name of researcher:...phone nr...
शोधकर्ताको नाम **फोन नम्बर**

Statement of consent सहमतिको विवरण

I have read the above information or had the above information read to me. मैले माथिको जानकारी पढेको छु वा माथिको सूचना मलाई पढेर सुनाइयको थियो।
I have received answers to the questions I have asked. मैले सोधेको प्रश्नहरूको जवाफ मैले पाएको छु।

eawag
aquatic research

I consent to participate in this research.
म यो अनुसन्धानमा भाग लिन सहमत छु।

I am at least ……. years of age.
म कम्तीमा … वर्षको भए।

Name of participant: ……
सहभागीको नाम

Signature or thumbprint of participant: ……………………………………………………………………
सहभागीको हस्ताक्षर वा औंठा छाप:
Date: …………………………
मिति

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Declaration of originality

The signed declaration of originality is a component of every semester paper, Bachelor's thesis, Master's thesis and any other degree paper undertaken during the course of studies, including the respective electronic versions.

Lecturers may also require a declaration of originality for other written papers compiled for their courses.

I hereby confirm that I am the sole author of the written work here enclosed and that I have compiled it in my own words. Parts excepted are corrections of form and content by the supervisor.

Title of work (in block letters):

ASSESSING THE PERFORMANCE AND HANDLING OF THREE FILTER DESIGNS FOR WATER TREATMENT IN RURAL HOUSEHOLDS IN NEPAL

Authored by (in block letters):
For papers written by groups the names of all authors are required.

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