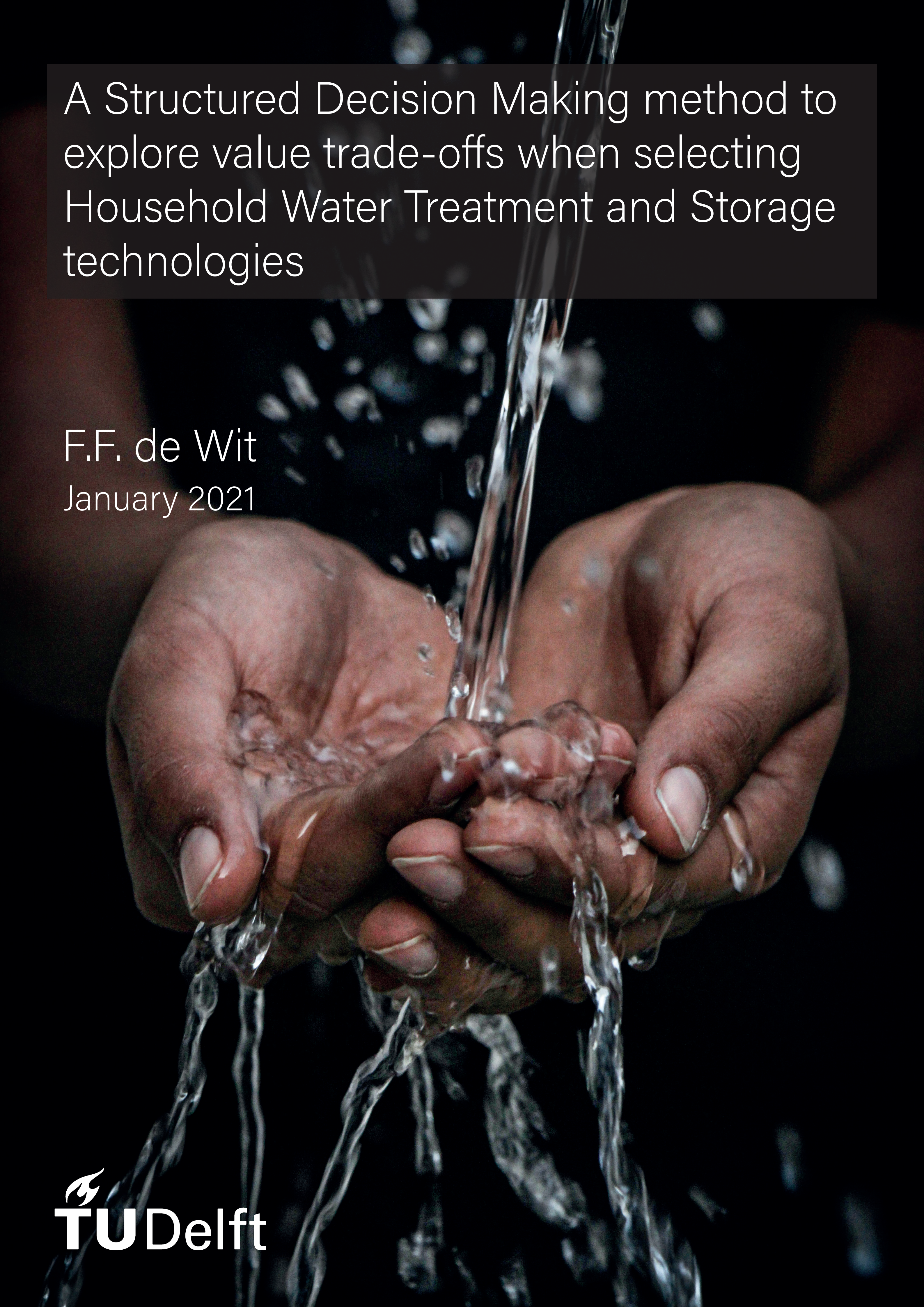
A Structured Decision Making method to explore value trade-offs when selecting Household Water Treatment and Storage technologies

F.F. de Wit

January 2021



TU Delft

The cover photo is downloaded from Unsplashed, Mrjn Photography.

A Structured Decision Making method to explore value trade-offs when selecting Household Water Treatment and Storage technologies

By

F.F. de Wit

A thesis submitted to the Delf University of Technology in partial fulfilment of the requirements for the degree of

Master of Science
in Water Management, Civil Engineering

Student number:	4302222
Supervisor:	Dr. ir. D. van Halem, TU Delft
Thesis committee:	Dr. L. Scholten, TU Delft
	Prof. dr. ir. L.C. Rietveld, TU Delft
	Dr. Ir. A. Mink, TU Delft

An electronic version of this thesis is available at http://repository.tudelft.nl/.

TU Delft

Acknowledgements

Completion of this graduation thesis signifies the finalisation of my Master of Science in Water Management, Civil Engineering at Delft University of Technology. It has been an interesting journey that began at a time of uncertainty because of the COVID-19 pandemic. This meant that we had to be flexible and adapt to what was still possible. It was a challenge, but I am very happy with the international subject that remained.

That so many people do not have access to save drinking water and so many children die of diarrhea, is something I find difficult to imagine and even more difficult to accept. That is why I am proud to have had the opportunity to do research on this subject. I hope that my work can contribute to an improved choice between HWTS (Household Water Treatment and Storage) products to ultimately lower the burden of waterborne disease.

The past few months have taught me a lot, and I would like to thank certain people for making that possible. I would particularly like to thank my thesis committee. To start with Doris van Halem, the chair of the committee and my daily supervisor. Our weekly meetings provided a lot of motivation, gave interesting ideas and kept me focused on improvements. She inspired me by her efficient way of discussing, where deep insight into the subject and creativity led to better research, without losing focus on the practical use. I would also like to thank Lisa Scholten, who taught me a lot and whose knowledge was essential to the process. Because of the many conversations and detailed feedback, she kept me focused on the choices I made and how that could affect the results. Annemarie Mink shared with me her insights and feedback on the human aspect of this subject, which proved to be of great value in the research and also greatly sparked my interest. I would like to thank Luuk Rietveld for sharing his considerable knowledge about HWTS with me. His enthusiasm on the subject and on the importance of this research has motivated me greatly. It was a pleasure and a privilege to work with this committee.

I had the privilege to speak to many HWTS experts around the world. This inspired me and gave me a lot of energy during the research. I would like to thank everyone who took the time to share their experiences with me through interviews or the survey.

I want to show my gratitude to the people around me, who have supported me throughout the process. I was fortunate to study with friends during my master's degree, and I would like to thank them for their support and the good times we had. My family and friends, who always encouraged me and showed their interest in the research. A special word of thanks to Tijn and to my parents, for all your help with rereads and discussions, which helped me greatly.

Fleur de Wit
Amsterdam, 15-01-2021

Summary

Worldwide, three out of ten people do not have access to safely managed drinking water, which contributes significantly to the global burden of disease. One way to reach those people and provide clean drinking water, is to use Household Water Treatment and Storage (HWTS). When selecting a suitable HWTS, many factors have to be considered, of which the importance can vary per specific situation. This can make HWTS selection overwhelming, especially for decision-makers who are not WASH (Water, Sanitation and Hygiene) specialists. As a result, the selection of an HWTS is often not based on structured decision-making, leading to a sub-optimal choice or even to failure of the HWTS implementation. The aim of this research is to aid structured HWTS selection by improving the understanding of the trade-offs. To make the complex decision between HWTS more structured and insightful, Structured Decision Making (SDM) is used. SDM is a process to inform the decision-makers, instead of prescribing the best solution and works for multiple, potentially conflicting, objectives. The steps of the SDM structure used in this research are shown below. The main research question of this research is: **How to adapt Structured Decision Making to aid HWTS selections in different contexts?**

Step 1 – Clarify the decision context (introduction)
The developed SDM structure showed that only one major adaptation is required, specifically to aid in HWTS selection, which is "the estimation of consequences". The estimation of consequences is the fourth step of SDM and was found to demand differentiation between *generic* and *situation-specific* criteria.

Step 2 – Identify objectives and criteria (chapter 3)
The objectives and criteria for HWTS selection are identified using literature study and interviews with 12 HWTS experts. The final criteria set comprises three focus areas: health improvement, acceptability/adaptability and accessibility. In addition, the set of criteria is divided into general criteria, that can be used to make a generic comparison between HWTS, and situation-specific criteria, that need local research.

Step 3 – Include HWTS and contexts (chapter 4)
Six of the most widely applied and tested technologies are included in this study: (1) ceramic candle filter, (2) ceramic pot filter, (3) biosand filter, (4) pressure-driven membrane ultrafiltration, (5) solar disinfection (SODIS) and (6) chlorination. The contexts chosen to include are (1) rural villages, (2) outbreak of infectious waterborne disease, (3) informal urban slums, (4) refugee camps and (5) emergency response after natural disaster.

Step 4a – Estimate preference (chapter 5)
Rate HWTS on general criteria using a value matrix
The HWTS are rated on the general criteria in a value matrix. The ratings per criteria differ between HWTS, but there is no HWTS that consistently scores high or low. The values given to the HWTS are found in literature, overall showing a medium to high consistency.

Weighting of the general criteria in every context
Weights for the general criteria are calculated with the Best-Worst Method (BWM). Input data for the BWM was retrieved through a survey among 39 HWTS experts. A difference in weight height is observed, both between contexts and between criteria (groups). Firstly, when comparing the weights of contexts, it is striking that the distribution and height between the (semi-)permanent contexts ('rural village' and 'urban informal slum') are similar, compared to the three emergency contexts. The Kruskal-Wallis test showed no significant difference of the median of the weights between contexts. Secondly, there are also differences in the weight height between criteria (groups). The criteria of the accessibility category are as a group overall lower than the categories health improvement and acceptability/adaptability. Within the health improvement category, the microbial log reduction shows a high weight and the risk of by-product formation low. Within the accessibility/adaptability category, the ease of operating is high, and approval of authorities is relatively low. For the accessibility category, there is no general conclusion due to variation between contexts.

Ranking of the HWTS per context
Ranking of the HWTS was done by two separate methods, TOPSIS and the Weighted Sum Method (WSM) with the Max-Min method for normalisation. TOPSIS was used to make the final ranking of HWTS, because WSM with Max-Min is less range sensitive. The TOPSIS ranking differs per context, as was expected because the calculated weights differ per context. But the difference between the HWTS in the rankings are generally very low.

Step 4b – Evaluate trade-offs of situation specific criteria (chapter 6)
The next step after evaluating the generic criteria, is to conduct local research for the situation-specific criteria. Suggestions are made for actions needed to evaluate the criteria. This can be summarised in three actions: (1) test quality of the source water, especially the turbidity of the water (2) plan minimally five to eight interviews with targeted HWTS users with a different background (3) collect information through stakeholders on the local market and guidelines.

Introducing the selection guide for decision-makers (chapter 7)
A selection guide is made as a first step to translate the information from this research into an instrument that can be used in practice. Because the results and information from this research are included in the guide, a considerable amount time and resources are saved. And that is why there is no need to be a WASH specialist to use the selection guide. Using the selection guide results more structured decision making, which increases the chance of a successful implementation of the HWTS**.**

It can be concluded that SDM needs to be adapted to aid HWTS selection by assessing the general and situation-specific criteria separately. Going through the steps of the method has given extended insight into the trade-offs per context, since differences in weights were observed. The method itself and the obtained knowledge will support decision-makers in making a structured and well-informed choice in HWTS.

Table of contents

List of figures

List of tables

Abbreviations

BMW	Best-Worst Method
CAWST	Centre for Affordable Water and Sanitation Technology
COM-B	Capability, Opportunity and Motivation model
EPA	United States Environmental Protection Agency
HAA	Halo acetic acids
HWTS	Household Water Treatment and Storage
MCDA	Multi Criteria Decision Analysis
MCDM	Multi Criteria Decision Making
NGO	Non-governmental organization
NTU	Nephelometric Turbidity Units
PET	Polyethylene terephthalate
PVC	Polyvinyl chloride
RANAS	Risk, Attitude, Norm, Ability, and Self-Regulation model
SDG	Sustainable Development Goal
SDM	Structured Decision Making
SODIS	Solar Disinfection
THM	Trihalomethanes
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization
WSM	Weighted Sum Method

1 Introduction

Sustainable Development Goal target 6.1: "By 2030, achieve universal and equitable access to safe and affordable drinking water for all"

The United Nations Sustainable Development Goal on water and sanitation (SDG 6) contributes to the ambition to "ensure availability and sustainable management of water and sanitation for all". Target 6.1 is focused on drinking water and is stated above. The goal is apparent: for all people to have a protected drinking water source on-premises, available when needed and free from contamination [1]. However, in 2017, 2.2 billion people (over three out of ten people worldwide) did not have access to safely managed drinking water. And even 785 million people did not even have access to basic water needs [2]. These numbers also reflect geographical, socio-cultural and economic inequalities. People living in rural areas, with low incomes and/or in informal settlements are less likely to have access to improved drinking water sources [3].

We are not there yet; be we still have another 10 years to reach the SDG target 6.1.

1.1. The problem with microbial contaminated drinking water

The lack of access to safe drinking water contributes significantly to the global burden of disease [4]. Contaminated water is linked to diseases such as diarrhoea, cholera, dysentery, hepatitis A, typhoid, and polio [3]. Diarrhoea is a common symptom of waterborne illness, caused by a range of protozoa, bacteria and viruses [5]. Diarrheal disease yearly kills 1.6 million people, of which a large percentage are children under 5 years [6], [7]. Worldwide, one out of five child deaths is because of diarrhoea, which is a greater share of global infant mortality than AIDS, malaria and measles together [5]. People with acute persistent diarrhoea are losing a significant amount of fluids, which can lead to dehydration and may cause death [8]. Besides mortality, dehydration can lead to malnutrition, underweight and stunted growth [9], [10], [11]. Improving the quality of drinking water and making it more accessible will also have social and economic benefits. For example, people will have to spend less time and effort on collecting water, which gives them time and energy to spend on something else. This provides more economic opportunities. For children specifically, less disease means better physical and mental development and higher school attendance [3].

1.2. Household Water Treatment and Storage can improve drinking water

Drinking water can be treated at different locations. For example, it can be treated centrally in a drinking water treatment plant, after which it is transported to households via pipelines. Other options are community-based water treatment, like a borehole or a dug well, and water treatment at the point of use, with Household Water Treatment and Storage (HWTS) [12]. The World Health Organization (WHO) indicates that the ultimate goal is to provide every household with a safe and reliable connection to piped water infrastructure. This is a long-term goal, whereas implementing HWTS is a directly workable step towards clean drinking water at the point of use. Improving the central water treatment and infrastructure are thus complementary with the promotion of HWTS [13], [14]. Using HWTS has several reasons. HWTS is very cost efficient, as it has a high cost-benefit ratio [15] and low yearly costs [16]–[18]. HWTS can be relatively quickly implemented by vulnerable populations [12], [17]. Additionally, research by quantitative microbial risk modelling and epidemiological studies show that HWTS improves the microbiological water quality and reduces diarrheal disease [4], [9], [19], [20].

However, as the WHO points out, the positive effect of HWTS on health is only achieved if a considerable effort will be made to understand the contextual factors of the situation in which HWTS is deployed [20]. Effectiveness and protective effects of the HWTS are strongly related to a consistent and correct use of the product [20]. If the water is treated intermittently or seasonally, if users are not only drinking clean water, or if not all members of the household are drinking clean water, the protective effects on health are not optimal [21], [22]. This makes it important that when choosing a suitable HWTS, several social, psychological and economic criteria have to be considered.

There are many HWTS and also multiple products within each system. Therefore, aid organisations, local authorities and commercial organisations have many options when implementing a programme for HWTS. The selection of a suitable HWTS can be overwhelming, especially for decision-makers who are not WASH (Water, Sanitation and Hygiene) specialists. That is because many factors have to be considered and the importance of these factors can vary per situation. As a result, the selection of an HWTS is often not based on structured decision-making. This can lead to a sub-optimal choice and may result in failure of the HWTS in that situation [23]. Several studies have already been conducted on making a more structured choice in HWTS [17], [22], [24]–[27]. In existing literature, the context in which the HWTS will be used is often not specifically included, or only one context is included (often development aid). Additionally, it is usually a general comparison that is presented. That means that the decision-maker can only use the outcome as information for HWTS selection [23]. For this reason, an evaluation of HWTS is needed in which the decision-maker can ultimately follow the structure offered, to make a well-considered choice. Moreover, it is necessary to investigate the trade-offs between the selection criteria in different contexts.

1.3. The need for Structured Decision Making (SDM)

The choice of which HWTS to implement is complex. It affects interest and resources of multiple stakeholders and multiple, potentially conflicting, objectives and criteria need to be considered. In order to make this complex decision clearer and more insightful, it is useful, and even necessary, to structure the decision process. If the problems, objectives and solutions are not made sufficiently clear, time and other valuable resources may be wasted, conflicts may arise, or the final decision may be less effective [28]. Thus, analysing the decision process using a decision framework will improve the quality of decision making [28].

One way to structure the process of decision making is to use the steps of Structured Decision Making (SDM). SDM is a framework to help decision-makers to structure decisions with multiple, potentially conflicting, objectives [29], [30]. SDM has been successfully applied to similar problems [28], [31]–[34]. Because there is not one optimal HWTS for every situation, it is important to discuss the trade-offs. SDM is well suited for this form of decision-making, as it is a process to inform the decision-makers, instead of prescribing the best solution [31], [32], [35], [36]. Within the steps of SDM, formal modelling methods can be combined with deliberative aspects [35]. SDM includes the steps: (1) clarify the decision context; (2) identify objectives and generate criteria; (3) generate alternatives; (4) estimate consequences; (5) evaluate trade-offs and select optimal decisions and (6) implement and monitor [31], [35], [37], [38].

This research presents a structure that decision-makers can use in their choice of HWTS. It is decided to use a modified version of the SDM in this research, in order to make the structure more efficient for the selection of a suitable HWTS. In this version, step (4) is divided into the consequences of general criteria (step 4a), and the consequences and trade-offs of situation-specific criteria (step 4b).

1.4. Research objective

The aim of this research is to aid HWTS selection by improving the understanding of the trade-offs. The focus in this research is on HWTS for disinfection. The research helps to create an overview of important criteria for choosing between HWTS in a certain context. To do so, an explorative assessment is made of HWTS preferences in various contexts. The research is specifically intended for organisations without in-house WASH experts. This leads to the main research question:

How to adapt Structured Decision Making to aid HWTS selections in different contexts?

This can be divided into the following sub-questions:
1. What are the technical, social and economic criteria to consider when choosing HWTS and how to assess them?
2. How can HWTS be scored on the set of criteria using a value matrix?
3. Are the criteria weights of different magnitude within a context and between contexts, when using the Best-Worst Method?
4. How can a modified version of Structured Decision Making practically be used by decision-makers?

1.5. Structure of the research

The modified SDM structure used in the research is shown in Figure 1. The steps from modified SDM also form the structure of this report. The decision context is clarified in this introduction (step 1). SDM does not include fixed methods for the completion of the steps. Therefore, methods have been selected for each step. The methods used are further explained in chapter 2. The identification of objectives and criteria (step 2) is explained in chapter 3. Chapter 4 entails the choice of HWTS and the contexts to include in this research (step 3).
Within step 4, a distinction is made between the general criteria and the situation-specific criteria. The estimation of consequences based on the general criteria (step 4a) are shown and calculated in chapter 5. This is done by rating every HWTS to the criteria in a value matrix and assigning weights to every criterion, making it possible to rank the HWTS. The focus in

this research is on the steps 1 to step 4a, which is the more general part of this method. This part is shown in black in Figure 1. The last steps from 4b to 6 are shown in grey.
Chapter 6 includes the evaluation of the situation-specific criteria (step 4b). A selection guide for the decision-maker is presented in Chapter 7. Chapter 8 entails the discussion of this research and chapter 9 the recommendations and conclusions.

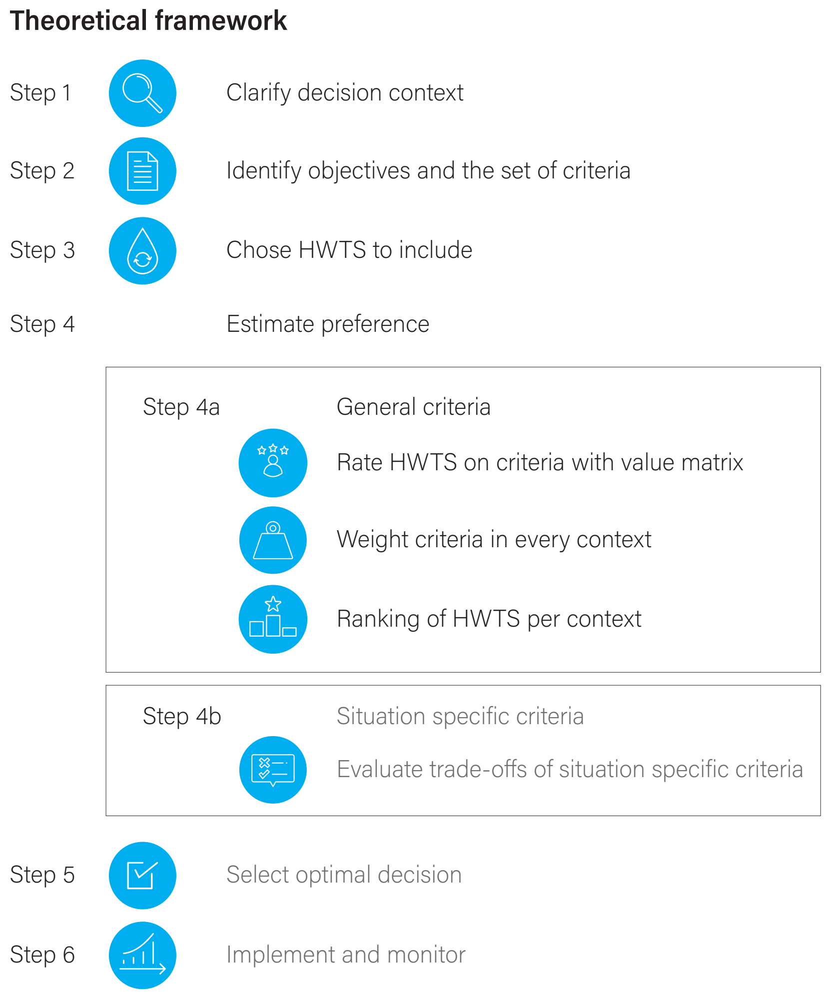


Figure 1: The steps of Structured Decision Making used in this research

2 Methodology

The aim of this research is to aid HWTS selection by improving the understanding of the trade-offs for different contexts. Throughout the research, a modified version of Structured Decision Making (SDM) is used to make the choice for a suitable HWTS. SDM is a framework to help decision-makers structure decisions with multiple, potentially conflicting, objectives. SDM is a process to inform, instead of prescribing the best solution. This is well suited for the selection of a HWTS, because there is no one perfect solution. SDM has been modified in this research to make the structure more efficient for the selection of a suitable HWTS.

SDM does not provide fixed methods to complete each step. This subchapter briefly explains which methods have been chosen for each step in SDM, after which the next subchapters will give further explanations. All assumptions and choices made have been written down in the appropriate parts of the report and added separately as a list in Appendix A.

Although the goal of this research is to aid decision-makers, the experience of experts has been used in several steps. The decision-maker makes the final decision on which HWTS to choose and implement. Experts in this research are people who are knowledgeable about a particular area in the selection of HWTS. The experience of experts has been used to gather information about the trade-off in practice. It is not fixed who these people are, but it gives an indication on their backgrounds.

2.1. Overall methodology

Figure 2 shows the methods chosen to complete the steps of the modified SDM. To identify the objectives and criteria in step 2, a literature review is conducted. The information on objectives and criteria is structured using an Objective Hierarchy. The draft set of criteria is discussed with experts on HWTS in face-to-face interviews. Because different groups of experts are consulted in this research, each group is given a separate name to maintain an overview. The group of experts consulted for the face-to-face interviews is named expert group A. In the final set of criteria, a distinction is made between general criteria that can be used to rank the HWTS per context and situation-specific criteria that need local research. To generate alternatives (step 3), a literature study was used to choose which HWTS and which contexts to include in this research and to obtain information on them.

In the case of a multi-criteria problem, there is generally no solution where all the criteria have been optimized. A compromise solution must therefore be found [39]. This can be done by estimating the consequences of the general criteria in step 4. In this research, this step is adjusted to two separate steps. Step 4a is focussed on the consequences of the general criteria, while step 4b focuses on the situation-specific criteria. The general criteria and situation-specific criteria are of the same importance. It was chosen to assess the general criteria first, before doing local research for the situation-specific criteria.

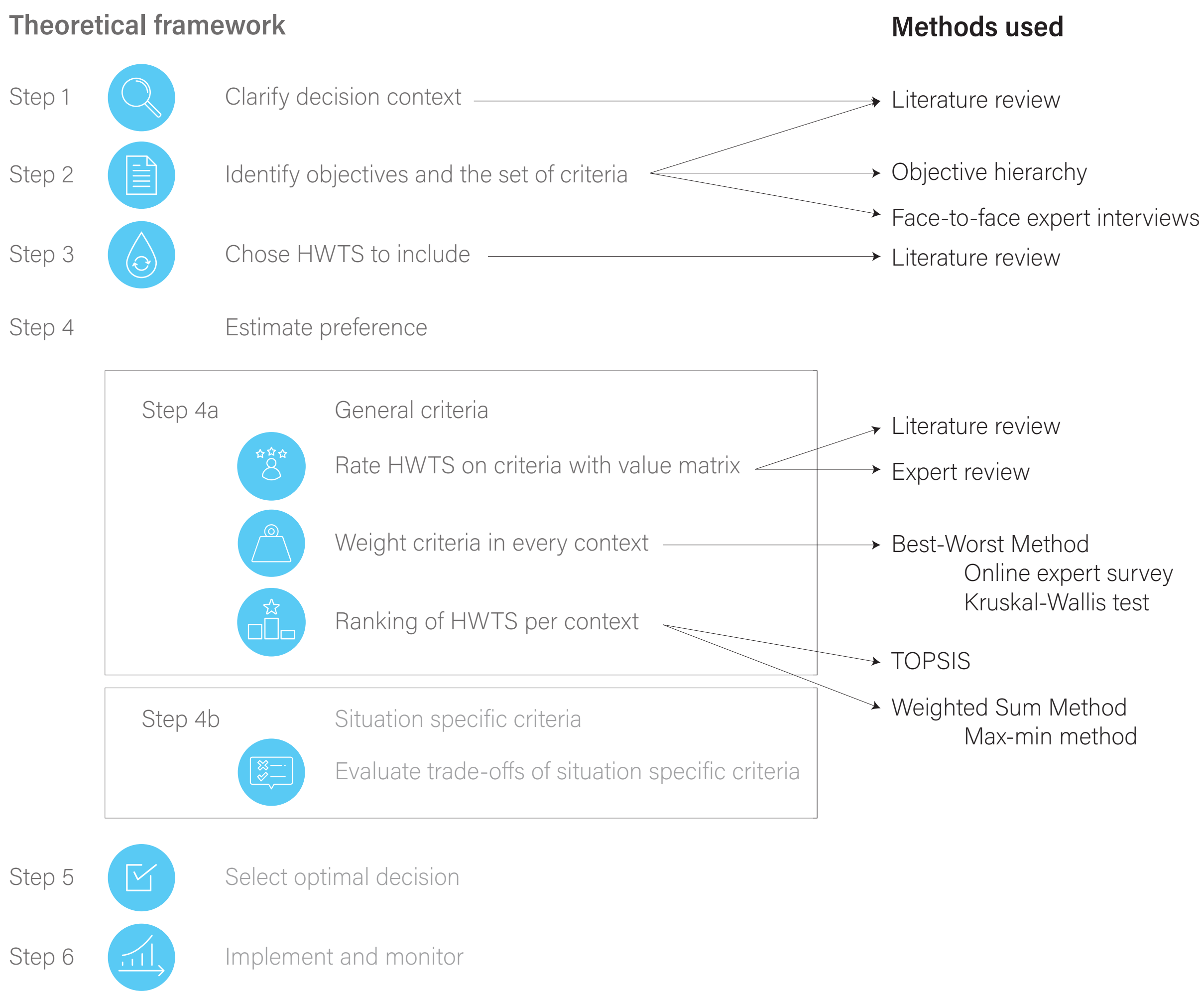


Figure 2: Methods chosen and used in every step of the modified SDM theoretical framework.

Part of step 4a is to rate the HWTS on the general criteria by making a value matrix. The values in the value matrix are found through literature review. A concept version of the value matrix has been presented to several professors at the Delft University of Technology, who have experience with HWTS research, referred to as expert group B. Not every general criterion in the value matrix is equally important in making the final choice. So, weights for the general criteria need to be calculated, using the Best-Worst Method (BWM). Input data for the BWM was retrieved through an online survey among HWTS experts with experience in the chosen contexts, referred to as experts group C. The statistical Kruskal-Wallis test is used to test if there is a significant difference between the medians of the weights between the contexts. The last part of step 4a is ranking of the HWTS. The decision was made to include two methods for the ranking of the HWTS: TOPSIS and the Weighted Sum Method (WSM). Because the values in the value matrix are measured in different quantities, normalisation was needed. The Max-Min method was chosen as the normalisation method for WSM.
Step 4b is focussed on the situation-specific criteria. From this step onwards, it is not a generic recommendation but an analysis of the specific situation. Suggestions are made for the final steps in this report. The focus of this study is on steps 1 to 4a.

2.2. Identification of objectives and criteria

The objectives and criteria were identified using literature review. This is explained in chapter 2.2.1. A tool to structure the information and identify the objectives is called 'Objective Hierarchy', further explained in chapter 2.2.3. This first set of criteria was discussed with HWTS experts by face-to-face interviews with expert group A, discussed in chapter 2.2.2.

2.2.1. Literature review

A literature review was conducted, not a systematic literature study, because the goal is to provide a summary of literature on the topic of HWTS criteria and not to answer a focused clinical question [40]. Literature was found by using multiple search terms and through the reference list of useful articles or books. Occasionally articles or reports from organisations involved in HWTS have been used. To help identify the criteria on acceptability and adaptability, literature on model on behavioural change was consulted.

Models on behavioural change

In order for the HWTS implementation to succeed, it is useful to gain more insight into the behaviour of users, and to understand why people do or do not use HWTS. Behavioural models are therefore used as input for defining the set of criteria for HWTS selection. The final set of criteria shown in chapter 3 indicates which criteria are based on the models on behavioural change. Two models that describe aspects of behavioural change and are used in this research are the RANAS model and the COM-B model. The RANAS model consists of five sections: Risk, Attitude, Norm, Ability, and Self-Regulation. The model focuses on behavioural change in the WASH sector in developing countries [41]. The COM-B model stands for the three components to behaviour (B): Capability (C), Opportunity (O) and Motivation (M) [42]. The COM-B model gives an understanding on what drives behaviour and how decisions are made [43]. The model is more generic, without a focus on WASH. Further explanation of these two behavioural change models can be found in appendix B.

2.2.2. Face-to-face interviews with HWTS experts

The focus of the interviews was to obtain better insights on the range of criteria and their importance under different circumstances. A draft criteria set was presented to experts in HWTS, with experience with one or more of the included HWTS and contexts. The goal of the interview was to get feedback on the draft list of criteria, with the focus on the criteria on acceptance and adaptation. The experts were asked whether they found these criteria relevant, whether any criteria were missing, whether any unnecessary criteria were included, and how they experienced acceptance in their projects. The draft set of criteria was adjusted where necessary after the interviews.
An (online) face-to-face interview has several advantages and disadvantages. The main advantage is that the interviewee can notice non-verbal signs. This could add extra information to the answer and make it easier for the interviewee to notice when a question is unclear. A disadvantage is that respondents might feel uneasy about their anonymity [44].

The interviews were semi-structured. This was chosen because it was clear in advance what the objectives of the interview were and what the requested information was. A PowerPoint presentation was used with information on the research and the questions of the interview. An advantage of a semi-structured interview is that it gives a clear structure to the conversation, but still allows more flexibility in the conversations based on the interactions during the interview. This makes it possible for the researcher to discover underlying issues, ideas and thoughts from the interviewed expert [44]–[46]. A disadvantage of semi-structured interviews is that only a number of people can be reached [47] and it is not possibly to make a systematic comparison between the interview responses [48].

Participants

The interviews were conducted with 12 HWTS experts between June 8 and July 2, 2020. Experts were sought who have field experience with HWTS. When selecting the experts, the desired variation in focus area, type of function, and a limited number of respondents from the same organisation were considered. Experts were identified through the contacts of TU Delft professors and were approached to see if they were willing to participate. The function types of the participants include decision-maker, technical expert and context expert. The participants work for NGO or commercial companies and the focus locations differ. More information on the background of the interviewed experts can be found in Appendix C. The online program Zoom was used for the interviews. The conversation was in Dutch or English and took about 45 minutes to 1 hour. The interview was recorded if the interviewee gave permission.

2.2.3. Objective Hierarchy

Clear formulation of the objectives can greatly enhance the quality of a decision-making process. An Objective Hierarchy is a way to structure the identified information on objectives and criteria. The hierarchy helps to lower dependencies and to make sure no criteria are measured double [49]. Keeney and Raiffa [50] use the Objective Hierarchy as a tool to specify the intended meaning of the general objective and to specify the objective into more detail for operational purposes. In addition, it is an important step towards the development of the criteria set. The structuring ensures that the criteria taken into account measure the objectives, without objectives being measured double.

To make the Objectives Hierarchy, the problem owner needs to be indicated. In this research the problem owner is the decision-maker of the choice which HWTS to include in a context. The second step is to find an appropriate main objective. The main goal should not be too broad but is useful to formulate a more abstract goal so no attributes will be missed. To get to the main objective, the question “why” can be asked [51]. The next step is to identify the sub-objectives by asking "what does that mean?" [51], [52]. The intended preferred direction of change needs to be included. The list of objectives must be both comprehensive and concise. The lowest layer of the hierarchy is the criteria against which the sub-objectives can be measured. In this layer of criteria, the unit of measurement is therefore indicated.

2.3. Estimate consequences of general criteria on HWTS

2.3.1. The value matrix

A tool to summarize the rating of the alternatives on the set of criteria is a ‘value matrix’, also called ‘consequence table’ or ‘alternative matrix’ [28]. This is part of the fourth step of SDM, to estimate the preference of HWTS. The value matrix is a decision-making tool to evaluate and prioritize alternatives, based on a set of criteria. The value matrix can be represented as the matrix [53] shown in Equation 1.

$$A = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{pmatrix} \quad \text{Equation 1}$$

In the value matrix, the set $\{a_1, a_2,\ldots, a_m\}$ is the set of HWTS alternatives and the set $\{c_1, c_2,\ldots, c_n\}$ is the set of criteria. p_{ij} represents the score of the alternative *i* for the criterion *j*.

To fill in the scores p_{ij} of the value matrix, a literature review has been conducted. Quantitative values found in the literature were kept in quantitative ratio if possible as it is more precise. However, it often was necessary to use a constructed scale. The rating system for the constructed criteria in the value matrix is a 5-point scale where 1 is the lowest and 5 is the highest level of desired characteristics [23], [54].

To estimate the reliability of the values p_{ij}, it helps to have an overview of the sources that have been used and whether the values are consistent. The following aspects are taken into account:

- The source of the findings. It will be indicated whether findings have been obtained from literature, expert interviews, the manufacturer, the WHO, or whether assumptions have been made.
- The amount of literature found on the subject. Not a specific number will be given, but it will indicate whether a lot of research already exists for that research.
- The consistency of the findings.
- Whether findings have been proven in the field, in existing situations.

To make the value matrix more robust, feedback sessions with HWTS experts from the Delft University of Technology were conducted. The values in the value matrix for that HWTS were discussed in a semi-structured interview and checked. Participant information and notes of the conversations are shown in appendix D.

2.3.2. Weight general criteria

The next step in estimating the preference of HWTS is to calculate the weights for the general criteria. The weights are calculated for each criterion in every context, showing the relative importance of that criterion. The linear Best-Worst Method (BWM) was chosen to calculate the weight of each criterion in each context. An online survey was chosen as a method to get the input data for the BWM. The online survey link was sent to HWTS experts from all over the world with experience in multiple of the contexts included in this research. Further elaboration on the survey can be found in subchapter 2.3.3.2. The weights are tested with a Kruskal-Wallis test to see if the median of the context differ significantly.

2.3.2.1. Best-Worst Method

The SDM method does not indicate a fixed method to calculate weights. In this research the Best-Worst Method (BWM) is chosen to calculate the weight for the general criteria. The linear version of BWM is chosen, because this method can calculate unique results with fewer pairwise comparisons [55]. The choice for the method was made after it was clear how many criteria would be included in the value matrix and thus for how many criteria weights should be calculated. The BWM is a method to solve Multi Criteria Decision Making (MCDM) problems. A MCDM problem exist when a decision needs to be made between different workable alternatives, that depends on multiple criteria (Rezaei, 2014). The BWM, developed by J. Rezaei, is used to get the weight w_j for all the criteria [53]. BWM is a form of pairwise comparison, in which the most important and least important criteria are determined by an expert, after which the rest of the criteria will be compared to the most and least important criteria.

The input data for BWM was received through an online expert survey. The online survey is filled in by 39 HWTS expert from all around the world. The survey exists of two layers: the first layer exists of the groups of criteria. The second layer exists of all the criteria belonging to these groups. The final weight was computed by multiplying the weight of the main group with the weight of the second layer criteria [56] (F.Liang personal communication, July 28, 2020).

The BWM solves the inconsistency problem of pairwise comparison, by identifying the worst and the best criterion by participating experts. This results in a range of evaluation before the comparison of the other criteria starts. BWM also gives the possibility to check the consistency of the comparison [57]. Another advantage of BWM is that it requires fewer comparisons than other MCDM techniques [58]. This was an important reason to choose BWM, as this research includes many criteria. BWM needs $2n-3$ comparisons, while other MCDA methods (for example Analytic Hierarchy Process) need $n(n-1)/2$ comparisons [53]. A drawback of the method is that BWM might not work as well in situations that are uncertain and subjective. Sometimes the MCDM problems are so complex that it might be hard for decision-makers to give a precise judgment on the importance of the criteria [59], [60].

Linear BWM obtains the weights of each individual respondent of the expert survey. To calculate the final weight, the individual weights are aggregated by the arithmetic mean of the individual weights [61].

Linear BWM has five steps to calculate the individual criteria weight [53]**:**

1. Determine the relevant criteria $\{c_1, c_2, \ldots, c_n\}$.

2. Determine the best and the worst criteria.
   In this step, each decision-maker indicates what he thinks is the best and the worst criteria in making the final decision. This is done by every expert that participated in the online survey.

3. Determine the preference of the best criterion over all the other criteria using a number between 1 (equally important) and 9 (absolutely more important).
   The Best-to-Others vector then is:
   $A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})$
   a_{Bj} indicates the preference of the best criterion *B* over the other criterion *j*.

The experts participating in the online survey indicated their preference of the other criteria over the best criterion.

4. Determine the preference of all the criteria over the worst criterion using a number between 1 (equally important) and 9 (absolutely more important).
   The Others-to-Worst vector then is:
   $A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})$
   a_{jW} indicates the preference of the other criterion *j* over the worst criterion *W*.

   The experts participating in the online survey indicated their preference of the other criteria over the worst criterion.

5. Find the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$
   This step is done by the researcher.
   The optimal weight for the criteria is the one where, for each pair of wB=wj and wj=wW, we have wB=wj ¼ aBj and wj=wW ¼ ajW.

   The optimal weights are the one where, for each pair of w_B/w_j and w_j/w_W, we have $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$.
   This is the case for the solution where the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ are minimized for all *j*.

   This gives the following problem:

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\}$$

$$s.t.$$

Equation 2

$$\sum_j w_j = 1$$

$$wj \geq 0, \text{for all j}$$

   Problem (Equation 2) can be transferred to the following:

$$\min \xi$$

$$s.t.$$

Equation 3

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi, \text{for all j}$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \text{for all j}$$

$$\sum_j w_j = 1$$

$$wj \geq 0, \text{for all j}$$

Solving problem (Equation 3) will obtain the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and give the value for ξ^*.

Consistency ratio

Consistency of the answers can be checked within the BWM method [62]. That is because the experts participating in the online survey are asked how much more important the most important criteria are than criterion *j* and vice versa, how much more important criterion *j* is than the least important criteria. The consistency is checked with the output-based consistency ratio, shown in Equation 4 [57]. Linear BWM does not include a threshold value for the consistency ratio. But the closer the consistency ratio is to zero, the more reliable the results are. In this research a consistency of 0.25 is chosen as the threshold (J. Rezaei personal communication, November 16, 2020). Data with a lower consistency is excluded from the calculation of the weights.

A comparison is consistent if $a_{Bj} * a_{jW} = a_{BW}$ for all criteria *j*.

Consistency Index is a robust Index, given for every preference of the best criterion over the worst criterion (a_{BW}). The consistency ratio ∈ {0,1} can be calculated using ξ^*:

$$Consistency\ ratio = \frac{\xi^*}{Consistency\ Index} \qquad \textit{Equation 4}$$

2.3.2.2. Expert survey

The goal of the survey was to gain insight into the importance of the criteria in the choice for an HWTS and if this differs per context. The survey was used as input data for the BWM. The survey was filled in by 39 experts from around the world. The survey was conducted between 6 and 31 October 2020 and took 30-45 minutes. The online survey was made with the program ‘Qualtrics’.

The online survey started with an introduction where the purpose of the research was explained. In the first question of the survey, the respondents had to choose three context which they had most experience in. The core of the survey exists of three steps. Every step was a separate part of the survey, divided into three subparts. In every subpart, the focus was on one context. The same questions are asked for all the chosen contexts. Information about the context, the meaning of the criteria and the range of values for the criteria are shown to the respondents. This information can also be read in a separate document that the respondents received in the invitation by e-mail.

An online survey was chosen as a method because it is a useful way to collect data for a large group of people, especially when respondents live in different geographical regions [44].

Other advantages are that respondents can reply at their convenience, and answers of the respondents are automatically processed. Disadvantages of an online survey are that any doubts or misunderstanding that the respondents have cannot be clarified, no follow-up questions can be asked by the researcher and the respondent must be willing to complete the survey [44].

Participants

For the survey, we searched for experts with relevant backgrounds in HWTS in the several contexts mentioned earlier. When selecting the experts, the desired variation in nationality, focus area, type of function, and a limited number of respondents from the same organisation were considered. Of the 39 respondents, 54% were male, 31% female and 15% it is unknown. The distribution of the function types of respondents can be seen in Figure 4 and the distribution of organization types of the respondents is shown in Figure 3. The regions where the respondents have experience in, is shown in Figure 5. More information about the survey respondents, referred to as expert group C is added in Appendix F.

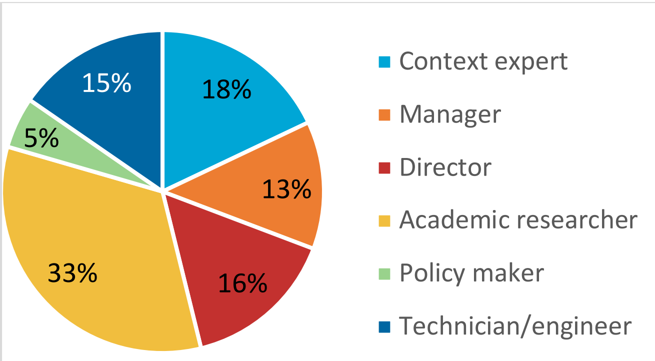


Figure 4: Distribution of function types of the respondents.

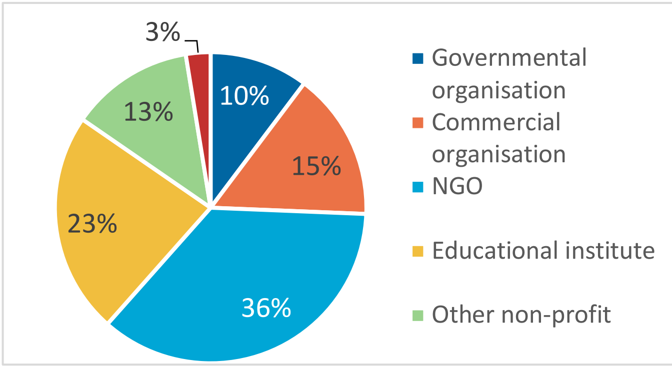


Figure 3:Distribution of organization types of the respondents.

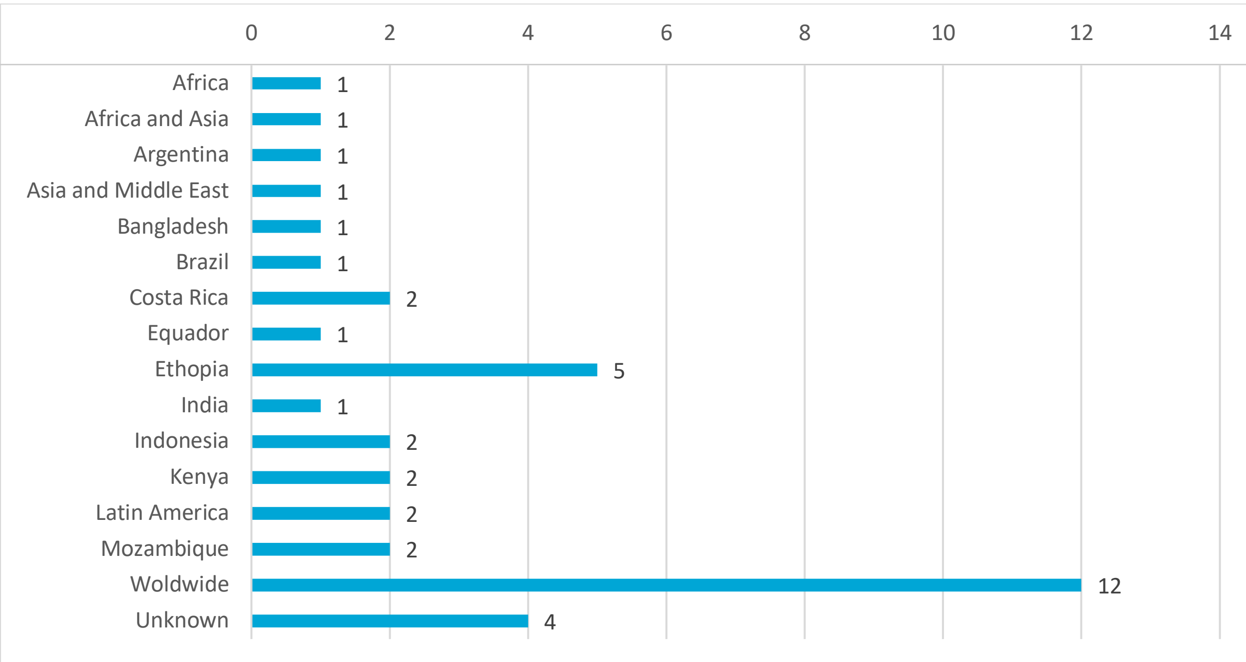


Figure 5: Focus region of the respondents.

The experts who participated earlier in the face-to-face interviews (expert group A) were approached to participate in the survey. Also, new experts were identified through the contacts of Delft University of Technology professors and approached to participate. All these experts were asked in the invitation e-mail of the survey for other experts who could be contacted.

In total 39 respondents finished the survey. Each respondent had to choose three contexts (of the five in total) with which they had the most experience. The number of responses for every context is shown in Table 1. To calculate the weights with the BWM, the minimal responses wanted is 7 to 10. All the contexts had more responses than the minimal. Although the context refugee camp had very minimal responses in the first weeks that the survey was online. A more targeted search for experts with experience in refugee camps was done. Organisations that focus on refugee camps were contacted by sending e-mails and by adding posts in relevant groups on LinkedIn. In addition, a post was placed in the HWTS Knowledge Point with the request for HWTS experts with experience in refugee camps. The number of respondents for this context did not increase much afterward.

Table 1: Number of responses for every context in the online survey.

	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of respondents	37	17	30	12	21

Design against bias

To make the results of the survey as reliable as possible, several requirements had to be taken into account for the design. The design of the survey was done based on the book by Sekaran and Bougie [44], the literature on the BWM [53], [56], [59], [60] and on feedback from professors.

Special attention was given to the wording of the questions. The choice of language must be appropriate to the intended respondents and consider the expertise, level of education, expected knowledge of technical terms, level of the English language and idioms in the culture of the respondents [44]. This has been taken into account in the survey design:

- Where appropriate and possible, technical terms were explained in more detail.
- The goal of the survey is to get the input for the BWM. This input can only be generated through closed questions. This immediately indicates a limitation of the survey, as respondents with closed questions cannot explain their answers. This effect has been reduced by adding an open question after every step, where the respondent can explain their answers.
- Questions were asked in such a way to minimalize the social desirability bias. This bias exists when there is an expectation of socially acceptance or the idea of a general truth.
- To keep the survey at an acceptable length, only necessary information is included with as little text as possible.
- In the survey, there are two layers of comparison: comparison between the criteria groups and the comparison of the criteria within these groups. Which comparison should come first in the survey, was a trade-off between the comprehensibility of the survey and a chance of splitting bias [63], [64]. Splitting bias can occur when more sub-attributes are

added to a group, increasing the weight given to that group. Because every group includes another number of criteria, this can cause splitting bias. Testing of the survey with three professors from Delft University of Technology, showed that when the survey started with a comparison of the main groups, more ambiguity arose. It was therefore chosen to compare the criteria groups at the end of the survey. This increases the clarity of the survey but creates a chance of splitting bias.
- Information on the criteria is presented in tables at the beginning of the first step. Efforts have been undertaken to ensure that the information on each criterion has approximately the same length to prevent splitting bias: that certain criteria are given more attention and possibly being considered more important [65], [66].
- Ranges of the values of the criteria have been added to the information table in the survey for every criterion. This gives more information about the way the criteria are measured in this research.

Another important part of the design was the general appearance. An attractive and neat survey is important, to make it easier for the respondent to answer the questions [44].
- A concise introduction is included, with the identity of the researcher and the purpose of the survey.
- Information on anonymization of the data is included in the introduction, lowering the chance in biased answers. Personal information is asked at the end of the survey, with the option to stay anonymous. The text included that the data won't be shared with third parties and personal information will be made anonymous if indicated that that was preferred. Any personal data will be stored during the research period for the researcher only to see. This was chosen to be able to contact the respondent if feedback was wished. It was indicated that personal data will be deleted after the research report is finalized. The survey was checked and approved by the TU Delft Human Research Ethics committee.
- The survey has a clear structure with nine different sections, which is explained to the respondents in the introduction. The nine sections consist of three steps for all three of the contexts. The three steps are the same for all the contexts.
- Example questions and answers are added for every step to minimalize ambiguity. It was deliberately chosen not to do the example question about HWTS, to avoid anchoring bias [67]. Anchoring bias occurs when respondents rely too much on their answers on the first information given. A sample question on a different subject was chosen.
- Pretesting happened with three experts from Delft University of Technology. Two of the experts are from the department of Sanitary Engineering with focus on HWTS in their research, checking the comprehensibility of the method and the definition of criteria in the pretesting. The third expert from Delft University of Technology is specialized in decision making in the water sector, checking whether biases can arise due to the way of questioning.

Attention has been paid to the classification of data. The answers of the survey can be exported from Qualtrics in an Excel file. To keep the overview clear between the many questions, all the questions and the answer options received a code.

2.3.2.3. The Kruskal-Wallis test

The Kruskal-Wallis test is performed to test the significance of the difference in the weights between the contexts. With the Kruskal-Wallis test, it is explored if the medians differ significantly between groups [68]. This non-parametric statistical test is developed by Kruskal and Wallis in 1952 [69]. It is fitted for three or more groups, which is needed with five contexts to be checked. The test assumes unpaired data. This is debatable for this research, but it was chosen because no repeated measurements were done on the same group of people for all contexts. The dependent variable, the weight, is measured at interval level. There is no need for the data to be normally distributed. The Kruskal-Wallis test is conducted with the program SPSS. The null hypotheses states there is no significant difference between the medians of all the groups. The alternative hypothesis states that at least two group medians significantly differ from each other. A confidence interval is 0.95. So if the probability is smaller than 0.05, the null hypothesis will be rejected. The test is used in this research to investigate the difference between contexts and not the difference between the importance of criteria.

The following hypotheses are tested with the Kruskal-Walis test [68]:

$H_0: F_1(x) = F_2(x) = \cdots = F_k(x)$, for all x *Equation 5*

$H_1: F_i(x)F_j(x)$, for at least one $i, j \in \{1, \ldots, k\}$ for some x *Equation 6*

The Kruskal-Wallis is a non-parametric test and is chosen because the data is not normally distributed and exists of less than 30 datapoints. SPSS can be used to test is the data is normally distributed. The Shapiro-Wilk can be used, as this is stricter. The null hypothesis is that the data is normally distributed. If the probability is lower than 0.05, the null hypothesis is rejected, and it can be assumed the data is not normally distributed [68]. Overall, it can be concluded that the data is not distributed normally, and a non-parametric test will be used. The complete set of results for test of normality are reported in appendix H.

If the Kruskal-Wallis test finds a significant difference in the means of one of the contexts, Dunn-Bonferroni approach can indicate which specific means are significant from the others [70]. Dunn's Multiple Comparison Test is a post hoc non-parametric test.

2.3.3. Ranking of HWTS per context

After the construction of the value matrix and calculation of weights, the HWTS can be ranked. A ranking was chosen in order to get an overview of how the HWTS score on the general criteria. A ranking problem is when the alternatives need to be ranked from the best to worst suited [71], [72].

The values in the value matrix are measured using different scales. So, before the values in de matrix can be compared or added up, the values must be normalised. Normalising means adjusting the values to a scale between 0 and 1, so that the values have a commons scale. After that, the values can be aggregated to get the HWTS ranking. Two techniques are used for aggregation: Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and the Weighted Sum Method (WSM). The Max-Min method is used to normalize the input data for the WSM. The two different techniques are used to see whether a different ranking of HWTS will arise.

2.3.3.1. TOPSIS

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was introduced in 1981 by Hwang and Yoon [73]. TOPSIS measures the distances from the alternatives to the positive and negative ideal solutions. The highest ranked alternative has the shortest distance to the positive ideal solution and the farthest distance to the negative ideal solution [74]. TOPSIS is a method used in this research for normalisation of the value matrix and aggregation of the values to rank the alternatives.

Advantages of TOPSIS are that criteria weights are incorporated in comparison and the best alternative can be pursued by a mathematical form that is straightforward and understandable [75]–[77]. Also, a large number of criteria can be included in the calculations and it is suited for mixed quantitative and qualitative indicators [72]. Disadvantage of TOPSIS is that it can cause 'rank reversal'. This means that the ranking can change if alternatives are added or removed [75], [78].

The TOPSIS method includes the following steps after the construction of the value matrix [74], [79]:

1. The first step is to normalize the value matrix values, to create a standard decision matrix (R). TOPSIS does include a step for normalisation within the method, whereas WSM required the Max-Min method to be used for standardization.
   With the Equation 7, the normalized matrix R (Equation 8) is obtained:

$$r_{ij} = \frac{p_{ij}}{\sqrt{\sum_{k=1}^{m} p_{kj}^2}}$$ *Equation 7*

$$R_{ij} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}$$ *Equation 8*

2. The second step is to construct the weighted standard decision matrix (V). Matrix 'V' is constructed when the element of matrix 'R' is multiplied by the corresponding weight w_j.

$$V[v_{ij}] = [w_j * r_{ij}]$$ *Equation 9*

   And shown as a matrix:

$$v_{ij} = \begin{pmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{pmatrix}$$ *Equation 10*

3. The next step is to determine the positive ideal solution (A^*) and the negative ideal solution (A^-):

$$A^* = \left\{\left(\max_i v_{ij} \middle| j \in J\right), \left(\min_i v_{ij} \middle| j \in J'\right)\right\} = \{v_1^*, v_2^*, \dots, v_n^*\}$$ Equation 11

$$A^- = \left\{\left(\min_i v_{ij} \middle| j \in J\right), \left(\max_i v_{ij} \middle| j \in J'\right)\right\} = \{v_1^-, v_2^-, \dots, v_n^-\}$$ Equation 12

J stands for the utility (maximalization) and *J'* for the costs (minimization).

4. The Euclidean distance of each alternative to the positive and negative ideal solutions are determined:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}$$ Equation 13

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}$$ Equation 14

5. The final step is to calculate the relative closeness of the alternative to the ideal solution, C^*_i. The value from C^*_i lies between 0 and 1. The closer the value of C^* to 1, the higher the position of that alternative in the final ranking. The calculation of C^*_i is shown in the formula (Equation 15):

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*}$$ Equation 15

2.3.3.2. Weighted sum method

In addition to TOPSIS, the weighed Sum Method (WSM) is used for aggregation of the values in the matrix, so that the alternatives can be ranked. TOPSIS and WSM are two separate methods with separate steps. The choice was made to use two methods to check whether there is a different ranking of HWTS between the two methods. An advantage of the WSM is that it is a straightforward approach, which is widely used [77], [80]. Disadvantages are the values need to be normalized first if a multi-dimensional problem is used [80], [81]. For normalisation a separate method is needed.

The WSM is a method for evaluating multiple alternatives in terms of criteria.

1. Before the WSM can be used, the performance value p_{ij} needs to be normalized. There are multiple normalization methods that can be used for the WSM [82]. For this research the Max-Min normalization method is chosen. Max-Min method is most widely used [83], normalizing indicators to have a range [0, 1] [39].

If a higher value of p_{ij} is desired, use Equation 16. For all the criteria used in the value matrix, except for ‘lifecycle costs’ a higher value is desired as a value of 5 is the best score given and 1 is the worst score given.

$$v_{ij} = \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}$$ *Equation 16*

If a lower value of p_{ij} is desired, use Equation 17. This is only used for the criterion ‘lifecycle costs’.

$$v_{ij} = 1 - \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}$$ *Equation 17*

Where max{x} is the highest value in the matrix for that criteria. Min{x} is the lowest value.

2. Weighted sum is the normalised performance value v_{ij} of the alternative for that criteria multiplied by the weight of the criteria *wj.* For every alternative, the sum of these weighted sums is calculated as shown in Eq. 7 [55], [84], [85]:

$$WS_i = \sum_{j=1}^{n} v_{ij} w_j \, , for\ i = 1, 2, 3, \dots, m$$ *Equation 18*

The WS from Equation 18 gives a score for every alternative, making it possible to rank the alternatives.

3 Identified objectives and criteria

The second step of the modified SDM structure is to identify objectives and the set of selection criteria for a suitable HWTS. The information on objectives and criteria is structured using an Objective Hierarchy. This tool can be used to ensure that no criteria are measured double or have been missed. Literature and face-to-face interviews with expert group A have been used to fill in the objectives hierarchy, resulting in a list of criteria to select an appropriate HWTS. Chapter 3.1 shows the objectives hierarchy with the list of selection criteria found. These criteria will focus on health improvement, acceptability and adaptation and accessibility of HWTS. Not all of these criteria are part of the value matrix, because some criteria are too situation dependent. The general criteria are explained in chapter 3.2 and the situation-specific criteria are explained in chapter 3.3.

This chapter answers the sub question: *What are the technical, social and economic criteria to consider when choosing HWTS and how to assess them?*

3.1. Objectives hierarchy

The main objective for the hierarchy was: "Optimal use of HWTS for disinfection to lower waterborne disease". The problem owner used for the Objectives Hierarchy is the decision-maker of the HWTS used in contexts. The objectives hierarchy is shown in Figure 6. To make the Objective Hierarchy, literature is used and input from the face-to-face interviews.

The WHO states that as long as the product meets the targeted protection, the focus should be on criteria aimed at correct and consistent use and effective implementation [20]. Health gains can only be realized if the product is used properly, consistently and throughout the household [21], [22]. This makes it important that the products are integrated in daily routines [21], [86], [87]. It is therefore important that the HWTS is accepted and the behaviour adapted so that the HWTS is also used in the long term. Health gains are not the only motivator when treating drinking water [88]. So, to ensure the objection of 'optimal use of HWTS to lower waterborne disease' is reached, criteria on health gains, acceptability/adaptation and accessibility are included. The lowest layer are the criteria, shown in green or orange in Figure 6, with the measurement between brackets. The general criteria, colored green, are included in the value matrix. The situation-specific criteria, colored orange, are not included in the value matrix, because they are too situation-specific. Sometimes, the measurement of the criteria is 'constructed labelling'. This means the criteria is a constructed attribute and the value of the criteria are shown in different constructed levels. For most of the criteria a 5-level is chosen. For the criterion 'water quality' a 4-level construction is chosen, as this is based on the 4-level rating of the WHO research used. The values of the constructed levels are shown in Table 2 and Table 3.

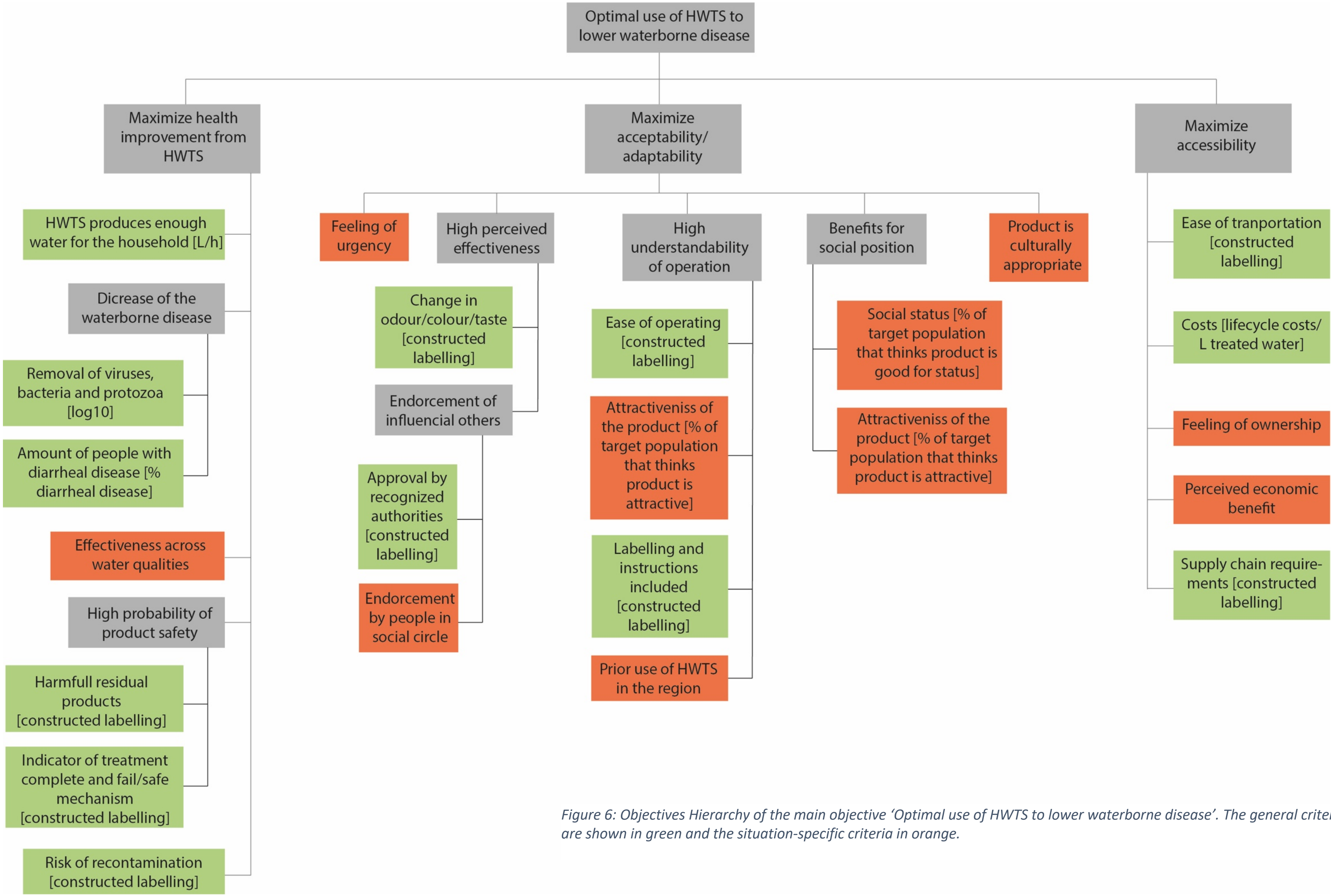


Figure 6: Objectives Hierarchy of the main objective 'Optimal use of HWTS to lower waterborne disease'. The general criteria are shown in green and the situation-specific criteria in orange.

Table 2: Constructed criteria level of the criterion 'quality', measured in log10 reduction of bacteria, viruses an protozoa. The 4 levels are the same as constructed by the WHO in their 'Scheme to Evaluate Household Water Treatment Technologies' [20], [89].

	Lowest level of desired characteristics **1**	**2**	**3**	Highest level of desired characteristics **4**
Water quality*	Bacteria <2 Virus < 3 Protozoa <2	Two of the three pathogens levels are at rate 3	Bacteria ≥2 Virus ≥3 Protozoa ≥2	Bacteria ≥4 Virus ≥5 Protozoa ≥4

*Measured in log10 reduction.

Table 3: Constructed criteria levels with value 1 (left side of the table) as the worst value and 5 (right side) as the best value.

	Lowest level of desired characteristics **1**	**2**	**3**	**4**	Highest level of desired characteristics **5**
Risk of recontamination	Risk of recontamination high: storage must be self-regulated and is not included in the product	No tap system or cover and no residual protection	Medium storage tank included (<10L) with tap system and a cover, no residual protection	Bigger storage tank with cover included (> 10L) without a tap system, with residual protection or with a tap system but without residual protection	Risk of recontamination is low: big enough storage tank with a cover is included in the product with a tap-system, with residual protection
Risk of by-product formation	By-products are higher than WHO guidelines and or have proven negative health effect on humans in the long term	By-product concentrations lower than WHO guidelines, but in field research multiple WHO values were exceeded not resulting in (long term) health risks	The WHO guidelines are not exceeded in laboratory or in the field, but several by-products are added to the treated water not resulting in (long term) health risks	The WHO guidelines are not exceeded, only one by-product is added to the treated water in very low concentrations not resulting in health risks	No by-product formation in the treated water
Reliability of product safety	No indicator of treatment complete and no fail/safe mechanism	Indicator when treatment complete and no fail/safe mechanism OR no indicator when treatment complete, with fail/safe mechanism	Indicator when treatment complete and fail/save mechanism must be investigated by person (use of senses)	Indicator when treatment complete and fail/save mechanism that a person can measure with separate device	Indicator when treatment complete and fail/save mechanism that the product itself indicates

Odour/colour/taste	Product deteriorates the odour, colour or taste. Reported as a barrier to use the product	No change in odour and colour but worsens the taste by increasing temperature	Not designed to change odour, colour and taste	Not designed to change odour, colour and taste but reported to have lower temperature	Designed for positive change in odour, colour and taste of the water
Approved by recognized authorities	Approved only on local level	Approved on regional level	Approved on national level	Approved by the WHO	Approved by the WHO and proven effective in the field
Labelling and instructions	Labelling does not contain all the components or non-existing, instructions very long (>one page), complex or non-existing	Correct labelling partly included instructions very long/complex and only in 1 language	Correct labelling included if relevant, instructions length is medium, mostly text used and only in 1 language	Correct labelling included if relevant, instructions are short, and visuals are used	Correct labelling included if relevant, instructions are short and can be understood by only using the visuals
Ease of operation	Additional skills needed for the user to operate the product, time consuming (> 10 min/day) to operate the product	Some additional skills needed for the user to operate the product, takes little time daily to operate the product	Minimal training is needed to use the product but time consuming to operate the product	Minimal training is needed to use the product and takes little time (< 10 min/day) to use the product daily	Operation limited to filling in raw water and collecting treated water, no training needed and takes little time daily
Ease of maintenance	Maintenance is complex, takes a lot of time monthly (>20 min)	Maintenance is complex (can be done wrong), needs to be done regularly and takes little time	Maintenance is easy, needs to be one regularly and takes a lot of time monthly	Maintenance is easy, needs to be done regularly and takes little time	No need for maintenance
Supply chain requirements	Requires steady supply of replacement parts or consumables, which are vendor-specific	Requires steady supply of replacement parts or consumables, which are locally available	Requires periodic replacement parts or consumables, which are vendor-specific	Requires periodic replacement parts or consumables, which are locally available	No supply chain required. Everything is locally available in case of breakage
Ease of transportation	To heavy (>10 kg) or delicate to transport and must be assembled at point of use	Transport is possible but not easy. Heavy (5-10 kg), big (>50cm3) or very delicate	Product has a medium weight (1-5 kg) and size (<30 cm3), parts can break with a shock due to transport	Product is small (<30 cm3) and light (<1 kg), but parts can break with a shock due to transport	Light (<1 kg), small (<30 cm3) and not delicate, can be transported in large numbers

3.2. Set of general criteria

The objectives hierarchy shows a set of criteria with general and situation-specific criteria. This subchapter explains the general criteria, shown in Figure 7. Because these criteria can be evaluated generally, they are included in the value matrix. The use of general criteria will save a considerable amount of time and resources in making a choice, since there is no need to research the total set of criteria locally. The general criteria and situation-specific criteria are of the same importance. To make a general comparison before doing local research, there was chosen to address the general criteria first.

This chapter explains how the criteria were obtained and why they are important in the choice of a suitable HWTS. References in the subchapters show if information is derived from the consulted literature or expert interviews. References to expert interviews are indicated with a letter between square brackets, referring to a specific interview further elaborated in appendix C.

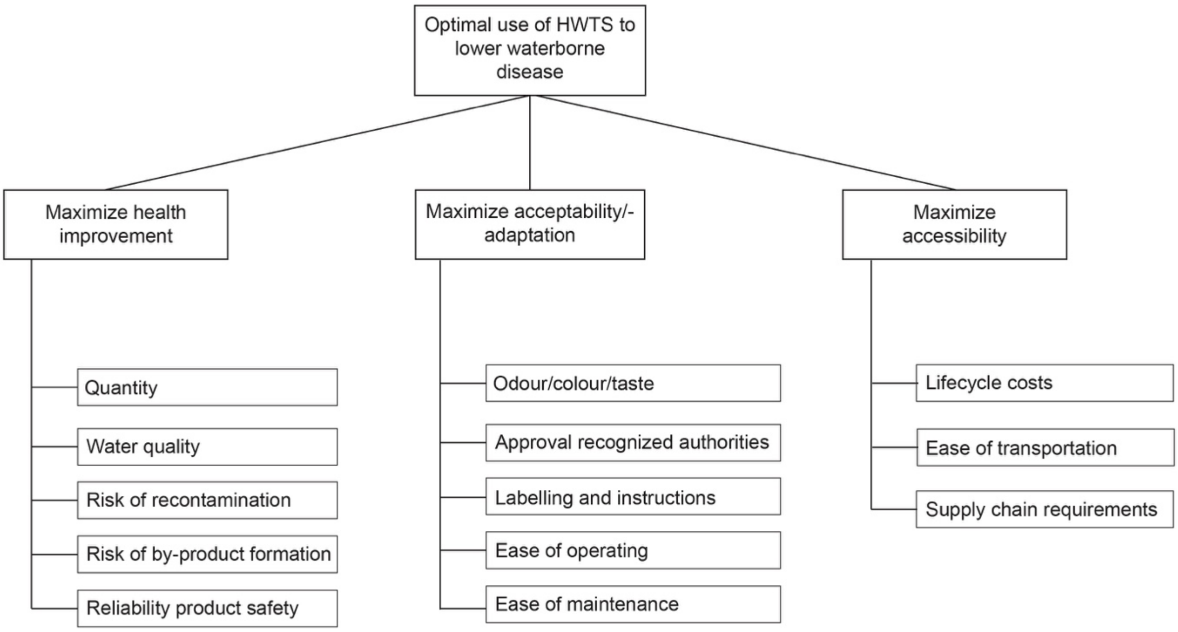


Figure 7: Overview of the identified criteria included in the value matrix.

3.2.1. Health improvement

The criteria for health improvement are based on the '*WHO International Scheme to Evaluate Household Water Treatment Technologies'* [20].

Quantity

Quantity entails consistency in delivering enough treated water for the household's daily needs [20]. This is important because if the availability of clean drinking water is lower than the daily household needs, the household will also drink untreated water [J]. Even a small amount of untreated water consumption will have a negative effect on health [26], [90]. It can even remove the health benefits of treated drinking water entirely [91]. The quantity of clean water from the product is related to the throughput or flow rate of the product [92]. Quantity is measured in liters per hour [L/h].

The daily amount of water needed per person is very situation-specific. A flow rate lower than what is minimally needed can be a problem for the household. But a higher flow rate than a household uses in a day will not add much more value. That means that the criterion quantity is not linear.

Water quality

A critical part of the WHO evaluation was whether the products could consistently treat the water to the required microbial level [22], [89], [92]. Water quality was measured as the microbial performance for the log reduction of bacteria, viruses and protozoa. The values are based on the evaluation of household water treatment options of the WHO. Log reduction shows the 10-fold (one decimal) of microbes that are eliminated. The log reduction can be converted to percentile reduction. For example, a 2log reduction means a 99% reduction and a 3log reduction means a reduction of 99.9%. So, the higher the log reduction, the better the product is at eliminating microbes.

In the WHO evaluation rounds I and II, several HWTS for disinfection are evaluated regarding their microbial performance. The reference pathogen for bacteria is Campylobacter, for viruses, it is the rotavirus, and for protozoa the reference pathogen is Cryptosporidium. The Log10 reduction required by the HWTS to be protective is shown in Figure 8 [20].

Target	Log_{10} reduction required: **Bacteria**	Log_{10} reduction required: **Viruses**	Log_{10} reduction required: **Protozoa**
Highly protective	**≥ 4**	**≥ 5**	**≥ 4**
Protective	**≥ 2**	**≥ 3**	**≥ 2**
*Interim**	Achieves "protective" target for two classes of pathogens and results in health gains		
Summary of performance requirements for small-scale and household drinking-water treatment, based on reference pathogens *Campylobacter jejuni*, *Cryptosporidium* and rotavirus (see Appendix 1).			

Figure 8: WHO target Log reduction values for bacteria, viruses and protozoa.

The elimination of microbes should in practice have an effect on the diarrhoea among users. The diarrheal reduction after the use of the HWTS can also be seen in the value matrix but is not included in further calculations.

Risk of recontamination

To realize the health improvement of water treatment, it is important to minimize the risk of recontamination. After the water is treated, safe storage prevents recontamination of the treated drink water [22], [89], [92]. The meta-analysis of Wolf et al. [19], [93] highlighted the importance of storage on the health effect. The reduction of diarrheal disease was shown to be 10% more for a filter with integrated safe storage. Recontamination can take place between water treatment and consumption, so even just before consumption [94]. The research of Rufener et al. in 2010 [95], showed that drinking cups are a high potential recontamination risk. Two-thirds of the drinking cups were contaminated with E. coli, significantly reducing the water quality of the treated water in the cups.

The Centre for Disease Control and Prevention has put together characteristics of a safe storage container. A storage container should be an appropriate size for the household, should have a tap system or small opening for safe access to the water and a cover to discourage users from using contaminated items in the stored water like hands or cups [96]. The constructed levels of this criterion are based on these characteristics.

Risk of by-product formation

This criterion entails the existence of residual by-product by leachates and disinfectant concentrations. WHO published the 'Guidelines for Drinking Water Quality' [20], showing the values at which the concentration of the residual disinfectant might be harmful to human health. This criterion includes all the unwanted substances added to the water by the product, even under the harmful concentration.

Reliability product safety

The reliability of product safety consists of two parts. The first part concerns the presence of a fail/save mechanism in the product, to indicate when treatment is not working properly and thus untreated water is provided [20]. This can be due to damage or end of life of the product [97]. The second part is if there is an indicator present to show when the treatment is done. Examples of indicators when treatment is complete are a visual sign on the product [20], change in smell or colour of the water, or displacement of treated water in a storage tank.

3.2.2. Acceptability and adaptation

The criteria of acceptability and adaptability focus on short- and long-term uptake of the HWTS. In the short term, people must find the HWTS attractive and reliable enough to use or invest in. In the long term, the product must become part of the household routine so that it remains in use. These criteria have been identified through the use of the behavioural change models RANAS and COM-B. The models are briefly explained in chapter 2.2.1 and further elaborated on in appendix B.

Odour, colour and taste

A psychosocial factor for accepting and trusting the HWTS is the emotional response on the new behaviour, such as a (dis)like for the new odour, colour, taste or change in the temperature of the treated water [41], [87], [88], [G], [L], [J]. This criterion is inspired by the attitude section of the RANAS model, and the motivation component of the COM-B model. Also the WHO indicates this criterion as a high priority, as aesthetically unaccepted water can lead to the consumption of water from less safe sources [12]. No WHO guideline concentrations have been drawn for components in the water that may affect colour, taste, odour if there is no direct link to negative health effects. The concentration at which it is objectionable is situation-specific due to various factors, such as personal taste perception and water quality to which the community is accustomed [12]. Besides, people often reject drinking water for odour, taste or colour at a much lower concentration than that which is dangerous to human health [17]. The temperature is seen as a part of the taste of water in this criterion. With the rating of the HWTS products, it must be kept in mind that a perception of taste and odour is personal. For example, the chemical smell and taste of chlorine can be perceived as negative, while other users like it precisely because they know that the water has been cleaned.

Approval of recognized authorities
This criterion is inspired by the norm section of the RANAS model, and the opportunity component of the COM-B model. Involvement and promotion by recognized authorities help with sustainable use of HWTS [88], [98]. For the users, it gives certainty that the product can be trusted [E]. The WHO is chosen as the highest recognized authority to approve, with a higher score if the HWTS is also proven effective in the field.

Labelling and instructions
The WHO takes labelling and instructions into account in the '*International Scheme to Evaluate Household Water Treatment Technologies'* (WHO 2019). An HWTS product should have the appropriate labelling if relevant. That means it includes the manufacturing date and if needed the expiration date, chemical contents and the lot number. Also, instructions should be included with the product. It helps to have simple instructions with a minimal number of steps, in both English and the local language and preferably communicated with only visuals [E], [I], [J]. Besides, this criterion is inspired by the ability section of the RANAS model, and the capability component of the COM-B model.

Ease of operation
The ease of operation is important for the acceptability and minimization of misuse. Low ease of operation is seen as a barrier to use the product [25], [26], [99], [100], [H]. Also, difficulties in operation can lead to misuse [101], which can result in less effective microbial reduction. Ease of operating for HWTS is especially important because operation is done by relatively untrained and unskilled people, in comparison with people managing central water treatment facilities [12], [102]. This criterion is also inspired by the ability section of the RANAS model, and the capability component of the COM-B model.

Ease of operation in this research includes the skills needed and the time it takes to operate the product. Both these aspects affect people's willingness to continue using the product and the change of misuse due to ambiguity or rushing. In the best case the operation is limited to filling in raw water and collecting the treated water [25]. Some products require training or extensive explanation in person to use them properly. The daily time required to treat the water only takes into account the actions of the consumer and not the flow rate.

Ease of maintenance
Maintenance is the requirement for interventions by the user to keep the product performing optimally [26]. Maintenance, therefore, concerns cleaning the product and possibly replacing damaged or broken parts. The efficiency of the HWTS highly depends on the correct cleaning and maintenance of the products [103], making it an important criterion to take into account [25], [104]. This criterion is also inspired by the ability section of the RANAS model, and the capability component of the COM-B model. The less maintenance is required for the product, the better [E]. It is also important that it is obvious how important cleaning is and how it works

[I]. Indicators of the criterion 'ease of maintenance' include how often maintenance is needed, how time-consuming it is, and how complex the actions for maintenance are.

3.2.3. Accessibility

In addition to the importance of the effectiveness of the product and its acceptance, it must also be economically feasible. The following criteria are included in the value matrix.

Lifecycle costs

An important economic criterion is the life cycle costs [88], [99]. Lifetime costs include the initial investment of the HWTS and operational costs during the lifetime of the HWTS [17], [22], [99], [105]. The investment costs include the costs of the HWTS and, if not included in the HWTS, a separate storage container. The lifetime of HWTS differs, so to make an honest comparison, the costs of the products is in liters treated water. The lifecycle costs will be measured in $ per liters treated water.

Not included in the lifecycle costs are any discount for purchasing a larger quantity, transport to buy the product or spare parts and possible additional implementation costs such as costs to run the program, raise awareness, educate people and to provide ongoing support [17]. The willingness to pay is seen as a separate criterion, which is further explained in chapter 3.3.

Ease of transportation

The ease of transport of an HWTS is important for distribution [84]. The ease of transportation is especially relevant in situations where large quantities have to be transported fast or if the location is difficult to reach. This both is mostly the case in emergency situations [C]. The elements for the criterion 'ease of transportation' are robustness, weight and size of the packed product while transported [92]. Robustness shows the sensitivity to shock loads [99].

Supply chain requirements

The supply chain refers to the requirements for the replacement of product parts or consumables [26]. Sustainable use of HWTS can be supported by an accessible and established supply chain [23], [106]. There is a difference between setting up a supply chain and the accessibility of an existing supply chain. Because the ease of setting up a supply chain is very location-dependent, the focus of this criterion is on the requirements of an existing supply chain. The criterion 'supply chain requirements' includes how often replacement or consumables are required and if the replacement parts or consumables are vendor-specific or generic [26], [99]. The ease of setting up a supply chain is included in another criterion: 'prior local use'.

3.3. Set of situation-specific criteria

As indicated earlier, the set of criteria is subdivided into criteria that are generic and criteria that are situation-specific. This subchapter includes the situation-specific criteria. Part of the criteria can be used in the choice of a suitable HWTS and part for implementation. The general and situation-specific criteria are, in principle, equally important when making a choice but are only processed and evaluated differently in this study.

Effectiveness across water qualities
Effectiveness of HWTS across water quality conditions is included in the '*WHO International Scheme to Evaluate Household Water Treatment Technologies*' [20]. The quality of the source water is important to include in the choice between the HWTS, as water quality can influence the effectiveness of the HWTS. For some HWTS, the source water needs pre-treatment at a certain level of turbidity (NTU). The higher the level of NTU, the more turbid the water is. Another aspect that differs per HWTS is the affect water quality has on the flow rate.

Importance of clean drink water knowledge
This criterion is part of the risk section of the RANAS model and the motivation component of the COM-B model. It is important that people know that the water they drink has a negative effect on their health [G], [K]. A lack of knowledge and information on the effects of untreated drinking water and waterborne diseases shows lower rates of consistent use [88]. If there is no knowledge about the health effects of untreated water, the implementation of the product is very difficult [I].

Prior local use
Implementing HWTS products that already have been used, have a greater chance of success [22], [107]–[109], [C]. People already have experience with the product, resulting in a high uptake in the community [110]. Using local products that are already in use also helps to reach as many people as possible as quickly as possible [L]. Prior local use also provides information about the existence or non-existence of a supply chain for an HWTS product. The general criteria 'supply chain requirements', discussed earlier, includes the extent to which having a supply chain is necessary for the HWTS. This criterion of prior local use includes whether a supply chain has already been set up or whether it needs to be set up itself.

Social influence from others
Social influence can be expressed in expectations from the social environment to behave in a certain way. The opinion about a product or technique can be positively or negatively adjusted by the experiences of others with that technique [24], [25]. Social influence from others is also part of the norm section of the RANAS model and the opportunity component of the COM-B model. In practice it is often experienced that people go along with the purchase of a product when people form the social circle, people with a high status or knowledgeable people use the product or advise to use the product [B], [H]. These criteria can be used in the implementation by, for example, using social influence in the promotion of HWTS.

Dignity and status
The norm section of the RANAS model and the opportunity component of the COM-B model include the importance of dignity and status on behaviour. Having an HWTS in your house can provide a greater feeling of dignity and effect someone's social status [111]. This can be a reason for people to purchase and use an HWTS. Status and social rank are for many people a reason to treat their water [88]. Part of the dignity and status is dependent on the attractiveness of the product [E], [I], [J]. Whether a product is attractive is subjective and can differ between individuals and cultures. If people see that a product increases their social status, the willingness to pay can increase [112].

Cultural appropriateness
Cultural acceptability and appropriateness is an important local condition for the choice of an HWTS [14], [113], [114]. It is inspired by the opportunity component of the COM-B model. Cultural appropriateness should already be taken into account when designing the product.

Van Boeijen and Zijlstra [115] focus on the importance of cultures for design, in their book 'Cultural Sensitive Design: A Guide to Culture in Practice'. Let's start with the five intentions for culture-sensitive design: (1) affirm a culture, (2) attune to a culture, (3) change a culture, (4) bridging cultures and (5) to bypass the culture in the design. For the design of the HWTS, the intention is to attune to a culture to match the product and the cultural group seems the most appropriate. In their book, van Boeijen and Zijlstra state that the most common aspects to consider in a design are forms, properties, functions, interactions, needs and values, to avoid a mismatch with the culture. In addition, there are various principles of a culture to bear in mind in the design. Three of these principles I would like to highlight: (1) cultures change, (2) cultures must be seen in their context and (3) cultural values are interconnected. This means that the dynamics of a culture, the place and time of the situation and the individual and cultural perspective have to be considered when designing an HWTS.

Ownership
This criterion is inspired by the opportunity component of the COM-B model and came to the attention in the interviews with experts. Opinions are still divided as to the effect of ownership on the use of a product. The efficiency when giving away products for free is discussed in the book of Banerjee and Duflo, named "*Poor economics: A radical rethinking of the way to fight global poverty*" [116]. The book discusses aid, in which products are distributed free of charge, without rejecting or advocating it. It discusses that the effectiveness of this type of aid depends on its specific situation and must therefore be evaluated per situation [116], [117]. Nevertheless, literature and expert conversation indicates that the creation of ownership is important for the acceptance of the technology [20], [118], [B]. HWTS products are sometimes offered free in effectiveness studies. These studies showed that when the research period was over, there was an increasing chance that the product was no longer used [111], [118].

Perceived economic benefit
For the buyer, it must be attractive to invest in the product. Because the price is worth the benefits or because the product is a cheaper, better quality option than other alternatives. Of course, the actual price is important for this, but also the willingness to pay and the ability to pay [26]. The ability to pay is something else than willingness to pay. The ability to pay is determined by the part of his income or capital that can be set aside to pay for the product and is a constraint that prevents consumers from making choices based on their willingness to pay [119]. Willingness and ability to pay are also highlighted in the opportunity component of the COM-B model.

4 Included HWTS and contexts

The third step in the SDM structure is to choose alternatives. In this research that means choose which HWTS and what contexts to include in the comparison. The choices which HWTS to include and information on the included HWTS are discussed in chapter 4.1. Chapter 4.2 informs about the guidelines for HWTS. And chapter 4.3 shows the choices on which contexts to include and information on these contexts.

4.1. HWTS included in this research

Various aspects were considered in the choice which HWTS to include in this study:

- The focus is on HWTS for disinfection to reduce bacteria, viruses and protozoa.
- The HWTS technique is already widely used in various locations around the world.
- The HWTS technique is used in low-income settings.
- The HWTS technique is suitable for a household of five people.
- There is no electricity needed for the HWTS technique to function.

This resulted in the choice of six of the most commonly used techniques to include in the study: (1) ceramic candle filter with activated carbon, (2) ceramic silver impregnated pot filter, (3) pressure-driven membrane ultrafiltration, (4) biosand filter, (5) SODIS UV-disinfection and (6) chlorination. In this chapter these six techniques will be explained. In chapter 5.1, the effectiveness of the HWTS will be discussed for each technique.

4.1.1. Ceramic candle filter

A ceramic candle filter is shown in Figure 10. The ceramic candle is made from clay and treats water by exclusion through size. The pores in the ceramic candle are extremely small, making a physical barrier to the bigger sized micro-organisms [88], [90]. The water runs through the porous wall of the ceramic candle, leaving behind pathogens. The candle is filled with activated carbon granules, which is very porous, making the surface area big. This increases the absorbent rate of chemicals from the water passing through and improves odour and taste [20].

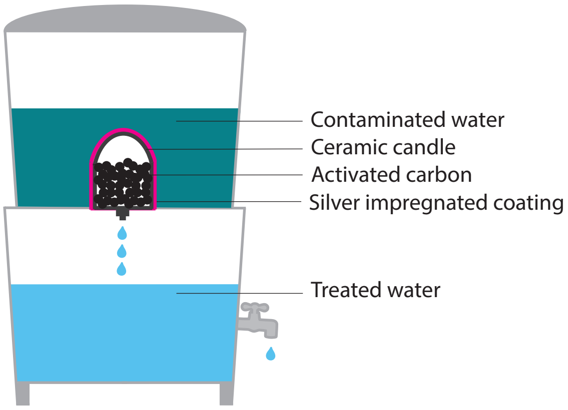


Figure 10: A schematic overview of the ceramic candle filter.

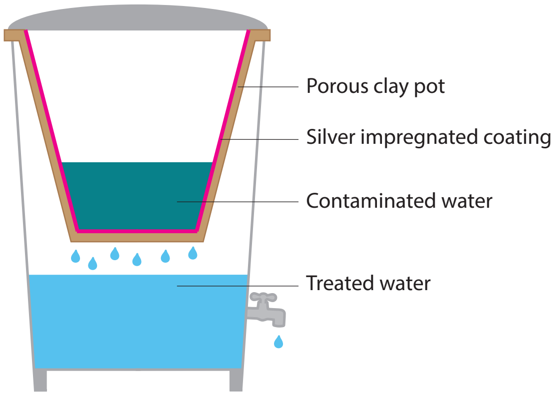


Figure 9: A schematic overview of the ceramic pot filter.

4.1.2. Ceramic pot filter

The ceramic pot filter comprises a flowerpot shaped ceramic filter, placed in a container, as seen in Figure 9. The pot filter works with exclusion through size. Water is poured into the ceramic pot and drips through the tiny openings in the porous pot into the lower container [120]. The filters are treated with colloidal silver against the growth of bacterial build up on the layers of the pot filter [121], [122].

4.1.3. Biosand filter

The biosand filter is an adaptation of the slow-sand filter, which is a type of purification system used for centralised and semi-centralised water treatment. The bio-sand filter is smaller than the slow-sand filter, making it a household size with an intermitted flow [108], [123], shown in Figure 11. The biosand filter consists of a container, filled with a layer of gravel on the bottom, a coarse sand layer and a layer of fine sand on top. Untreated water is poured into the top of the tank, after which the water runs down by gravity, along the gravel and sand [124], [125]. Because the outlet of the filter is higher than the layer of sand in the filter, water remains in the sand layer all the time. Because of this, a biological layer grows called 'schmutzdecke' in the top of the sand layer. The biological layer decomposes microorganisms and particles in the water, trapped in the filter media [125]. This biological layer increases water quality but lowers the flow rate [125]–[127]. A diffusion plate on top of the filter protects the biological layer when water is poured into the filter.

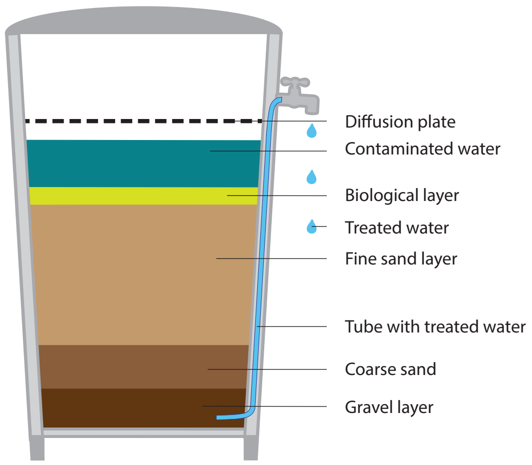


Figure 11: A schematic overview of the biosand filter.

4.1.4. Pressure-driven membrane ultrafiltration

Membrane filtration treats water by exclusion through size [126]. This mechanism is illustrated in Figure 12. The driving force of a pressure-driven membrane filter is a difference in pressure across the membrane. This pressure difference can be induced by two mechanisms. The first is created by a pumping system, where the user puts pressure in the container by pumping air into it. The second is by gravity as the container with untreated water is placed higher than the filter, as shown in Figure 13. This mechanism is included in this research. Depending on the pore size, these membrane filters can be classified in micro-filtration, ultrafiltration and nanofiltration [20]. Nanofiltration has the smallest pore size, resulting in more blocked micro-organisms. For nanofiltration a higher pressure is needed to filter the water [128].

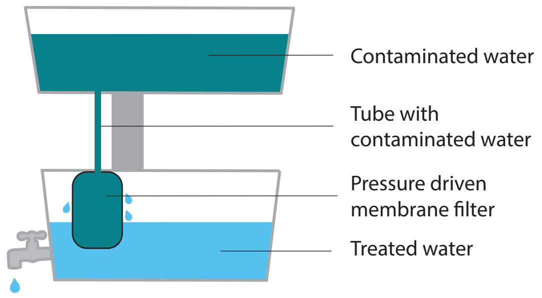


Figure 13: A schematic overview of a pressure driven membrane filter.

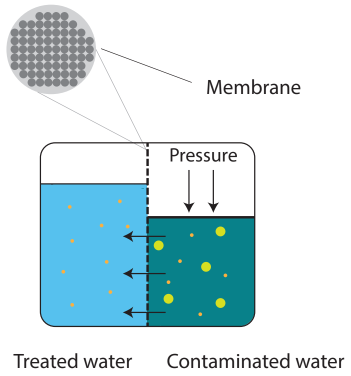


Figure 12: The mechanism of pressure driven membrane filtration.

4.1.5. SODIS UV-disinfection

Solar disinfection, or SODIS, is the exposure of untreated water to direct sunlight [23], [127], like shown in Figure 14. Untreated contaminated water is put in bottles and placed in the sun for several hours. The UV radiation from the direct sunlight and the climbing temperature of the water inactivates the pathogens. DNA of the pathogens in the water absorbs UV-A and UV-B radiation, injuring the DNA which makes the cells unable to reproduce. The water adsorbs infrared light, increasing the water temperature. In water above the temperature of 45 °C, cellular function of the pathogens is impaired [108], [127]. Both these processes reduce the existence of pathogens in the treated water. Solar irradiance and the turbidity of the untreated water determine the time needed to expose the untreated water to sunlight. With less than 50% clouds and low to medium turbidity, the water is treated and safe to drink after 6h of exposure in direct sunlight. With more than 50% clouds, the water should be exposed for 2 consecutive days [129].

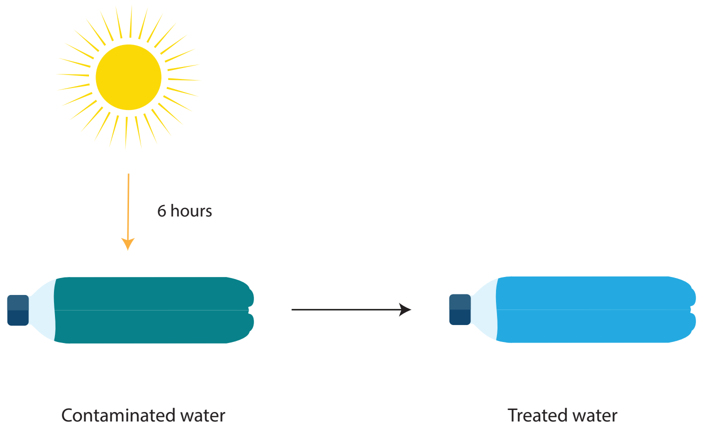


Figure 14: A schematic overview of SODIS.

4.1.6. Chlorination

Chlorination involves putting chlorine in the untreated water to remove pathogens. This can be done by means of tablets, powder and sometimes liquid chlorine. Chemical disinfectants, like chlorine, inactivate microorganism by creating openings in the cell membrane through damage, after which chlorine can enter and disrupt the cell respiration and DNA activity [17], [130].

4.2. Guidelines for HWTS

HWTS must be thoroughly evaluated before they can be used in practice. Documents that provide frameworks for these evaluations are from the United States Environmental Protection Agency (US EPA), the World Health Organization (WHO), and NSF International, set up by government agencies and international organizations [131], [132].

The WHO conducted a framework for safe drinking water and a framework for implementing the guidelines in their document '*Guidelines for Drinking-Water Quality*' [12]. Another important document is the '*Evaluating household water treatment options*', where the minimum microbial removal values that must be achieved by the HWTS are specified [93] [131]. The WHO has written many more documents useful in evaluating HWTS, such as '*A toolkit for monitoring and evaluating Household Water Treatment and Storage programs*' [133]. In 2012, the NSF set standards with minimum requirements for the safety of point-of-use water treatment options [134]. The NSF has drawn up the standards in consultation with the WHO and the US EPA guidelines [131], [132].

Besides these national frameworks used for evaluating HWTS, national guidelines should be considered. National documents will play a bigger role in the implementation of HWTS than the evaluation of HWTS. For example, national hygiene protocols and strategies are important to take into account when implementing HWTS in that country.

A document widely used for humanitarian response is the Sphere Handbook [135]. It sets standards on a humanitarian response for four principles, including WASH. The handbook includes a decision tree on what kind of HWTS should be used for what type of situation or for what type of water quality.

4.3. Contexts included in this research

HWTS can be used in different situations and contexts, making it important to include several contexts in this research. The choice which contexts to include was based on four things. Firstly, the contexts must differ from one another, so that it was possible to research if criteria were of different importance within those contexts. Secondly, the contexts must be located in low-income settings. Thirdly, HWTS must have been used before in the context. And finally, the context generally does not yet have a permanent way of obtaining safe and affordable drinking water. The contexts chosen to include are (1) rural villages without water supply, (2) outbreak of infectious waterborne disease, (3) informal urban slums, (4) refugee camps and (5) emergency response after natural disaster. It is important to understand a context before the choice of a suitable HWTS can be made.

4.3.1. Rural villages without safe water supply

For a rural village the distance to other communities is big and the population density is low [136]. There are rural villages that already have access to some form of water supply, such as piped water or wells. But the quality of drink water from pipes or wells is often not good enough [137], and the additional use of HWTS is often desired or even necessary. The focus of this research will be on villages without a form of safe water supply, which there are still a lot of [138]. A rural village is a permanent situation where people own their houses and are part of a self-supporting economy [139], [140]. Because of the poor condition of internal road networks and the long distances, the rural villages are difficult to reach [138]. In addition, there are few shops in rural areas. Distribution costs can be high due to the need to transport and to store large quantities of HWTS (spare)products [139], [B], [E].

4.3.2. Infectious waterborne disease outbreak

The outbreak of an infectious waterborne disease is a specific situation that can occur in different contexts. In an outbreak, more cases of that disease are present than in a normal situation for a specific area, season or community. The duration of the disease outbreak can be several days to several years. Also, the area over which the disease outbreak spreads can remain relatively small or spread over several countries [138]. The focus in this research is on the outbreak of waterborne diseases. The most common ones are cholera, typhoid fever, shigellosis, dysentery, and hepatitis A and E [24]. After confirmation of a disease outbreak, it is part of the acute emergency phase. A standardized dosage or product is important. In some situations of disease outbreak, different products are used, making it confusing and increasing the change of wrong usage [141], [C].

4.3.3. Informal urban slums

A slum comprises households that have no access to treated water, improved sanitary infrastructure and sufficient and sustainable housing [24]. The focus in this research will be on informal, urban slums. With informal housing, there is unclarity about land tenure, so informality about the use and purpose of the land cannot be determined according to the rules or the law [142], [143]. The stress on the water quality and existing water supply is getting higher due to the increasing urbanization and crowded living situations [144]–[146].

4.3.4. Refugee camps

Refugees are defined as “persons who flee their own country because of war, violence, famine, or a well- founded fear of persecution for reasons of race, religion, or nationality” [115, *page 1*]. Refugee camps consist of a displaced population and are in a so-called ‘post emergency’ state, where the focus is not only on emergency aid, but also on development [147], [148]. A characteristic of this phase is that public health corresponds to a similar village [114], [147]. Refugee camps are often crowded, increasing the risk for disease outbreak [149]. The camps often lack basic infrastructure [150].

4.3.5. Emergency response after natural disaster

There are different emergency settings where HWTS could be used [151]. The focus in this research will be on emergency response after natural disasters. The definition of natural disasters are “catastrophic events with atmospheric, geologic, and hydrologic origins” [90, *page 15*]. Emergency response after natural disaster is an example of an acute-emergency phase, which is a chaotic and difficult phase. There are limitations in logistical possibilities, lack of resources, lack of coordination and security problems, while people seek safety after trauma [152]. In most cases, after a natural disaster, there is a large-scale population displacement towards crowded camps [153], increasing the change of disease outbreaks [24], [147]. The situation of displacement is mostly a temporary where the people have the intention to go home when possible [147]. The supply chain might be disrupted because of damage to the infrastructure, restricting access to the affected region [23], [F].

5 Estimated general context preference

The fourth step in the modified SDM structure is to estimate preference of the HWTS. This step is divided in the consequences of HWTS on the general criteria (step 4a) and the situation-specific criteria (step 4b). This chapter focusses on the estimated preference of the general criteria, so step 4a of the modified SDM. Firstly, the HWTS are rated on the general criteria using a value matrix. Secondly, criteria weights are calculated for every context. And finally, a ranking is made for all the HWTS per context, using the value matrix and the criteria weights. The value matrix with explanation is presented in chapter 5.1, the calculated criteria weights are presented in chapter 5.2 and the HWTS ranking per context in chapter 5.3.

5.1. The established value matrix

The value matrix rates the included HWTS on the obtained general criteria. The ratings in the value matrix are accomplished with literature review and information received from experts from group B. Consistency of the findings from experts and literature are discussed in chapter 5.1.7. The final value matrix for the chosen HWTS techniques is presented in Table 4.

The second sub question was: *How can HWTS be scored on the set of criteria using a value matrix?*
The general criteria receive a qualitative value, so they can be compared in the value matrix. Most criteria have been given a constructed range from 1 (lowest level of desired characteristics) to 5 (highest level). From the final value matrix can be concluded that the ratings per criteria differ between HWTS, but there is no HWTS that consistently scores high or low. The values of the value matrix overall show a medium to high consistency. Low consistency was found in literature on 'water quality' for SODIS, 'risk of by-product formation' for the ceramic pot filter, 'odour/colour/taste' for ceramic pot filter, SODIS and chlorination, and 'ease of maintenance' for the biosand filter.

5.1.1. Ceramic candle filter

Health improvement

- Quantity
  The flow rate of ceramic candle filters reported in the literature lies between 1 and 3 L/h [17], [20], [123]. In the value matrix the value of 2 L/h is included as this is in the middle of the values from literature.

- Water quality
  In the WHO second round of the '*international scheme to evaluate household water treatment technologies*' both the Tulip table top filter and the Nazava water filter, both ceramic candle filter have targeted protection and receive 1 star [20]. In addition to the microbial log10 reductions obtained from the WHO study [20], we also looked at the reduction of diarrheal in practice. The results of the diarrheal reduction in the field after using a ceramic candle filter are between 51 and 70% [22], [154]–[156].

Table 4: Value matrix showing the scores of the HWTS for the identified criteria set. The values are not yet normalized.

		Ceramic candle filter	Ceramic pot filter	Membrane filter	Biosand filter	Sodis	Chlorination
Health improvement	**Quantity [L/h]**	2	2	12	35	2,5	40 [4]
	Water quality	2 [1 5]	2 [1 2]	3 [1 3]	1	2	2 [1 4]
	Health quality	*51-70%*	*46-70%*	*14-29%*	*Mostly 44-60%, max 27-74%*	*Mostly 31-42.5%, max 9-86%*	*Mostly 15-48%, up to 84%*
	Risk of recontamination	4	4	3	2	4	4
	Risk of by-product formation	4	3	5	5	2	1
	Reliability of product safety	3	2	2	2	1	4
Acceptability /adaptation	**Odour/colour/taste**	5	4	3	4	2	1
	Approval by authorities	5	5	5	5	5	5
	Labelling and instructions	4 [5]	4	5 [3]	2	4	5 [4]
	Ease of operating	5	5	5	5	3	4
	Maintenance needed	2	2	3	2	4	4
Economic feasability	**Lifecycle costs [$/treated L]**	0.0017 [6]	0.0015 [6]	0.0033 [3 6]	0.0011 [6]	0.0009 [6]	0.0053 [4 6]
	Ease of transportation	3	2	4	1	5	5
	Supply chain requirements	2	3	2	4	4	1

[1] Values from the WHO research. This has been investigated in a lab or information provided by the producer. The values in practice in the sheet can be different.
[2] Based on the product 'Purifaaya water filter' from SPOUTS of water.
[3] Based on the product 'LifeStraw Family 2.0' from Vestergaard Frandsen.
[4] Based on the product 'Aquatabs' from Medentech Ltd.
[5] Based on the product 'Nazava Riam water filter' from PT Holland for Water.
[6] Only investment costs and operational costs are included, not the costs for transportation, education etc.

- Risk of recontamination
  Assuming a table-top design, the lower container provides safe storage to prevent recontamination [17], [103] [P]. The ceramic candle filters itself does not have residual protection of the treated water [157]. But if the ceramic candle is impregnated with silver, small concentrations of silver leaches in the treated water, reducing microbiological recontamination during the storage [158]–[160]. There may be a risk of recontamination from the use of improperly cleaned drinking cups.

- Risk of by-product formation
  Due to the source materials used to make the ceramic candle, arsenic can leak into the water [20]. The WHO Guidelines for Drinking-water Quality state the maximum concentration to be 10 µg/L [12]. But there are still uncertainties about the health effect of low concentrations, so effort should be made to keep the arsenic concentrations low. The WHO showed that the leachate concentrations from the filter test was below 10 µg/L. Also, silver can leach from the thin layer of silver nitrate on the ceramic candle into the treated water. Concentrations are too low to have a negative effect on health.

- Reliability of product safety
  After a certain amount of time, the ceramic candle needs replacement because the diameter of the candle lowers due to cleaning of the candle [20], [161]. It depends on the product if a fail-safe mechanism is included to check this. The Nazava water filter and the Tulip Tabletop filter include a tool to measure the diameter of the candle. The semi-circular tool must be held against the candle. The moment the tool fits on the candle, the diameter is too low, and the candle must be replaced. If the product does not include a fail-safe tool like this one, it is hard for the user to see when the candle needs replacement. In this study it is assumed the product includes a tool like this.
  In addition, it is possible that a leakage occurs because of an opening at the connection of the candle or because of cracks in the candle. Since the candle is attached to the rest of the filter with glue, it is possible that it is not attached properly during production or that the candle comes loose after some time [M]. There may also be a crack in the candle, which may not be visible to the user. For both these problems, no fail/safe mechanism is present. There is an indicator when the treatment is complete, as the treated water ends up in the lower container.

Acceptability/adaptation

- Odour/colour/taste
  The candle filter includes activated carbon, which adsorbs residual iodine, improving the taste of the water [17]. In a survey hold for local households in the Dominican Republic, 83.6% reported to like the taste of the treated water [162].

- Approval by recognized authorities
  Multiple ceramic candle filters are tested and approved by the WHO in the second round of the international *'Scheme to Evaluate Household Water Treatment Technologies'* [20]. The ceramic candle water filter is also tested and proved effective in the field [163], [164].

- Labelling and instructions
  The instruction for the Nazava Riam filter includes text in two languages: English and the local language. Although visuals are used, the text is needed to understand the instructions [161]

- Ease of operating
  The candle filter is easy to use. The action for the consumer, after installation, is only to put water in the top of the filter and to collect the treated water when clean water is wished [22]. This action for operating is not time consuming.

- Maintenance needed
  Cleaning needs to be done two times a week [103] and includes quite some steps. Clean water is needed for the cleaning of the filter, otherwise recontamination can occur after cleaning. The cleaning of the candle needs to be done softly [103] and no detergent should be used, but in practice this is not always the case. So, cleaning can be done wrong [17]. Some training is needed to know how to clean the filter [157]. Also, breakage can occur more easily during cleaning or replacement [162].

Accessibility

- Lifecycle costs
  The investment costs of a ceramic candle filter ranges between 15 and 30 dollars [17], [155], [165], [166]. Chosen in this research are investment cost of 25 dollars as this is reported the most. The lifetime of the ceramic candle is 2 years or 14600L (20L per household per day) and costs around 8 dollar to replace [17], [166]. The outer part of the filter can last longer, around 4 years [167]. So, if the investment of 20 dollars lasts 4 years and operational costs of 8 dollar and lasts 2 years, the costs are 0.0017 $/L treated water.

- Ease of transportation
  A ceramic candle filter overall has a medium weight but in table top version is quite big [165]. There are no mechanical parts to break, but the ceramic candle is fragile and can crack or break in cases of poor transportation [17], [110]. The ceramic candle filter is thus not easy to transport [23].

- Supply chain requirements
  Overall, the parts of ceramic candle filters are not made locally but shipped to the country of usage, where the candles are put in the plastic outside of the filter. The candles need to be replaced every two years, and the tab system may need to be replaced if damaged [17], [23]. Both are vendor-specific parts.

5.1.2. Ceramic pot filter

Health improvement

- Quantity
  The flow rate of ceramic pot filters reported in literature lies between 1 and 3 L/h [17], [22], [106], [123], [159], [168], [169]. In the value matrix the value of 2 L/h is included as this is in the middle of the values from literature.

- Water quality
  In the WHO second round of the '*international scheme to evaluate household water treatment technologies*' one ceramic pot filter was included: the Purifaaya water filter. Based on this product, the HWO evaluated the ceramic pot filter and found it gives targeted protection and receives 1 star [20]. In addition to the microbial log10 reductions obtained from the WHO study [20], the reduction of diarrheal in practice was also investigated. The results of the diarrheal reduction in the field are between 46 and 70% [19], [22], [123], [154], [170]–[172].

- Risk of recontamination
  The ceramic pot filter design has a lower container for the treated water, working as a storage container. This container has a tap system to get to the treated water [170]. The lower container provides safe storage to prevent recontamination [17], [173]. The ceramic pot filters itself do not have residual protection in the treated water [157]. But if the ceramic pot is impregnated with silver, small concentrations of silver leaches in the treated water, reducing microbiological recontamination during the storage [158]–[160]. There may be a risk of recontamination from the use of improperly cleaned drinking cups.

- Risk of by-product formation
  Silver-impregnated ceramic pot filters can leach different components into the water, dependent on the source materials used to make the ceramic pot.
  Ceramic pot filters can leak arsenic into the water [20]. The WHO Guidelines for Drinking-water Quality state the maximum arsenic concentration to be 10 µg/L [12]. But there are still uncertainties about the health effect of low concentrations, so effort should be made to keep the arsenic concentrations low. The WHO indicated that the leachate arsenic concentrations from the ceramic filters tested below 10 µg/L. Further research shows different results. In the research of Archer et al. [174], in 95 percent of the time the arsenic concentrations leaked in the water from the clay are equal or less than the WHO health guideline of 10 µg/L. Schaefer et al. [175] found that the initial arsenic concentration is very high, but that 80% of the arsenic is released in the first 100L of water from the filter. The arsenic concentrations typically stayed above the 100 µg/L the first 100L of water use. It took 300L of water addition to meet the WHO health guideline of 10 µg/L. Van Halem et al. [122] showed that several metallic compounds leach from the ceramic water filter into the water, also depending on the location of the production and the clay used. The WHO guideline was not reached, and the concentrations decreases rapidly. This does show that the location of the production and thus the clay used for the ceramic filter determines which elements are present and in which concentrations.

  There is no health-based guideline concentration for silver in drinking water from the WHO. They do state that higher levels up to 0,1 mg/L could be tolerated without health risk [12]. Mwabi [176] found silver leaching between 0.22 and 0.28 mg/L during infiltration of groundwater and between 0.24 and 0.28 mg/L during infiltration of surface water. The leached concentration decreased over time. Lantagne's research [177] showed much lower values for silver. No sample approached the silver concentrations of 0,1 mg/L. only two samples of the 24 homes exceeded a detection limit of 5 µg/L, with concentrations of 6 and 15 µg/L. Silver leaching in the research of van Halem et al. [169] was also far below the WHO guideline.

From these studies it can be concluded that the development of products is very dependent on the materials used locally to make the ceramic pot and is not standard for the ceramic pot filter [P]. Therefore, there is a chance that by-products will leach into the treated water. However, this effect decreases significantly after first weeks of use and in practice will usually only be present for the first few weeks.

- Reliability of product safety
  The ceramic pot water filter does not have a fail-safe indicator [20]. Cracks can occur in the ceramic pot and it might be hard to visually inspect this [17]. A crack in the pot can be heard by knocking. But this is undesirable because there is a risk of breaking and infection due to touching the ceramic pot. There is an indicator when the treatment is finished, since the treated water ends up in the lower container.

Acceptability/adaptation

- Odour/colour/taste
  Ceramic based water filters overall improve the taste and odour of the treated water [159]. In the research of Lemons et al. 91 to 100% of the consumers reported a satisfactory or excellent taste and appearance. For smell the respondents reported liking it between 83 to 100%. When using strong smelling influent water, the odour of treated water after filtration was no longer perceptible. The yellowish colour of the raw influent water, due to dissolved organic carbon, didn't change after filtration [122]. Temperature of the effluent is overall a bit lower than the influent water [122], [P]. Yang et al. [178], on the other hand, states that the ceramic water filter doesn't significantly change the taste or temperature of the treated water. Temperatures in the research of Lantagne [177] also stayed the same pre- and post-filtration. Except when ceramic receptacles were used instead of plastic, reducing the temperature by 2-3ºC.

  Besides the change depending on the influent water, a taste and colour can also be added by the ceramic filter at the first use [M]. This is expected to be the effect from the released iron elements from the clay material. Since this odour and colour decrease and are only present in the first 2 weeks, it is not alarming [122].

  Because the ceramic pot filter is not designed to significantly improve odour, colour or taste, the value given would be average. But the ceramic pot lowers the temperature a bit. That is very positive for taste, resulting in a value of 4.

- Approval by recognized authorities
  The ceramic pot filter is tested and approved by the WHO in the second round of the international '*WHO International Scheme to Evaluate Household Water Treatment Technologies'* [20]. The ceramic pot filter has been tested in practice and proved effective, which also shows in the diarrheal reduction.

- Labelling and instructions
  The instructions include text and visuals and are short. The instructions can be understood without the text [179]. If the ceramic pot filter is made locally and is not a branded product, it is not guaranteed that the instructions are included with the product. This makes that the score of 4 is given instead of 5.

- Ease of operating
  The ceramic pot filter is easy to use [173]. The action for the consumer, after installation, is only to put water in the top of the filter and to collect the treated water when clean water is wished [22], [122]. Operating a ceramic filter is not time-consuming [26].

- Maintenance needed
  Cleaning needs to be done 2 times a week [26], [123], [170] and can be done wrong. Clean water is needed for the cleaning of the ceramic filter, but no detergent should be used for the ceramic. The risk of recontamination is possible during cleaning. If untreated water is used for cleaning, the pot is touched with dirty hands or placed on a dirty surface [17], [122]. Also, the risk of breakage of the ceramic filter is bigger while cleaning the filter [122].

Accessibility

- Lifecycle costs
  The costs of a ceramic pot filter differs between 5-30 dollar [17], [110], [123], [170], [180]. In this research investment costs of 20 dollars are included, as this is the average of the values found. The lifetime is 3 years [110], [181]. The ceramic pot needs replacement every year and costs around 4 dollars. That make the costs around 0.0015 $/L treated water.

- Ease of transportation
  A ceramic pot filter itself is locally made and then transported without the plastic or ceramic container [P]. The ceramic pot filter has a weight of 8-10 kg and is medium sized [170]. There are no mechanical parts to break, but the ceramic pot is fragile and can crack or break during transportation [17]. The ceramic pot filter is thus not easy to deploy [23].

- Supply chain requirements
  Periodic replacement is needed only for damaged or broken parts [23], [26]. Pot filters are mostly locally made, which is expected to make it easier to get spare parts.

5.1.3. Membrane filter

Health improvement

- Quantity
  The flow rate of an ultrafiltration membrane filter strongly depends on the design of the product. But in literature shows a flow rate of 12L/h [89], [182], [183], based on the products of LifeStraw Family 1.0 and LifeStraw Community.

- Water quality
  In the WHO first round of the '*International Scheme to Evaluate Household Water Treatment Technologies'* includes several ultrafiltration membrane filters. The microbiological protection differs between the products. The water quality in this research is based on the LifeStraw Family 2.0 and thus receives 2 stars from the WHO [89]. In addition to the microbial log10 reductions obtained from the WHO study [20], the reduction of diarrheal in practice was investigated. The results of the diarrheal reduction in the field are between 14 and 29% [172], [182], [184], [185]. Kirby et al. [186] found a higher reduction of 50%, but this was only among children under 5 years. It is striking that

the reduction of diarrhoea in adults is relatively low compared to other HWTS techniques, while the microbial log reduction is relatively high. There are several reasons why the range of diarrheal reduction may be different from the microbial log reduction of the product. For example, differences in diarrheal reduction can occur due to the quality of the water, the health of the individual and the community. But it can also be due to inconsistent or incorrect use of the product, resulting in untreated water being consumed. There is no clear answer why the membrane filter specifically, differs so much between the log and diarrhoea reduction.

- Risk of recontamination
  Membrane filter come in very different shapes and sizes. As this research includes techniques and products for a household, membrane filters with a container are now taken into consideration. Most designs, like LifeStraw Community, LifeStraw Family and the LifeSaver all have containers for the treated water, including a tap system. The lower container provides safe storage to prevent recontamination [17]. The containers and the filter itself are sealed off so that they can't be reached, increasing the hygiene. But there is no residual protection in the treated water [133], [157]. There may be a risk of recontamination from the use of improperly cleaned drinking cups.

- Risk of by-product formation
  The membrane filter has no by-product formation [23], [M].

- Reliability of product safety
  A membrane water filter does not have a fail-safe indicator [20]. The 'straws' in the membrane filter can be damaged over time, for example if there is a lot of pressure on the straws. These damages cannot be seen by the user [M]. In addition, the filter element may not be properly attached to the rest of the filter during production. This may have created a small opening and if small enough it is unable to see. Since a lot of production is now automated, this chance is much smaller [N]. Since the treated water ends up in the lower container, you can see when the treatment is finished.

Acceptability/adaptation
- Odour/colour/taste
  A membrane filter is not designed to significantly improve taste or smell. Because taste and smell are often caused by smaller particles, the membrane filter often can't filter it all out of the water [M]. A membrane filter does removes the natural organic matter, which can have a positive influence on colour, taste and odours [187]. Membrane filters are reported to give a visual improvement of the treated water [133] and to not give the effluent water an objectionable taste [23].

- Approval by recognized authorities
  Several ultrafiltration membrane water filters were tested and approved by the WHO in the first and second round of the international Scheme to Evaluate Household Water Treatment Technologies [89]. The ultrafiltration membrane filter is also tested and proved effective in the field [172], [188].

- Labelling and instructions
  Also, for this criterion, the value is dependent on the product of membrane filters. The instructions of the LifeStraw designs can be understood with only visuals [189].

- Ease of operating
  The membrane filter is easy to use [166]. The action for the consumer, after installation, is only to put water in the top of the filter and to collect the treated water when clean water is wished [23], [189]. Operating a membrane filter is not time-consuming [23].

- Maintenance needed
  Cleaning needs to be done every day and can be done by backwashing [103], [189]. Backwashing pumps water backwards through the membrane filter, by pulling a separate handle. The dirty water from backwashing ends up in a separate container and the water needs to be dumped. The daily maintenance is very easy and not time-consuming [23]. Other maintenance exists out of cleaning the lower container. The container is easy to open for cleaning [189]. Because the cleaning is easy but needs to be done so frequently, it is given the score 3.

Accessibility
- Lifecycle costs
  The costs of a membrane filter differ but in this study the costs of the LifeStraw Family 2.0 are taken into account. The investment costs are around 71.30 dollar and the lifetime is 3 years [190], [191]. That is 71.30/21900L = 0.0033 $/L treated water.

- Ease of transportation
  Overall, the weight of membrane filters is low because they are made from plastic. The size is very much depending on the design of the filter and is mostly the size of a jerrycan and thus medium. Because the product is relatively lightweight and small and robust, the transport is easy [23].

- Supply chain requirements
  Periodic replacement is needed only for damaged or broken parts. This asks for a reliable supply chain [89] with specific vendors.

5.1.4. Biosand filter
Health improvement
- Quantity
  The flow rate of a biosand filter ranges between 15 and 60 L/h in literature [22], [23], [125], [133], [192], [193]. In this value matrix the average of all these values is chosen: 35 L/h.

- Water quality
  The biological ‘schmutzdecke’ layer provides microbiological reduction [110], [194], [195]. In research on the levels of microbial reductions, the values differ due to dependence on the ripening time for the biolayer and the volume of water poured in the filter daily [196]. Bacterial removal is mostly reported to be around 1 log10 reduction [17], [125], [193], [197]. A higher reduction has also been reported, namely 2 log10 [196]. Virus removal is

between 0.5 to 2log10 reduction [17], [125], [196], [197]. For protozoa, the removal is between 2 and 4 [17], [125], [197]. The WHO uses the reference pathogen Campylobacter for bacteria, Rotavirus for viruses and Cryptosporidium for protozoa. Sobsey et al. used the same reference pathogens and found 1log10 reduction Campylobacter, 0.5log10 reduction for Rotavirus and 2log10 reduction for Cryptosporidium.
In addition to the microbial log10 reductions obtained from the WHO study [20], the reduction of diarrheal in practice was also investigated. The results of the diarrheal reduction in the field are between 44 and 60% [19], [22], [125], [154], [172], [198], [199]. A broader range, 27 to 74%, was found in a meta-evaluation from O'Connell [200]. He adds that this wide range is to be expected because diarrhoea can also be caused by anything other than low drinking water quality, the water quality differs in the studies and variation in personal health and public health.

- Risk of recontamination
The biosand filter does not include a storage container within the product. Normally if users buy a product, the container is included but is separate from the filter and without a tap system, making it less reliable [O]. The research of Curry et al. [94] showed that in 2 of the 40 households using a biosand filter, the water had high levels of e-coli because of recontamination. Fiore et al. [201] found a higher level of recontamination in the storage bucket, lowering the overall efficacy with 48%.

- Risk of by-product formation
The biosand filter doesn't produce any toxic by-products [108]. Also, the biological activity will not give a risk. This can only occur if the biological activity increases to such an extent that the oxygen content in the biolayer decreases sharply [O]. However, in a small household filter this will not happen as the 'schmutzdecke' itself consists only of a small area, lowering the biological activity.

- Reliability of product safety
It takes around 7 to 21 days after for the biological layer to work at the wanted levels of microbial reduction [110], [194], [195]. It also takes a couple of days after cleaning the filter for the layer to be back at this level. CAWST recommends users of the biosand filter to disinfect the effluent water up to one week after cleaning the biosand filter [124]. Measurements by Jenkins et al. [202] show that the reductive effect of the biosand filter after 7 days is the same as before cleaning. It is therefore not entirely clear to the user when the filter will work properly [O]. The filter does include an indication when the treatment is done since the treated water ends up in the lower container.

Acceptability/adaptation

- Odour/colour/taste
A membrane filter is not designed to significantly improve colour, odour or taste. But literature shows that odour, colour and taste all slightly improve [17]. In particular, it is reported that there is an improvement in visual appearance and taste [157], [203]. The amount of change is depending on the respiratory activity of the biofilter microorganisms. A bad odour indicates that cleaning of the biofilter is needed [196]. Others report "no objectionable taste" [23]. Although, Wu [204] found that 45.8% of the regular biosand filter user, indicated that they didn't like the smell and 41.7% answered that they didn't

like the taste. A positive effect of a concrete biosand filter is that the water is cooled and the temperature decreases [205]. In the research of Fewster et al., 94% of the households with a concrete biosand filter had effluent water at a lower temperature. this is considered an advantage for the taste [203].

- Approval by recognized authorities
  WHO indicates that locally manufactured HWTS, such as biosand filter is hard to evaluate because of variability in the manufacturing process and local materials that are used. Still the WHO states that biosand filters are important HWTS to consider [89], [93]. Biosand filter also show to be effective in the field, as can be seen in the diarrheal reduction rates.

- Labelling and instructions
  Instructions posters for the biosand filter include visuals but cannot be understood with only the visuals. The text needed to understand the operation of the biosand filter is only shown in English. Also, instructions are needed to setup the biosand filter. This includes what kind of sand is needed and where this can be found. This part includes a lot of text, also only in English [206]. If the biosand filter is made locally and is not a branded product, it is not guaranteed that the instructions are included with the product.

- Ease of operating
  The biosand filter is easy to use [157]. The action for the consumer, after installation, is only to put water in the top of the filter and to collect the treated water when clean water is wished [22]. The treatment is not time-consuming [23], [26].

- Maintenance needed
  For the biosand filter, the upper 1-2 cm of sand needs to be cleaned manually [124]. There is not a clear time schedule when a biosand filter needs cleaning, but can be determined if the flow rate is reduced [104]. This might be difficult to assess [133]. In practice, cleaning needs to be done monthly or even less, depending on the turbidity of the influent water, usage and season [22], [23], [26], [194]. The biosand filter can be cleaned with a "swirl and dump" method: fill the reservoir with water, remove the diffuser, swirl the top of the sand by hand, stick or spoon and decant the dirty water or scoop it out with a small container to dump it. This needs to be repeated if the flow rate is not restored [104], [126]. This takes up to 15-20 minutes [124]. The cleaning is medium complex, takes quite some time but is not needed very regular. Also, the storage tank needs to be cleaned regularly with clean water to make the changes on recontamination lower.

Accessibility

- Lifecycle costs
  The cost of a biosand filter depend on the type of biosand filter made from plastic has a lower price than when made from ceramic. The costs for a plastic biosand filter is between 25 and 75 dollar [17], [207] and for a ceramic filter around 10-50 [17], [208]. For this research a plastic biosand is assumed, making the average costs to take into account 50 dollar. The lifetime of the biosand filter is very high around 8-10 years for a plastic body [17], [23]. Operational costs are only replacement for the storage container separate from the biosand filter. Assuming the plastic storage container lasts 1 year and costs 2 dollars, the costs per L treated water is 0.0011.

- Ease of transportation
  The body of a biosand filter can be made of plastic or concrete. This makes a very big difference for the ease of transportation. The empty weight of the plastic body is 3.6 kg and the weight if filled with sand is 55 to 65 kg. The weight of a concrete body is 70-75 kg without sand [17]. The biosand filter is typically quite big [209], [210]. Assumed for this research is that the sand can be found locally, and the transportation of the filters will be done empty. Otherwise, the filter would be too heavy for transportation. Still, the sand than needs to be transported locally. The biosand filter thus needs assembly at the point of use [23]. If the filter is installed and filled with sand, it should not be moved [17]. The robustness of the biosand filter also depends on the materials used. When the biosand filter has a concrete body, the filter is prone to cracks, but the outlet pipe is embedded into the concrete, protecting it against breakage or leakage. If the body is made of plastic, the outlet is external and prone to breakage, but the body less prone to cracks [17], [109]. This all together makes biosand filters difficult to transport, especially ones made from concrete [23], [133], [157].

- Supply chain requirements
  The biosand filter often lasts for a long time without needing to be replaced [211]. So no supply chain is required for the filter [26]. The storage container needs replacement regularly, but this is not vendor specific.

5.1.5. SODIS

Health improvement

- Quantity
  Assuming a bottle of 1.5 liter and optimal conditions, it will take 6 hours to treat the water. That makes the flow rate 0.25L/h for one bottle. Assuming a household has 10 bottles, the flow rate is 2.5L/h.

- Water quality
  The reduction in bacteria (Campylobacter), virus (Rotavirus) and protozoa (Cryptosporitium) vary in the values found. Campylobacter reduction found is 3log10 [4], [197] to more than 4log10 reduction [212]. Bacteria reduction where another or unknown reference pathogen was measured gives a reduction of 3-4log10 [17], [213]. For Rotavirus the reduction differs between 0.5-1.5log10 [212] to 2log10 [4], [197] to 3-4log10 reduction [214]. Virus reduction where another or unknown reference pathogen was measured gives a reduction of 1-3log10 [17], [213]. For protozoa reduction of Cryptosporidium values differ from neglectable values lower than 0.5log10 [212], [215] to a 1log10 [4] and a 2log10 reduction [197], up to 4log10 reduction [216]. The variability in the values is expected, as this depends on the time exposed to sunlight, the sunlight intensity and turbidity of the water [212], [N].
  In addition to the microbial log10 reductions obtained from the WHO study [20], the reduction of diarrheal in practice was also investigated. The results of the diarrheal reduction in the field had different ranges. The most research found , reported a diarrheal range between 31 and 42.5% [19], [22], [154], [172], [217], [218]. A lower range, 9 to 26%, was stated in the research of Sobsey [166]. A bit of a wider range, 16-57% and an even wider range 9-86% are reported [113], [219].

- Risk of recontamination
  Storage of the water after SODIS is in the same bottle, so no intermediate storage is needed. Because the consumer can drink directly from the bottle, not even a cup is needed. In reality it is possible that users do not actually drink from the bottle and still use a cup, but with the explanation of the technique it is recommended to drink directly from the bottle [N]. When the water is kept in the same bottle, there is minimal likelihood of recontamination [89], [113], [133], [157], [212], [220].

- Risk of by-product formation
  For SODIS, bottles of different materials can be used like glass, polyethylene terephthalate (PET) or polyvinyl chloride (PVC) bottles. Overall, it is not recommended to use PVC bottles for SODIS, because they have more additives, like photo-stabilisers and plasticisers that can leach into the water [17], [166], [221]. Other plastic used in stiffer plastic bottles (made of polycarbonate) can leach chemical compounds like Besphenol-A. This is harmful for human health [212].

  PET bottles are much safer to use with a lower risk of by-product formation. The maximum concentrations of plasticisers (DEHA and DEHP) found in the treated water, when using PET bottles, are the same levels of plasticisers of commercial bottled water, not giving risk for human health. Difference in measured concentrations depended mostly on the country of origin of the bottles, while the amount of sunlight expose, and temperature have a lower decisive factor [222]. Also Santos [108] shows that there is no harmful by-product formation. Research in laboratories show that photoproducts are formed at the outer surface of the PET bottles [221]. The aging of the PET bottles doesn’t influence the risk of by-product formation [221].

- Reliability of product safety
  The duration of the treatment depends on the weather. That might be difficult to determine, as there is no clear indicator when treatment is complete. Also, there is no fail-safe mechanism to determine if the treatment is not working. If there are a lot of scratches on the bottle, the water may need a little longer time in the sunlight to get the same microbial log reduction. It is unclear to the user when this should be considered or even if the bottle needs to be replaced [N]. Only if there is an opening in the bottle through damaging, is it noticeable through leakage.

Acceptability/adaptation

- Odour/colour/taste
  There is no change to the taste, odour and colour of the treated water. This might give SODIS an acceptability problem [17], [22]. The visual appearance stays the same and might be negative because of residual turbidity [26]. Because the bottles have to be in the sun for several hours, the temperature of the water will increase. In practice, it often happens that users do not drink the water immediately after it comes out of the sun, but let it cool down for a while and drink it the next day, for example [N].

- Approval by recognized authorities
  SODIS is recommended by the WHO, Unicef and the Red Cross as a method with proven health effects for the treatment of drinking water in developing countries [223]. The

technique of SODIS has been tested in practice and proved effective, which also shows in the diarrheal reduction.

- Labelling and instructions
  No labelling is included, but that is unnecessary because it is not a branded product. The instructions made for the use of SODIS are very clear and understandable with only using visuals. The problem, however, is that the instructions may not always be included, since it is not a branded product where instructions are included in the packaging. In practice, when SODIS is recommended, the flyers are handed out [N]. As the explanation is good with only visuals, but it is not guaranteed to be present with the technique, it does not get the highest score but a 4.

- Ease of operating
  The action of treatment and operating itself is easy and no skills are needed [23], [113], [166]. Operation comprises filling the PET bottles with water, shaking the bottle, place the bottle in the sunlight, after the needed time the bottle can be picked up and the water consumed [22]. The operation of 1 bottle is not complex. But since 1 bottle gives not enough water, several bottles must be managed. Planning and managing all bottles is difficult, especially because it is sometimes difficult to determine which bottle is ready when and the water is safe [17], [22].

- Maintenance needed
  If the bottles are to be used for a long time, the bottles should be cleaned regularly with soap and clean water [17]. Apart from cleaning, no maintenance is required [26].

Accessibility

- Lifecycle costs
  A PET bottle costs around 0.25 dollar, depending on the location [224], and holds 1.5 liters. Assuming a PET bottle is used for 6 months [224] every day before it needs replacement, it is used 180 times. This makes the costs 0.0009 $/L treated water.

- Ease of transportation
  Plastic bottles are lightweight and not easily breakable, so a high ease of transportation [23], [166].

- Supply chain requirements
  If the bottles are too old or are heavily scratched, the amount of UV light passing through the bottle is too low and replacement is necessary [17], [212]. Because PET bottles are locally available, no vendor-specific supply chain is needed [22], [26].

5.1.6. Chlorination

Health improvement

- Quantity
  The amount of water that can be treated with chlorination, is based on the product Aquatabs [225]. One tablet can treat 20L and takes 30 minutes. That means that 40L of water can be treated in 1 hour, making is 40L/h.

- Water quality
  In the WHO first and second round of the '*international scheme to evaluate household water treatment technologies*' multiple chlorination products were considered. The microbial protection level ranges from little or no protection to targeted protection. For this research targeted protection, indicated by 1 star by the WHO, is included in the value matrix for chlorination, as the products of Aquatabs received that rating [20], [89]. In addition to the microbial log10 reductions obtained from the WHO study [20], the reduction of diarrheal in practice was also investigated. The results of the diarrheal reduction in the field are mostly between 15 and 48% [19], [22], [154], [166], [172]. A higher range, 22-84% was reported by the Centre for Disease Control and Prevention. The studies in this range included people in rural and urban areas, of all ages, low-income, from different individual health and used water of different turbidity. [226].

- Risk of recontamination
  Residual chlorine in the treated water protects against recontamination [17], [227], [228]. Consumers have to provide own storage, which can cause less residual security. So, although residual protection is present, people often have to get water from the storage container with a cup in the container. This makes a slight risk for recontamination.

- Risk of by-product formation
  For safety of human health, the concentration of residual chlorine should not exceed the concentration of 5 mg/L [20]. None of the samples had residual chlorine above the concentration of 5 mg/L [20], [108], [229], [230]. Although the chlorine concentration is not exceeded, chlorine can react with naturally according organic compounds in the water, resulting in adverse health effects. Common by-products are trihalomethanes (THM) and haloacetic acids (HAA) [231]. THM is formed when chlorine reacts with organic compounds in the water such as decomposing plant and animal materials [232]. There is epidemiological evidence that these by-products can cause malignant growth of fundamental organs and increase the changes of cancer [231]–[234]. There is also some evidence of a link between THM and growth retardation in young children, and to a lesser extent premature birth [233]. Although the health effects of the use of chlorination can be very negative due to these by-products, the WHO stated that "the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection" [12].

- Reliability of product safety
  It can be inspected when the water is treated due to the odour of chlorine in the water. There is also a clear time indication after which the water is safe to drink. There is only not a clear fail safe indicator [20].

Acceptability/adaptation

- Odour/colour/taste
  Chlorine in the water can be recognized by humans by taste and smell. The appreciation can differ: some people will find it unappealing taste and smell; others will appreciate it because they know that the water has been treated. Literature shows a potential objection or negative reaction of consumers to the changed taste and odour of the treated water [24], [88], [226]. Some studies only refer to an objectionable taste [23], [26].

Especially children may dislike the taste and odour of chlorination, using untrusted water sources [235].

Roma [236] investigated the response to Aquatabs on the Floris Island in Indonesia. The chlorine taste in the treated water was minimal. 7% of the study populations stopped using Aquatabs, mainly due to lack of appreciation of the taste and odour of the water. Of the 93% of the study populations who continued the use, 96% appreciated the taste of the treated water with Aquatabs. But only 14% was satisfied with the smell of the treated water. Taste and odour objections were reported as the most significant reason for stopping with the method. This is consistent with other literature on chlorination. As most of the literature found reported a negative reaction to the change in odour and taste, the value given to this criterion for chlorination is low.

- Approval by recognized authorities
  Multiple chlorination techniques are tested and approved by the WHO in the first and second round of the international Scheme to Evaluate Household Water Treatment Technologies [20], [89]. Chlorination is also tested and proved effective in the field [104], [236].

- Labelling and instructions
  The posters with instructions for chlorination are using only visuals and can be understood with only the visuals. Several products like Aquatabs use instructions with only visuals and includes labelling [237].

- Ease of operating
  The actions for using chlorination is easy and no additional skills are needed [22], [157], [166]. Depending on the turbidity of the water, 1 or 2 tablets need to be added to the container with water [22]. It is important that the correct amount of chlorine is added. Chlorination in the form of tablets is slightly easier to dose than, for example, liquid chlorine. A brief explanation is needed before the first use, also about the different dosages for turbid or non-turbid water [23], [26], [166].

- Maintenance needed
  The chlorination product itself does not need maintenance [22], [26]. But the container used for chlorination and for storage need to be cleaned regularly, with clean water. A tank can be cleaned relatively easily because you have good access to it. This is not time-consuming [23].

Accessibility

- Lifecycle costs
  Costs of chlorination are dependent on the product and type of chlorination used. In this research the price of Aquatabs is used as a reference. The price of Aquatabs goes down if you buy more tablets at once. The price for a household is around 10 cents per tablet if they buy a larger quantity but which is still realistic for a household. One tablet can treat 20 liters of water if it is not too turbid. With chlorination the user needs to buy a container. Assuming a container is 2 dollar and can last 1 year, the costs of Aquatabs is 0.0053$/L treated water.

- Ease of transportation
  Chlorination tablets, liquid or powder for household usage (so relatively small dosage) are small, light and robust. This makes chlorination products easy to transport [23], [229], [236].

- Supply chain requirements
  The chlorination products are being consumed so there will be a constant need for extra supplies [17], [22], [23], [26], [133]. In theory, a large quantity of chlorination products could be purchased, as they have a shelf life of 5 years (mist cooled, not stored moist in packaging) [225]. But that will be an enormous investment for a household, so it is not very realistic.

5.1.7. Consistency of the findings

The values in the matrix are based on literature and interviews with experts. It differs per value where the information comes from, how much literature has been found and whether the findings are consistent. To make clear how consistent the literature is, various aspects were looked at:

1. The source of the findings. It will be indicated whether findings have been obtained from literature, experts, researchers, the manufacturer of the HWTS product, the WHO, or whether assumptions had to be made.
2. The sources of the literature found and the consulted experts.
3. Whether findings have also been proven in the field.
4. The consistency of the findings.

The sources used and the conclusions on consistency are shown in Table 25 in appendix E. The values overall show a medium to high consistency. Low consistency was found in literature on ‘water quality’ for SODIS, ‘risk of by-product formation’ for the ceramic pot filter, ‘odour/colour/taste’ for ceramic pot filter, SODIS and chlorination, and ‘ease of maintenance’ for the biosand filter. A lower consistency may have several reasons. A value or valuation is often a situation-specific. The quality of the water, individual and community health, personal opinion and cultural differences can lead to different results. In addition, there may also be research where bias played a role in the results or studies that were not double-blinded [172]. Also, different products are used in studies when talking about the same HWTS. This can make it hard to compare the results and lead to a lower consistency.

5.2. Weighing of the general criteria

The weights are added to the general criteria in the value matrix and show the relative importance of every criteria in every context. To calculate the criteria weights the Best-Worst Method (BWM) is used. In this research the input data is collected by an online survey conducted with 39 experts. The final weights have been obtained by multiplying the category and local weights. They are used to make the ranking of HWTS and are discussed in chapter 5.2.1. The category weights are discussed in chapter 5.2.2. Local weights are the weights for all the criteria belonging in the criteria categories, discussed in chapter 5.2.3. All the respondents indicated their most and least important criterion for the three chosen contexts. Percentages of how often each criterion is chosen as most and least important is shown in chapter 5.2.4.

As part of the BWM, the consistency of the respondents in the online survey can be calculated. In this research a consistency threshold of 0.25 is chosen. Responses with a higher consistency than 0.25 are not included in the results.

The second sub question was: *Are the criteria weights of different magnitude within a context and between contexts, when using the Best-Worst Method?*
This study shows a difference of the weight heights between contexts. The weight height and their distribution in the context of rural village resemble those in the context of urban slum. For the situation of disease outbreak, all local criteria in the category of health improvement show high weights. The context of emergency response also shows relatively high weights for the criteria of health gain, but lower than for disease outbreak. The weights in emergency response are more average without clear high or low values. To test if the differences in weights between contexts are significant, a Kruskal-Wallis test is conducted. For almost all the criteria, the test showed no significant difference of the median of the weights between contexts.
There are also differences shown in the weight height between criteria (groups). The criteria of the accessibility category lower than the health improvement and acceptability/ adaptability categories. Within the health improvement category, there is a clear difference between criteria weights. Within the accessibility/adaptability category, there was also a difference but less clear. And for the accessibility category, there is no general conclusion due to variation between contexts.

5.2.1. Final weights per context

It was decided to group criteria into categories when using BWM, because too many criteria are taken into account. The criteria were compared in each group (local) and the groups were compared with each other (category). The final weights are calculated by multiplying the category weights and the local weights. A problem can appear when using category and local weights. The weights of every cluster add up to 1. However, the number of local criteria in each category differ. The category 'health improvement' and 'acceptability and adaptability' both have 5 local criteria while the category 'accessibility' has only 3 local criteria. This mean that the weights of the category with fewer local criteria are always relatively higher. To make a more realistic ranking, the final weights of the category 'accessibility' need to be compensated. The final weights with the compensated local weights of 'accessibility' are

shown in Table 5. The values are given shades of green with a darker shade for a higher weight. This makes the difference between contexts clearer.
The context refugee camp cannot be included in the set of final weights. This is because there were too few consistent responses in the online survey to be able to calculate valid weights. This will be further explained in the chapter on local weights.

Looking at the final weights in Table 5, a few things stand out. The weights and their distribution in the context rural village resemble those in the context urban slum. Criteria with a higher weight in both contexts are 'water quality', 'ease of operating', 'ease of maintenance', 'odour/colour/taste' and 'lifecycle costs'. Criteria which show a lower weight in both contexts are 'risk of by-product formation', 'ease of transportation' and 'approval by authorities'. The distribution and height of the weights in the situation of the disease outbreak is slightly different. All local criteria of the health improvement category show high weights in this disease outbreak situation. Less high weights are assigned to the criteria 'risk of by-product formation', 'lifecycle costs' and 'supply chain requirements'. The context of emergency response also has a high weighting for the criteria 'water quality', 'risk of recontamination' and 'ease of operation'. The weights in emergency response are more average without clear high or low values. The criteria of the accessibility category are generally lower than the other two categories.

Table 5: The final weights of all the criteria for all the contexts included. The final weights are the weights of the main groups multiplied by the local weights of every criteria group, compensated for the difference in number of criteria.

		Rural village	Disease outbreak	Urban slum	Emergency response
Health improvement	Quantity	0.069	0.115	0.058	0.092
	Water quality	0.126	0.216	0.142	0.157
	Risk of recontamination	0.085	0.125	0.082	0.125
	Risk of by-products formation	0.031	0.041	0.033	0.055
	Reliability product safety	0.065	0.100	0.059	0.062
Acceptability / adaptation	Odour/colour/ taste	0.094	0.058	0.107	0.088
	Approval by authorities	0.046	0.057	0.041	0.064
	Labelling and instructions	0.058	0.052	0.064	0.060
	Ease of operating	0.121	0.098	0.137	0.109
	Ease of maintenance	0.100	0.076	0.106	0.092
Accessibility	Lifecycle costs	0.095	0.038	0.087	0.048
	Ease of transportation	0.037	0.058	0.037	0.045
	Supply chain requirements	0.083	0.035	0.071	0.057

5.2.2. Category weights

The category weights are the ones for the criteria groups: health improvement, acceptability/ adaptability and accessibility. Table 6 shows the category weights for all the contexts. The number of consistent respondents is included in the table. The context of refugee camp only includes 7 consistent responses. 7-10 responses of experts are needed in the BWM to be able to calculate the weight. So, the 7 consistent responses in this research will do, but is minimal. Results of every respondent separately can be found in Appendix G.

As can be seen in Table 6, in all the contexts, 'accessibility' receives the lowest weight. It differs per context if 'health improvement' or 'acceptability/adaptability' receives the highest weight. The clearest difference is seen for the context disease outbreak, where 'health improvement' has a much higher weight than the other two categories.

Table 6: The category weights.

	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of consistent respondents	*22*	*12*	*15*	*7*	*12*
Health improvement	0.326	0.516	0.324	0.392	0.425
Acceptability / adaptation	0.363	0.295	0.394	0.350	0.358
Accessibility	0.311	0.189	0.282	0.257	0.217

To test the significance of these differences between contexts, the Kruskal-Wallis test is conducted. The results of the test in Table 7 show that the p-values of the category health improvement are below 0.05. This means the null hypothesis is rejected and indicates there is a significant difference between the medians of at least two of the contexts for the category health improvement. The medians are significantly different between the context of rural village and disease outbreak and between disease outbreak and urban slum.
The p-value for the criteria acceptability/adaptability and accessibility are not below 0.05 and thus indicates no significant difference between the population medians of the contexts. The complete set of results for the Kruskal-Wallis test are reported in Appendix I.

Table 7: Results from the Kruskal-Wallis test for the category criteria.

Criteria	Asymp. Sig.
Health improvement	0.006
Acceptability/adaptation	0.605
Accessibility	0.227

Figure 15 shows the average weight as blue dots and the standard deviation as black lines. The standard deviation shows the variation of the weights among the respondents. The standard deviation values in Figure 15 indicate that there is a considerable variation in the weights of the individual respondents.

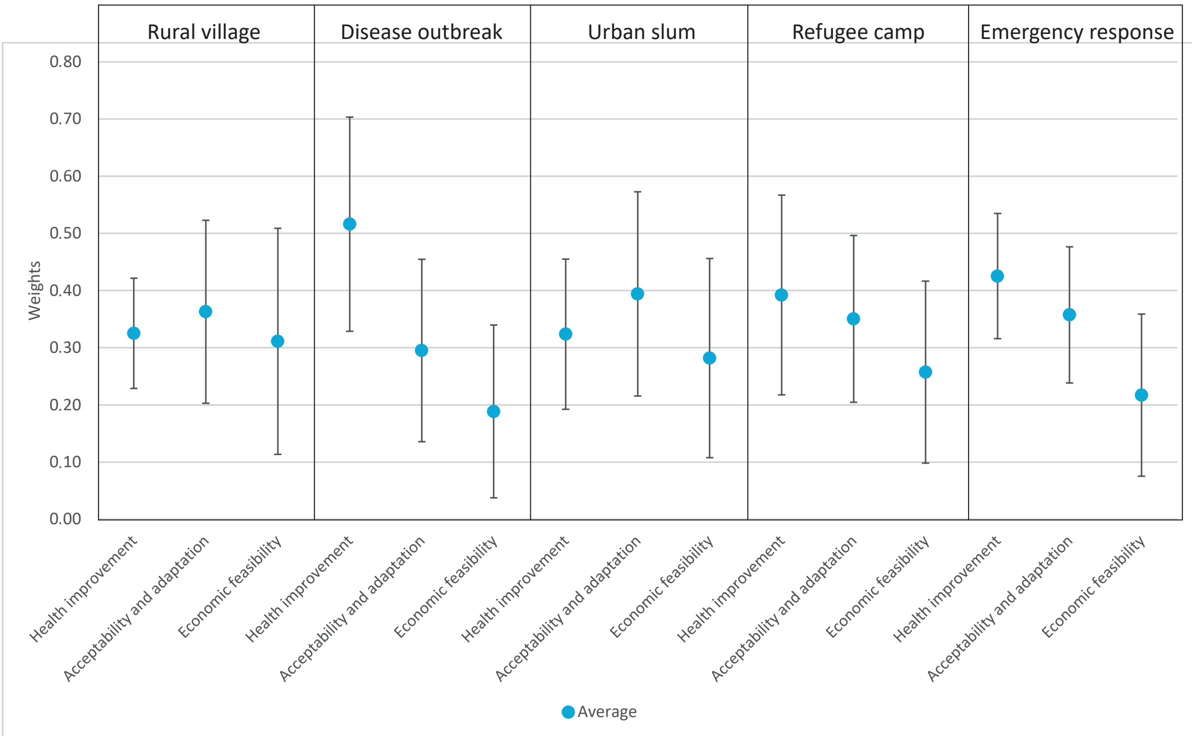


Figure 15: Average and standard deviation of the category weights of the survey respondents.

5.2.3. Local weights

The local weights are for the criteria within every category group. The local weights for every category are discusses separately. Results of every respondent separately can be found in Appendix G.

Health improvement

Table 8 show the local weights for the category of health improvement for all the contexts. In every context, 'water quality' has the highest weight and 'risk of by-product formation' has the lowest weight in this research.

Table 8: The local weights of the category 'health improvement'.

	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of consistent respondents	*31*	*16*	*28*	*10*	*18*
Quantity	0.184	0.193	0.154	0.257	0.187
Water quality	0.335	0.362	0.381	0.297	0.320
Risk of recontamination	0.227	0.209	0.219	0.202	0.254
Risk of by-products formation	0.082	0.068	0.088	0.084	0.113
Reliability product safety	0.172	0.167	0.158	0.160	0.125

To test the significance of these differences between contexts, the Kruskal-Wallis test is conducted. The results of the test in Table 9 show that none of the p-values are below 0.05, so the null hypothesis is not rejected. This indicates no significant difference between the population medians of all groups. The complete set of results for the Kruskal-Wallis test are reported in Appendix I.

Table 9: Results from the Kruskal-Wallis test for the health improvement criteria.

Criteria	Asymp. Sig.
Quantity	0.208
Water quality	0.161
Risk of recontamination	0.861
Risk of by-product formation	0.423
Reliability product safety	0.437

Figure 16 shows the average weight as blue dots and the standard deviation as black lines. The standard deviations indicate that there is a considerable variation in the weights of the individual respondents, but the standard deviation values are lower than the category weights.

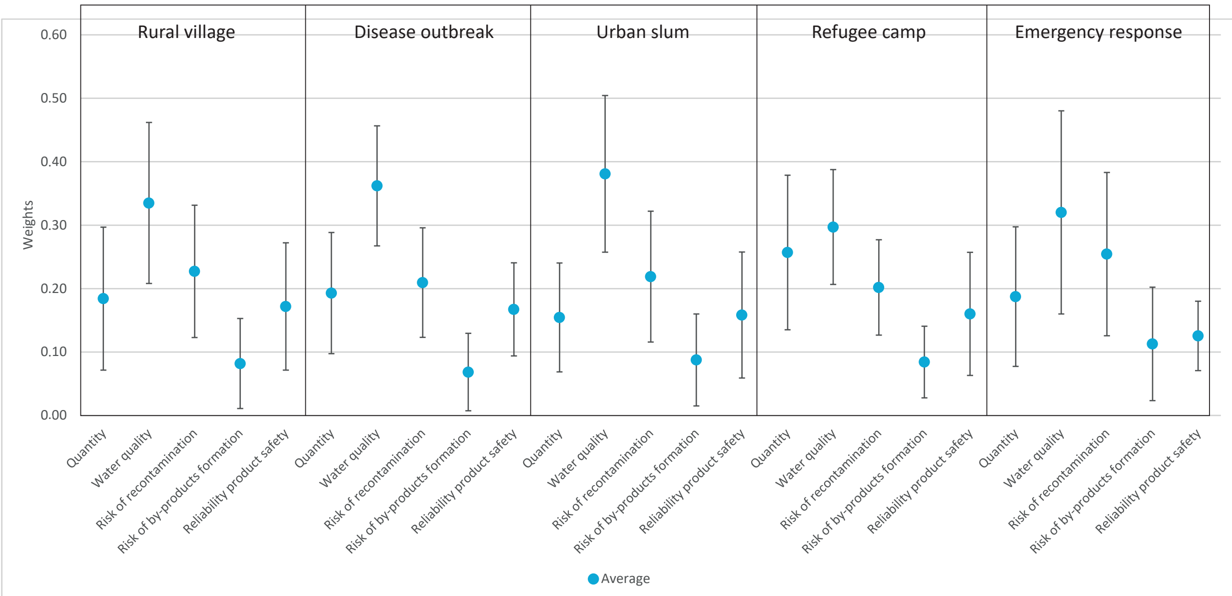


Figure 16: Average and st.dev.of the local weights of the survey respondents for 'health improvement'

Acceptability and adaptability

Table 10 shows the local weights for the category of acceptability and adaptability for all the contexts. In every context, 'ease of operation' has the highest weight. The height of the weight 'odour/colour/taste' differs slightly between the contexts when the average weights are looked at. In the contexts of rural village and urban slum this criterion has a higher weight than for the contexts disease outbreak and refugee camp. The context emergency response seems to be in between. The criterion weight 'approval by authorities' is overall low for every context but has a very low value for the context urban slum and rural village.

To test the significance of these differences between contexts, the Kruskal-Wallis test is conducted. The results of the test in Table 11 show that none of the p-values are below 0.05, so the null hypothesis is not rejected. This indicates no significant difference between the population medians of all groups. The complete set of results for the Kruskal-Wallis test are reported in Appendix I.

Table 10: The local weights of the category 'acceptability and adaptability'.

	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of consistent respondents	*29*	*15*	*25*	*10*	*16*
Odour/colour/ taste	0.225	0.169	0.236	0.154	0.213
Approval by authorities	0.109	0.167	0.089	0.129	0.154
Labelling and instructions	0.138	0.153	0.141	0.147	0.144
Ease of operating	0.289	0.287	0.302	0.315	0.265
Ease of maintenance	0.239	0.224	0.233	0.256	0.223

Table 11: Results from the Kruskal-Wallis test for the acceptability/adaptation criteria.

Criteria	**Asymp. Sig.**
Odor/color/taste	0.174
Approval by authorities	0.062
Labelling and instruction	0.999
Ease of operating	0.587
Ease of maintenance	0.818

Figure 17 shows the average weight as blue dots and the standard deviation as black lines. The standard deviations indicate that there is a considerable variation in the weights of the individual respondents, but the values are lower than the category weights.

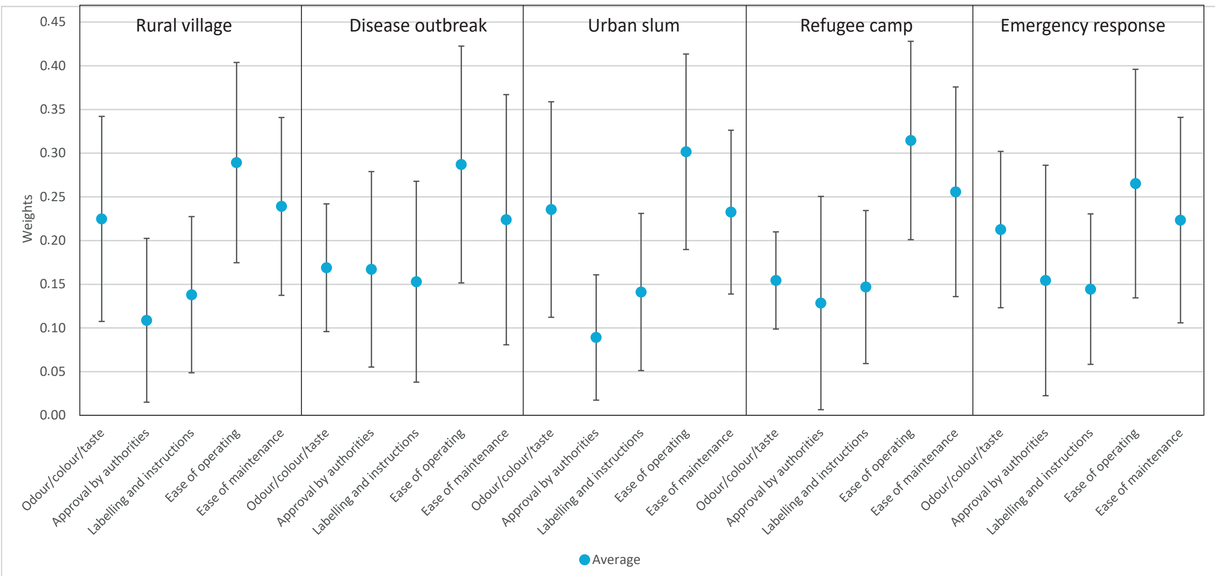


Figure 17: Average and st.dev. of the local weights of the survey respondents for 'acceptability and adaptability'.

Accessibility

Table 12 show the local weights for the category of accessibility for all the contexts. The context of refugee camp only had 5 consistent responses. Because at least 7 responses are needed in the BWM, refugee camp cannot be included in the calculation of the local weights in this category. When looking at the average criteria weights in this research, it seems there are differences in criteria weights between the contexts. The criterion 'lifecycle costs' has a very high weight for the contexts rural village and urban slum, but a medium weight for emergency response and refugee camp and a lower weight for disease outbreak. The criterion 'ease of transportation' has a very high weight for the contexts disease outbreak and refugee camp but a very low weight for rural village and urban slum. The differences between the criterion 'supply chain requirements' are a bit less. In the contexts rural village, disease outbreak and emergency response the weight of 'supply chain requirements' seems higher than in the situation of disease outbreak and refugee camp.

Table 12: The local weights of the category 'accessibility'.

	Rural village	Disease outbreak	Urban slum	Emergency response
Number of consistent respondents	*19*	*13*	*18*	*12*
Lifecycle costs	0.442	0.290	0.446	0.321
Ease of transportation	0.172	0.446	0.188	0.299
Supply chain requirements	0.387	0.265	0.366	0.380

To test the significance of these differences between contexts, the Kruskal-Wallis test is conducted. The results of the test in Table 13 show that the p-values of the criteria lifecycle costs and ease of transportation are below 0.05, so the null hypothesis is rejected for those criteria. This indicates there is a significant difference between the medians of at least two of the contexts for the criteria lifecycle costs and ease of transportation. Within the criteria life cycle costs, the Dunn-Bonferroni approach showed there is no significant difference in mean between the contexts. For the criteria ease of transportation, the medians are significantly different between the context of rural village and disease outbreak and between disease outbreak and urban slum. The p-value for the criterion supply chain requirements is not below 0.05 and thus indicates no significant difference between the population medians of the contexts in this criterion. The complete set of results for the Kruskal-Wallis test are reported in Appendix I.

Table 13: Results from the Kruskal-Wallis test for the accessibility criteria.

Criteria	**Asymp. Sig.**
Lifecycle costs	0.043
Ease of transportation	0.000
Supply chain requirements	0.311

Figure 18 shows the average weight as blue dots and the standard deviation as black lines. The standard deviations indicate that there is a considerable variation in the weights of the individual respondents. The values for standard deviations are higher than the other local weights and the category weights.

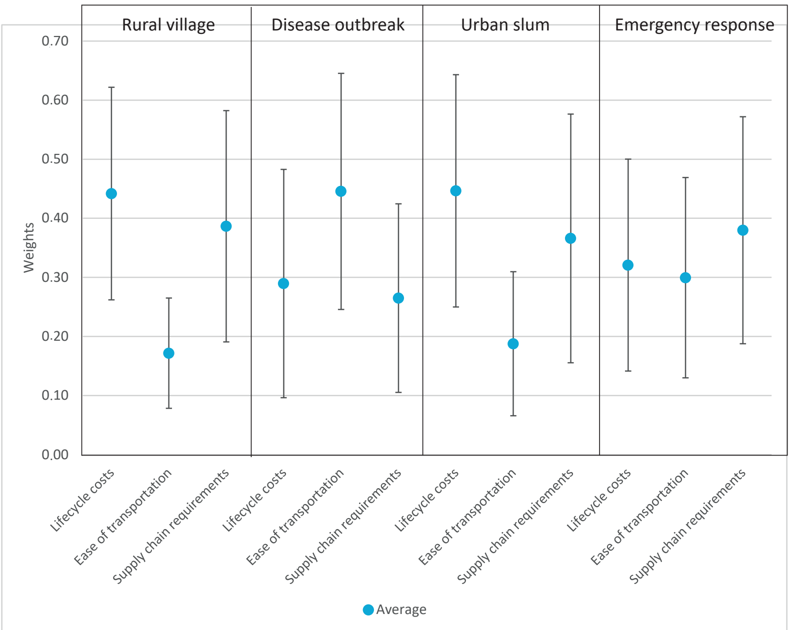


Figure 18: Average and st.dev. of the local weights of the survey respondents for 'accessibility'.

5.2.4. Most important and least important criteria

In the survey, every respondent had to choose one criterion as 'most' and criterion as 'least' important for the choice of a suitable HWTS. The frequencies of category and local criteria chosen as most or least important are presented in this chapter. The number of respondents per context is indicated within the table. To clarify the differences, the tables are coloured. For the tables with the share of most important, a greener criterion indicate a relative high number of responses chose that criteria as 'most important'. For the tables with the share of least important, a redder criterion indicate a relative high number of responses chose that criteria as 'least important'.

Table 14 and Table 15 show the percentages for the category weights. Health improvement is the category that clearly has the highest percentage of most important and lowest percentage of least important. This is even more so for the context disease outbreak, refugee camp and emergency response. The category accessibility in every context has the highest percentage of the least important in the choice of HWTS.

*Table 14: Share of respondents that indicated the category criteria as the **most** important in the choice of HWTS.*

Category criteria	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of respondents	*36*	*17*	*30*	*12*	*21*
Health improvement	54%	82%	43%	92%	81%
Acceptability/ adaptability	35%	12%	37%	8%	10%
Accessibility	11%	6%	20%	0%	10%

*Table 15: Share of respondents that indicated the category criteria as the **least** important in the choice of HWTS.*

Category criteria	Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
Number of respondents	*36*	*17*	*30*	*12*	*21*
Health improvement	11%	0%	20%	0%	5%
Acceptability/ adaptability	32%	24%	27%	8%	14%
Accessibility	57%	76%	53%	92%	81%

Table 16 and Table 17 show the percentages of the local weights of the criteria chosen as most and least important. With regard to the local criteria in the 'health improvement' category, it is notable that the 'water quality' criterion was chosen more often as the most important criterion in the contexts of rural village, disease outbreak and urban slum than in the other two contexts. Furthermore, the criterion 'risk of by-product formation' has never been chosen as the most important and often as the least important. For the local criteria in the category 'acceptability and adaptability', it is striking that the criterion 'ease of operating' has often been chosen as the most important. The criteria 'approval by authorities' and 'labelling and instructions' have rarely been chosen as the most important and the least important. In addition to 'ease of operating', the 'colour/odour/taste' criterion has also been chosen little or never as the least important criteria. In the third category 'accessibility' it is striking that there are differences between contexts. The contexts of rural village, urban slum and refugee camp have often been chosen as the most important criterion. In the contexts of disease outbreak and emergency response, the percentages of most chosen are more divided. In the contexts of rural village and urban slum, the 'ease of transportation' criterion is clearly the most commonly chosen criterion of least importance and the 'lifecycle costs' criterion the least frequently chosen criterion of least importance.

*Table 16: Share of respondents that indicated the local criteria as the **most** important in the choice of HWTS.*

		Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
	Number of respondents	*36*	*17*	*30*	*12*	*21*
Health improvement	Quantity	14%	12%	7%	33%	33%
	Water quality	65%	76%	73%	33%	38%
	Risk of recontamination	16%	6%	17%	25%	19%
	Risk of by-products formation	0%	0%	0%	0%	0%
	Reliability product safety	5%	6%	3%	8%	10%
Acceptability/ adaptability	Odour/colour/taste	30%	18%	37%	17%	33%
	Approval by authorities	3%	12%	0%	0%	0%
	Labelling and instructions	0%	0%	3%	8%	0%
	Ease of operating	49%	59%	57%	50%	62%
	Ease of maintenance	19%	12%	3%	25%	5%
Accessibility	Lifecycle costs	51%	29%	70%	50%	33%
	Ease of transportation	5%	35%	7%	17%	29%
	Supply chain requirements	43%	35%	23%	33%	38%

Table 17: Share of respondents that indicated the local criteria as the ***least*** *important in the choice of HWTS*

		Rural village	Disease outbreak	Urban slum	Refugee camp	Emergency response
	Number of respondents	*36*	*17*	*30*	*12*	*21*
Health improvement	Quantity	16%	6%	17%	8%	19%
	Water quality	0%	0%	0%	0%	5%
	Risk of recontamination	5%	0%	7%	0%	10%
	Risk of by-products formation	59%	82%	67%	58%	48%
	Reliability product safety	19%	12%	10%	33%	19%
Acceptability / adaptabilit	Odour/colour/taste	0%	12%	0%	8%	0%
	Approval by authorities	41%	29%	53%	50%	33%
	Labelling and instructions	49%	41%	37%	25%	43%
	Ease of operating	5%	6%	3%	0%	10%
	Ease of maintenance	5%	12%	7%	17%	14%
Accessibility	Lifecycle costs	8%	41%	7%	25%	43%
	Ease of transportation	70%	24%	70%	42%	29%
	Supply chain requirements	22%	35%	23%	33%	29%

5.3. Ranking of the HWTS in every context

Now that the value matrix has been created and the weights have been calculated for the general criteria, a ranking can be made of the HWTS per context. Initially, two methods have been chosen to create a ranking: TOPSIS and the Weighted Sum Method (WSM). The Max-Min method was chosen to include for normalisation within the WSM. In the Max-Min method, the lowest value per criteria in the value matrix is given the normalised value 0 and the highest the normalised value 1. Because the Max-Min method uses the normalised range of {0,1}, the criteria range is always big. The Max-Min method thus has a lower range sensitivity [238], making it less useful for the HWTS ranking. Therefore, it is decided to use TOPSIS for the final ranking.
As the calculated weights differ per context, it was also expected that the ranking will differ per context. This also appeared to be the case. But the difference between the HWTS in the rankings is generally very low.

It was decided not to include the 'quantity' criterion in the calculation of the ranking. This was chosen because it is not a linear criterion. If the criterion exceeds a certain value, i.e., the minimum water demand, then a much higher value does not have a much greater advantage.

5.3.1. TOPSIS

Table 18 show the HWTS ranking of the contexts rural village and urban slum. As can be seen, there is a difference in the ranking in this research between the two contexts. However, note that the performance scores of all the HWTS are close to each other. This means that the difference between the HWTS in this ranking is small.

Table 18: The ranking of HWTS created by TOPSIS for the contexts rural village and urban slum.

	Rural village	Performance score		**Urban slum**	Performance score
1	Ceramic candle	0.581	1	Ceramic candle	0.601
2	SODIS	0.561	2	Ceramic pot	0.565
3	Ceramic pot	0.556	3	Membrane filter	0.554
4	Membrane filter	0.519	4	SODIS	0.533
5	Biosand filter	0.511	5	Biosand filter	0.494
6	Chlorination	0.405	6	Chlorination	0.406

For the context of rural village in this research, the ceramic candle filter is the highest ranked and chlorination is the lowest ranked. The ceramic candle filter has high values in the matrix for the criteria with high weights in this context, like odor/color/taste, ease of operating and risk of recontamination. On the other hand, chlorination scores low on odor/color/taste, ease of operating and lifestyle costs, all criteria with high weights in this context.
For the context of urban slum in this research, the ceramic candle filter is the highest ranked and chlorination is the lowest ranked. The ceramic candle filter scores high on the criteria odor/color/taste and ease of operating, two criteria with high weights for this context. While chlorination scores low on these two criteria and also low on lifecycle costs, a criteria with high weight in this context.

Table 19 show the HWTS ranking for the situation of a disease outbreak and the context emergency response. The performance scores for the context disease outbreak are within a slightly bigger range than the other contexts.

For the context of disease outbreak in this research, the membrane filter is the highest ranked and the biosand filter is the lowest ranked. The membrane filter indeed scores high in the value matrix on criteria that have received a high weight in the context of a disease outbreak. For example, the filter scores high on water quality and ease of transportation. The criteria on which the filter has a lower value also received a lower weight in this context, making the drawbacks of the membrane filter less important for this context. The biosand was also expected to rank low, because the biosand filter has low values in the value matrix on criteria with high weights for the context disease outbreak, like water quality, risk of recontamination and ease of maintenance.

For the context of emergency response in this research, the membrane filter is the highest ranked and the biosand filter is the lowest ranked. The membrane filter has high values for criteria with high weights, like water quality, ease of operating and ease of maintenance. On the other hand, the biosand filter has a lower value for the high weight criteria: water quality and risk of recontamination.

Table 19: The ranking of HWTS created by TOPSIS for the contexts disease outbreak and emergency response.

	Disease outbreak	Performance score		**Emergency response**	Performance score
1	Membrane filter	0.670	1	Membrane filter	0.630
2	Ceramic candle	0.586	2	Ceramic candle	0.616
3	Chlorination	0.569	3	Ceramic pot	0.560
4	Ceramic pot	0.510	4	SODIS	0.511
5	SODIS	0.478	5	Chlorination	0.473
6	Biosand filter	0.308	6	Biosand filter	0.425

5.3.2. Weighted sum method

Table 20 and Table 21 show the ranking of the HWTS for the context using the WSM. The ranking is different from the use of the TOPSIS method. The membrane filter always comes up first in any ranking. This is expected to be due to the fact that the membrane filter in the value matrix never has the worst rating and therefore nowhere receives the value 0 in the normalised matrix due to the Max-Min normalisation method.

Table 20: The ranking of HWTS created by WSM for the contexts rural village and urban slum.

	Rural village	Performance score		**Urban slum**	Performance score
1	Membrane filter	0.596	1	Membrane filter	0.634
2	Ceramic candle	0.592	2	Ceramic candle	0.617
3	Ceramic pot	0.562	3	Ceramic pot	0.581
4	SODIS	0.534	4	SODIS	0.532
5	Chlorination	0.468	5	Chlorination	0.487
6	Biosand filter	0.418	6	Biosand filter	0.425

Table 21: The ranking of HWTS created by WSM for the contexts disease outbreak and emergency response.

	Disease outbreak	Performance score		**Emergency response**	Performance score
1	Membrane filter	0.641	1	Membrane filter	0.629
2	Ceramic candle	0.591	2	Ceramic candle	0.604
3	Chlorination	0.568	3	Ceramic pot	0.557
4	Ceramic pot	0.532	4	SODIS	0.521
5	SODIS	0.499	5	Chlorination	0.516
6	Biosand filter	0.286	6	Biosand filter	0.354

6 Evaluate trade-offs of situation-specific criteria

Now the general criteria are considered, the next step is to evaluate the situation-specific criteria (step 4b). The focus in this research is on the first, more generic steps 1 to 4a. This chapter is intended to support the decision-makers by providing suggestions for evaluating the situation-specific criteria. How the steps will ultimately be completed is up to the decision-maker and depends on the time, budget and other resources available.

The situation-specific criteria are already introduced in chapter 3. Although evaluated differently, the general and situation-specific criteria are of the same importance. Table 22 shows a summary on how the situation-specific criteria can be measured, what actions are needed, and for what phase the information is useful. Chapter 6.1 focusses on the situation-specific criteria and how each criterion can be measured. Chapter 6.2 gives suggestions on the three actions needed to evaluate the situation-specific criteria.

Table 22: The situations specific criteria and the actions how these can be measured.

Action	**Situation-specific criteria**	**What to measure**	**Information useful in which phase**
Test source water	Effectiveness across water qualities	Quality of the source water and potentially chemical components in the water	Selecting optimal HWTS
Interviews with targeted HWTS users	Importance of clean dink water knowledge	Check knowledge and opinion about untreated water risks by targeted population	Implementation (promotion and education)
	Prior local use	Experience with HWTS of local population	Selecting optimal HWTS and implementation
	Dignity and status	Attractiveness of the product	Selecting optimal HWTS
	Cultural appropriateness	Attractiveness and appropriateness of the product	Selecting optimal HWTS
	Social influence from others	People who are trusted or looked up to	Implementation (promotion)
	Perceived economic benefit	Ability to pay	Selecting optimal HWTS and implementation
		Willingness to pay	Selecting optimal HWTS and implementation
Collect information on the local market and rules/guidelines	Prior local use	Existing supply chain	Selecting optimal HWTS and implementation
	Perceived economic benefit	Costs of alternatives	Selecting optimal HWTS and implementation
	Ownership	-	Implementation

6.1. Measuring the situation-specific criteria

Importance of clean drink water knowledge

For the HWTS to be adopted by users, the population must know the effect is of drinking untreated drinking water [88]. These criteria can be examined in an interview with the targeted users. If the importance of clean drink water knowledge is low, it is particularly important that attention is paid to increase knowledge. The first step is to create awareness to encourage people to get informed about the problem with untreated water and the options to get safe drinking water. This can be done by promotion. It should quickly be followed by education to increase knowledge [17]. For the steps, health promotors and trainers are needed that give educational sessions with the head of each household [107]. The health promotors should be trusted people who live in the community [17].

Prior local use

When people already have experience with the product, there will be a higher uptake in the community [110]. The existing experience of the local population with HWTS can be examined in an interview [110]. Additionally, prior local use of HWTS provides information about the existence of a supply chain for an HWTS product. This criterion can be used in the selection of an optimal HWTS and for an implementation plan.

Dignity and status

Having an HWTS in the house can affect a person's social status [88], [111]. Having clean drinking water alone can help with the sense of dignity and status. Part of the dignity and status retrieved from the HWTS is dependent on the attractiveness of the product. Measuring attractiveness is a simplification to evaluate the HWTS for these criteria. Because attractiveness is subjective, it is important to listen to the targeted users [239]. The attractiveness can be measured in an interview or focus group by showing photographs or drawings of HWTS products. One could ask what the first impression is, what is appreciated or not, or to rate the HWTS based on attractiveness [240], [241].

Cultural appropriateness

Cultural appropriateness of the HWTS is an important condition for the acceptance of potential users [14], [113], [114]. This criterion can be measured in an interview, the same way as the attractiveness of the product under the 'dignity and status' criterion.

Social influence from others

Social influence can be expressed in expectations from the social environment to behave in a certain way [24], [25]. This criterion can be used in the implementation phase. It helps if the HWTS is supported by health promotors with social influence [17]. To get more information on the people with social influence, local population can be asked what people in their community they trust or even look up to.

Perceived economic benefit

It must be attractive for the buyer to invest in the product. If it is already certain that the HWTS are distributed for free, this criterion is less important to investigate because it focusses on the perceived economic benefit of the buyer. Important components are the economic benefits, ability to pay and willingness to pay. Economic benefits can occur because the new product is cheaper or better than other alternatives [26]. The ability to pay is something else than willingness to pay. The ability to pay is determined by the part of his income or capital that can be set aside to pay for the product and is a constraint that prevents consumers from making choices based on their willingness to pay [119]. An interview with the target population can be used to obtain an impression of the ability to pay and the willingness to pay of the target population. To get information on the ability to pay, questions can be asked about the income and what part of it can be saved to purchase an HWTS [208]. Asking for the willingness to pay can be more difficult. There are several options to ask about the willingness to pay, like pairing or making a budgetary context [242]. Lastly, the costs of alternatives to treat water can be obtained by collecting information about the local market for clean drinking water options. Information about this criterion can be taken into account not only in the choice for a suitable HWTS, but also in the implementation strategy.

Ownership

Ownership is the feeling that the HWTS product is seen as own property. Whether users have to pay for the product and how ownership is used is something to consider when making the business plan and the implementation strategy of the HWTS. There is no unambiguous effect of ownership on the use of a product, that depends on the situation [116], [117].

6.2. The actions needed

Test the source water

The efficacy of HWTS can be influenced by the water quality of the source water. Source water refers to the existing source for drinking water. Characteristics of water quality like organic and inorganic matter, pH, temperature and turbidity may have an influence the efficacy. It can vary per HWTS how much influence these characteristics have on the efficiency. A distinction can be made between techniques with reduced performance under certain circumstances (e.g., lower flow rate or more maintenance needed) and techniques that under certain circumstances no longer work well enough. Several tests are possible to undertake. Which tests could be done depends on the resources available for research and the expectation of additional problems with the source water. A recommended test to undertake is for the level of turbidity, measured in Nephelometric Turbidity Units (NTU). This is because it is an easy test and can have a big influence on the efficacy and use of the HWTS [20]. How well the HWTS can cope with turbidity depends on the technique used. The biosand filter, the ceramic pot filter and the ceramic candle filter, need pre-treatment if the turbidity of the water is over 50 NTU [17]. Often these filters can handle a higher turbidity, but the flow rate will decrease, the filter become clogged faster and needs cleaning more often [210]. SODIS needs pre-treatment for water with a turbidity over 30 NTU [20], [212], [224]. With a higher NTU value, the remaining UV-A radiation is too low for the penetration depth and the treatment is not effective. The efficiency of chlorination lowers with more turbid waters, and the dosage of chlorine needs to be higher for turbid water [237]. Membrane filtration works for turbid water, but the filter can get clogged. This makes backwashing important and more often needed. Turbidity can be easily tested with a Secchi disk. The disk exists out of a black and white disk, on the bottom of a hole tube or on a line. When using a line, lower it in the water until the disk is no longer visible. If a tube is used, poor water into the tube until the disk is no longer visible. The depth at which the disk is not visible indicates the turbidity of the water.

Interview targeted HWTS users

Interviews are a research method based on direct contact with participants [243]. It is a method to collect information on experiences, attitudes and opinions of the participants. Table 22 shows that several criteria need to be investigated by contacting the targeted users. An interview is suitable for discussing a wider range of topics. Below are several elements for the preparation and execution of the interviews:

- The number of interviews required depends on the scope and objective [47], [246], with time and resources as limitations [247]. A small group of respondents between 3 and 36, already have a very high reliability, depending on the agreement between respondents [31]. Van Boeijen states that ten to fifteen interviews provide 80% of the information needed [30]. For a minimum number of interviews, three to eight are recommended by Van Boeijen [246] and Mink stated minimally 5 but preferably more [247]. It is therefore recommended to conduct at least five to eight interviews. If time and resources are available, more interviews can be considered. There is no need for new interviews when no more new information is obtained [246].
- There are no unambiguous guidelines on how long the interview should be. Individual interviews typically are no longer than one hour [45], [246].
- Participants in this research are targeted HWTS users. When selecting participants, include people with different characteristics [244], [245], [247]. Especially a difference in gender, age and income or social class are recommended. Other distinguishing characteristics that can be used are for example religion, ethnicity and occupation. Once it is clear what the characteristics of the participants should be, an established stakeholder network can be used to find the participants [244], [247], [248]. It is important to inform the participants before agreeing to the interview about the intentions of the research [248], the time the interview will take [247] and about compensation [244].
- There are different types of interviews: structured, unstructured or semi-structured. It is recommended to use a semi-structured interview because they are most commonly used in participatory rural appraisal [45]. A semi-structured interview has a pre-defined structure, but there is also freedom to formulate questions during the interview. As part of the preparation, it is important to draw up an interview guide with a topics list that need to be discussed [246]. The criteria that are part of the interview section in Table 22 should be part of the topics list.
- During the interview it is important to make sure people feel at ease and trust the interviewer. The free structure of a semi-structured interview already helps [247]. In addition, it can help to do the interview in a familiar place of the interviewee, such as at home or at work [244], [245] and in the language spoken by the interviewee [45].

After the interview, it may be decided to carry out further research on specific subjects, but this is not necessary. If quantitative data is desired, a questionnaire is a good method, and if a specific subject should be further discussed a focus group is useful. A questionnaire can either be filled in by people themselves or can be read out and completed by the researcher [243]. With a questionnaire, extra attention needs to be paid to the wording, answer options, structure, length and the layout [243].

Focus groups are group interviews consisting of a few participants [243]. Larsen and Flensborg [244] state that focus groups normally have 4 to 10 participants, along with a translator and facilitator. Narayanasama [245] advises six to eight participants with a similar background. A session will last around 2 hours [244].

Collect information on local market and rules/guidelines

Table 22 lists subjects on which information should be obtained: the existence of a supply chain for HWTS, the cost of alternatives for obtaining drinking water and important rules and guidelines. Additional information may be required, for example, on setting up a supply chain. This information is best obtained through an established stakeholder network. In order to build an established stakeholder network, it must be clear who the stakeholders are.

A tool for obtaining an overview of stakeholders is 'stakeholder mapping' [243]. This is a way of creating a visual overview of the stakeholder and their relationships. Before the stakeholders can be mapped, they need to be identified. In this step it is important to make an exhaustive list [243]. Stakeholders can be individuals, groups or organisations who have an interest in the project, are negatively affected by it, are powerful players or who can cause problems in the project's realisation [243]. To create stakeholder maps, an organised structure needs to be added by indicating important relationships or hierarchy [243]. There is not one right way of expressing the stakeholder map. After mapping the relations, a possible, but recommended part of stakeholder mapping is prioritizing the stakeholders. There are several methods for this, but one commonly used is the division of stakeholders over a grid. The extended version is to use a matrix consisting of three dimensions: the power of the stakeholder to influence the project, the stakeholder's interest in the project, and the stakeholder's attitude towards the project [249]. This creates a matrix as shown in Figure 19, where each place in the matrix indicates a different stakeholder relationship. The way of dealing with the stakeholder is then also determined by the location in the matrix. A simplified way of prioritising stakeholders is to make a matrix of only power and interest [250], creating a matrix as shown in Figure 20.

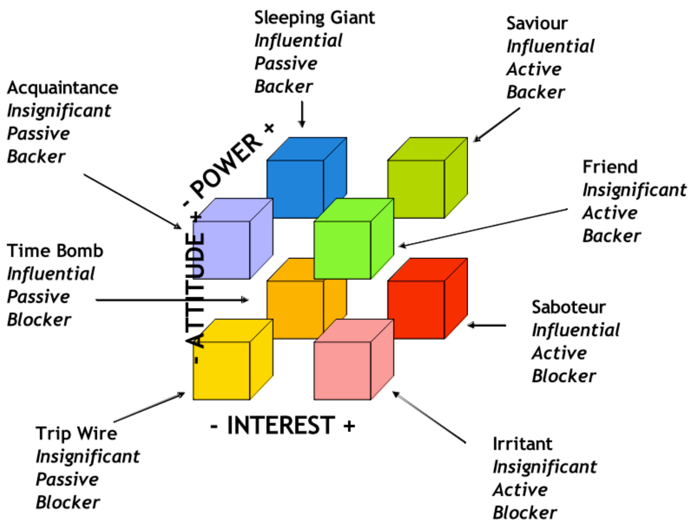


Figure 19: Interest, Power, Attitude grid [249].

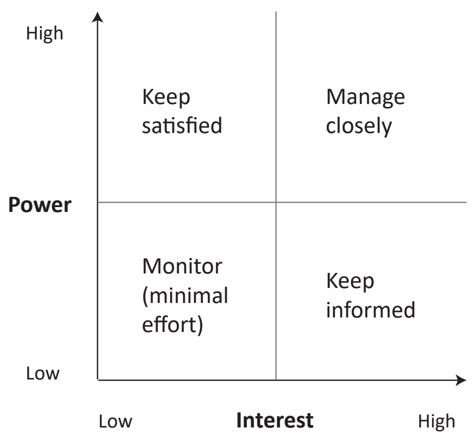


Figure 20: The Power, Interest grid [37].

After stakeholder mapping it is clear who the stakeholders are, what the mutual relationships are, and what kind of relationship it is. Now that these insights are available, it is possible to obtain the information from the right stakeholders. It is unnecessary to conduct an interview but obtaining informal insight may be enough. It is especially important to build a relationship, so the stakeholder will be more willing to share information [247].

7 Introducing the selection guide

The aim of this research was to aid HWTS selection by improving the understanding of the trade-offs. A modified version of SDM has been proposed and the first, more generic steps have been completed in this research. Now the next step is to translate this information into an instrument or method that can be used in practice. For this purpose, the selection guide is presented. The selection guide is an addition to the main objectives of the study and takes a first step towards setting up such an instrument in practice. The selection guide serves as an overview of the steps to be taken for a structured selection of a suitable HWTS. This also answers the fourth sub question: *How can a modified version of Structured Decision Making practically be used by decision-makers?*

The selection guide can be used by anyone who has to make a choice in HWTS but is specifically intended for organisations without in-house WASH experts. Because the results and information from this research are included in the guide, a considerable amount of time and resources can be saved. Using the selection guide results in more structured decision making, which increases the chance of a successful implementation of the HWTS. However, it must be taken into consideration that the selection guide contains several steps and therefore the necessary time must be allocated to it.

The selection guide consists of two pages. The first page is shown in Figure 22 and contains the 'overview of the method' to select a suitable HWTS for the implementation context. The method consists of the steps from modified SDM, which have also been followed in this research. The steps are mentioned and briefly explained. This general page can be used for each set of HWTS and contexts.
The second page is shown in Figure 23 and contains the 'selection guide for decision-makers'. This page follows the same steps as explained in page one but incorporates the results of this research. It is therefore possible for decision-makers without a WASH background to go through the steps. The 'selection guide for decision-makers' is specific for an included set of HWTS and contexts. As can be seen, the selection guide for decision-makers refers to the annex. This annex comprises 4 pages and can be seen in Figure 24, Figure 25, Figure 26 and Figure 27.

For each step in the selection guide, it is indicated what persons are is needed. This is divided into four groups of expertise: decision makers, HWTS experts, method experts and local experts. Who these people are, is not fixed and can vary per situation. It indicates what kind of background is needed to go through the steps. Only the decision-maker and a local expert are needed when the 'selection guide for decision-makers' is used because the expert steps are already carried out in this research.
The decision makers are the ones who make the final decision on which HWTS will be implemented and maintain the overview of the process. An HWTS expert is someone who is knowledgeable about HWTS and preferably has experience with HWTS in the field. A method expert is someone who is knowledgeable about the used methods and is involved in the calculations. Local experts are knowledgeable about the context where the HWTS is going to

be implemented and are available locally for research. This person can be someone living in the community, from an NGO that works there or from a local organisation. It helps when the local expert is also a trusted person in the community, but that is not necessary. Who is a trusted person can vary per country and situation.

Figure 21 shows where in this report more information on the steps can be obtained, if desired. The description of step 1 is provided in this chapter.

Step 1	Clarify specific WASH problem	
Step 2	Identify objectives and the set of criteria	**Chapter 3**
Step 3	Select HWTS to include	**Chapter 4**
Step 4	Rate HWTS on criteria with value matrix	**Chapter 5.1**
Step 5	Weight criteria in every context	**Chapter 5.2**
Step 6	Rank the HWTS per context	**Chapter 5.3**
Step 7	Evaluate trade-offs of situation specific criteria	**Chapter 6**
Step 8	Select optimal decision	
Step 9	Implement and monitor	

Figure 21: References to sections of the report for more information per step.

Step 1 - Clarify the specific WASH problem

To clarify the problem, make use of 'decision sketching'. This means working quickly through the first three to five steps of SDM. This can take from two hours up to two days, depending on the level of detail [35]. This includes looking at possible alternatives to be considered and getting informed about the context. It is not necessary to do this in detail within step 1 [35]. The choice on the range of alternatives can, for example, be made using information already on hand about local availability.

Based on the decision sketching, a work plan can be drawn up. A work plan should at least include a budget plan, a schedule with the required time, and the people needed to complete the steps.

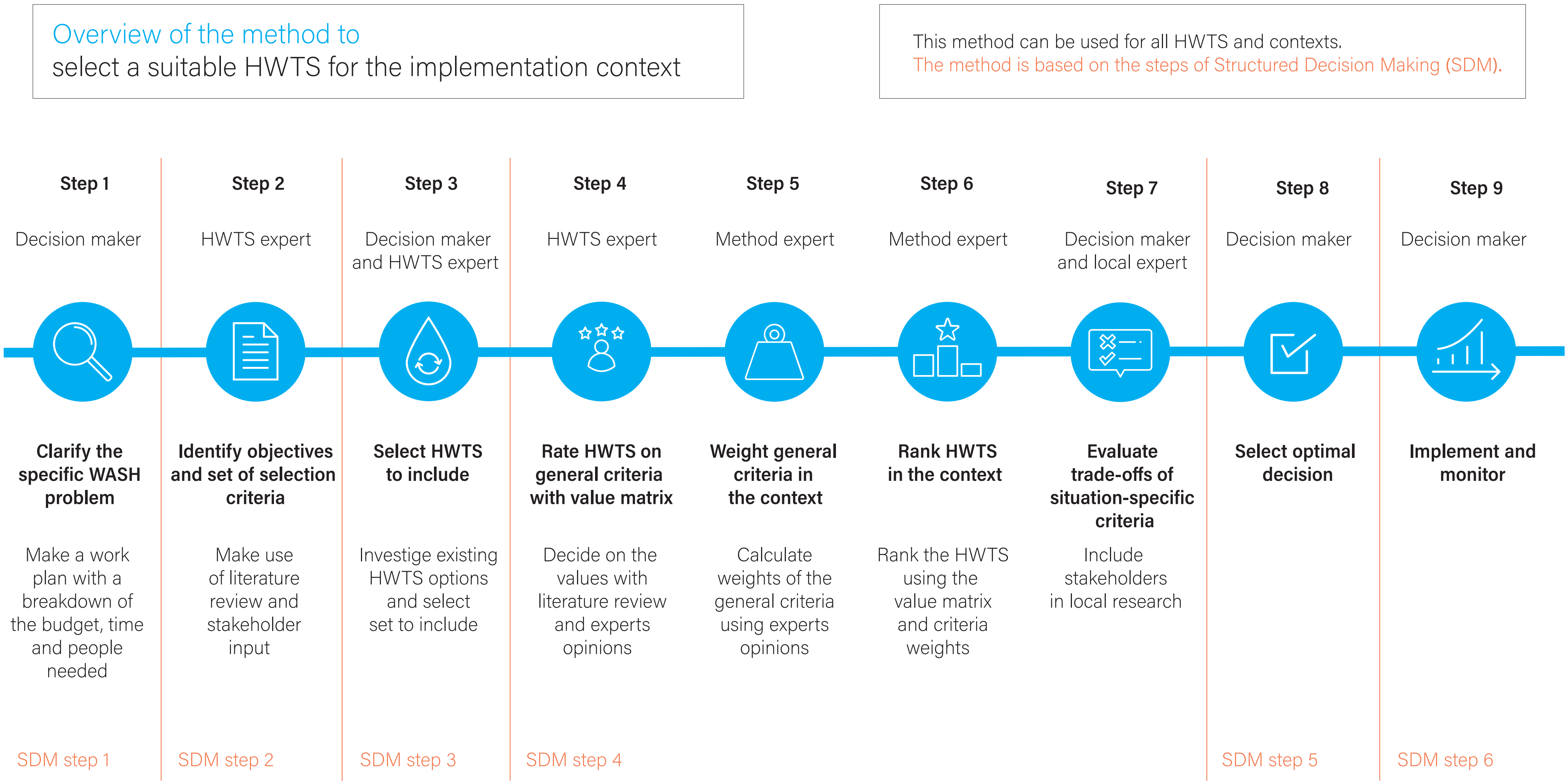
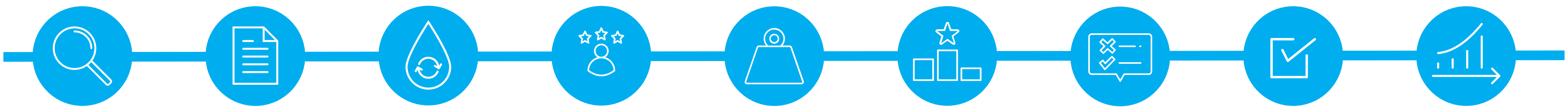


Figure 22: The selection guide: 'overview of the method'.

Guide for policy-makers to
select a suitable HWTS for the implementation context

This page shows the method for an established set of HWTS and contexts. The first steps have already been calculated in research and can be found in the annex.



Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9
Clarify your specific WASH problem	**Read through set of selection criteria**	**HWTS that are included are listed below**	**Read through the value matrix**	**Look at the weights of the general criteria**	**Include the three highest ranked HWTS from selected context**	**Make trade-offs between the HWTS for situation-specific criteria**	**Select a suitable HWTS for the specific situation**	**Make a plan for implementation and monitoring**
	[included in annex]	• Ceramic pot filter • Ceramic candle filter • Biosand filter • Membrane ultrafiltration • SODIS • Chlorination	[included in annex]	[included in annex]	[included in annex]	[included in annex]		

Figure 23: The selection guide 'guide for decision-makers'.

Annex for the guide to
select a suitable HWTS for the implementation context

Step 2

The set of criteria for HWTS selection is shown below:

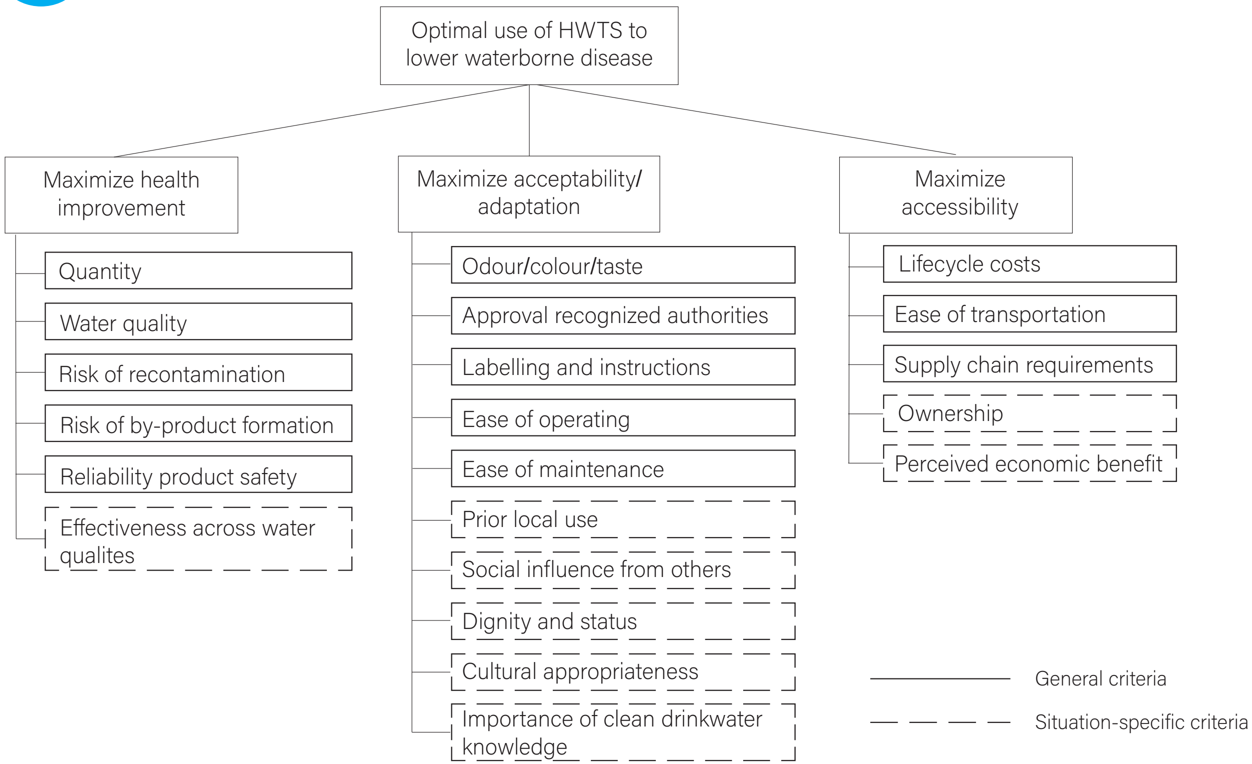


Figure 24: First page of the selection guide annex.

Annex for the guide to
select a suitable HWTS for the implementation context

Step 4

The value matrix for the included HWTS set is shown below:

		Ceramic candle filter	Ceramic pot filter	Membrane filter	Biosand filter	Sodis	Chlorination
Health improvement	Quantity [L/h]	2	2	12	35	2,5	40
	Water quality	2	2	3	1	2	2
	Risk of recontamination	4	4	3	2	4	4
	Risk of by-product formation	4	3	5	5	2	1
	Reliability of product safety	3	2	2	2	1	4
Acceptability/ adaptation	Odour/colour/taste	5	4	3	4	2	1
	Approval by authorities	5	5	5	5	5	5
	Labelling and instructions	4	4	5	2	4	5
	Ease of operating	5	5	5	5	3	4
	Maintenance needed	2	2	3	2	4	4
Economic feasability	Lifecycle costs [$/treated L]	0.0017	0.0015	0.0033	0.0011	0.0009	0.0053
	Ease of transportation	3	2	4	1	5	5
	Supply chain requirements	2	3	2	4	4	1

Figure 25: Second page of the selection guide annex.

Annex for the guide to
select a suitable HWTS for the implementation context

Step 5

The weights of the general criteria are shown below:

		Rural village	Disease outbreak	Urban slum	Emergency response
Health gains	Quantity	0.069	0.115	0.058	0.092
	Water quality	0.126	0.216	0.142	0.157
	Risk of recontamination	0.085	0.125	0.082	0.125
	Risk of by-products formation	0.031	0.041	0.033	0.055
	Reliability product safety	0.065	0.100	0.059	0.062
Acceptability / adaptation	Odour/colour/ taste	0.094	0.058	0.107	0.088
	Approval by authorities	0.046	0.057	0.041	0.064
	Labelling and instructions	0.058	0.052	0.064	0.060
	Ease of operating	0.121	0.098	0.137	0.109
	Ease of maintenance	0.100	0.076	0.106	0.092
Accessibility	Lifecycle costs	0.095	0.038	0.087	0.048
	Ease of transportation	0.037	0.058	0.037	0.045
	Supply chain requirements	0.083	0.035	0.071	0.057

Figure 26: Third page of the selection guide annex.

Annex for the guide to

select a suitable HWTS for the implementation context

Step 6

Select the most appropriate context for HWTS implementation.

- Rural village without water supply
- Urban informal slum
- Waterborne disease outbreak
- Emergency response after natural disaster

Rural village	
1. Ceramic candle	0.581
2. SODIS	0.561
3. Ceramic pot	0.556
4. Membrane filter	0.519
5. Biosand filter	0.511
6. Chlorination	0.405

Urban slum	
1. Ceramic candle	0.601
2. Ceramic pot	0.565
3. Membrane filter	0.554
4. SODIS	0.533
5. Biosand filter	0.494
6. Chlorination	0.406

Disease outbreak	
1. Membrane filter	0.670
2. Ceramic candle	0.586
3. Chlorination	0.569
4. Ceramic pot	0.510
5. SODIS	0.478
6. Biosand filter	0.308

Emergency response	
1. Membrane filter	0.630
2. Ceramic candle	0.616
3. Ceramic pot	0.560
4. SODIS	0.511
5. Chlorination	0.473
6. Biosand filter	0.425

Step 7

Suggested actions to evaluate trade-offs of the situation-specific criteria:

- Test quality of the water source, especcialy turbidity of the water using a Secchi disk
- Interviews with targeted HWTS users. Recommended to have minimally five to eight interviews with participants with different characteristics.
- Collect information on the market and policy

Figure 27: Fourth page of the selection guide annex.

8 Discussion

This chapter discusses which parts may cause uncertainty or even have an impact on the results. A list of assumptions and choices made in this research is added in appendix A.

8.1. Clarify decision context and identify criteria

It should be considered that HWTS is not the desired solution for some situations, but that for example community-based solutions should be examined. HWTS has the potential to improve the quality of drinking water in places where this is not yet sufficient. The goal remains clean and affordable drinking water for everyone. This will ultimately be achieved by reliable and a safe piped water connections to each household [13], [14]. HWTS does not increase access to water and therefore remains an interim solution [251].

The final set of selection criteria is based on literature and interviews with experts. A fully representative set of criteria set can never be guaranteed. Due to the amount of research and the use of different sources, it can be assumed that the set of criteria is a good and comprehensive reflection of the important aspects when choosing a suitable HWTS.

8.2. The Value matrix

The completeness and the final values in the value matrix are based on literature and feedback from experts. There is no guarantee that the values in the matrix are completely correct for every situation and future point in time. Especially values resulting from inconsistent literature. Because of the amount of research and the use of different sources, it can be assumed that the value matrix is a good and comprehensive reflection of the characteristics of the included HWTS. A possible improvement in future research could therefore focus on the values with a higher inconsistency of sources.

8.3. The criteria weight

8.3.1. Using the Best-Worst Method

The final weights assigned to the general criteria did not show the absolute importance of those criteria. They indicated the relative importance of that criterion compared to the rest of the criteria included in this study. This does not affect the research but is the reason the weights have to be recalculated if the set of criteria changes.

The final weights were calculated by multiplying the weights of the categories by the local weights. This process made it possible to compare factors that were never compared by the experts. It was chosen because the set of criteria was too large to compare each criterion using the BWM. It is not completely clear how this multiplication affects the final weight and whether the weight would be different if all criteria were compared separately by experts.

To calculate the weights, experts were asked to complete the survey. Expert input is part of the BWM and is also argued in the methods section. The weights calculated by experts input were used in this research to give decision-makers better insight into the trade-offs. It should therefore be taken into account that the weights could differ if the survey had only been completed by decision-makers.

Additionally, it could be that the weights will be different when another method than BWM is used to calculate them [252].

8.3.2. The expert survey

Getting information from experts can create uncertainties because of bias [65]. Only in the calculation of the weights, experts were the main source of information. Thus, in the survey extra attention was given to minimise bias. More explanation can be found in chapter 2.3.2.2. Two points to consider are shown below. Because the survey is designed to prevent these biases, it is not expected that this will have a significant effect on the weights.

- The survey contains two layers of comparison: the comparison between the categories, and the comparison of the criteria within these categories. It was decided to compare the criteria within the categories first, and then the categories themselves. This increased the clarity of the survey, since respondents know what the sub criteria were. However, it creates a chance of splitting bias, since each group contains a different number of criteria. This would mean that respondents may have rated the categories 'health improvement' and 'acceptability and adaptability' higher than 'accessibility', because those groups contain five criteria instead of the three of 'accessibility'.
- The respondents of the online survey probably have experience with a few HWTS but not with the complete set that was included. Respondents may prefer a specific HWTS and be biased in their responses to the questions.

8.3.3. Reliability

The consistency of the answers of the experts can be calculated in the BWM. Because there is no threshold indicated, a threshold of 0.25 has been taken in this study. If a different threshold would result in a different amount of data that can be included in the calculation of the final weights. This means that the chosen threshold for consistency has an influence on the final value of the weights.

The consistency turned out to be lower than expected, resulting in fewer data to include in the calculation of the weights. Respondents indicated that it was a complicated questionnaire to follow. In addition, several respondents indicated that specifying the importance of criteria was complicated since they considered all criteria as important and did not immediately have a preference. This may be a reason for the relatively low consistency of the online survey [253]. The low consistency can also be a result from distractions while filling in the survey, the wording in the survey, or the length of the survey [254]. Because the values above the consistency threshold were not included in calculating the weights, it is not expected to have influenced the final weights.

When selecting the significance test, it must also be taken into account whether the data is paired or unpaired. The Kruskal-Wallis test, which is based on unpaired data, was chosen. However, it is not possible to speak of unpaired data, as the respondents provided input over several contexts. Since the difference between paired and unpaired tests is normally very small, and the results were very clear, the Kruskal-Wallis test results were used.

8.4. Ranking of the HWTS

This study assumes that one criterion can be compensated by another. This means that an HWTS that scores low on one criterion but high on other criteria, can end up high in the ranking [238]. While in reality it is possible that scoring low on one criterion means that the HWTS is no longer a good option. Preferences are often not entirely compensatory.

The choice of methods for normalisation and aggregation may influence the result of the ranking [28], [255], [256]. In this study, two ranking methods were considered, WSM with the Max-Min method for normalisation and TOPSIS. The methods showed a different ranking of HWTS, with the HWTS close to each other, indicating the method chosen effects the ranking.

The ranking method reflects the preferences and benefits of the technology on the set of criteria. Strictly interpreted, this would mean that a ranking method must be chosen separately for each decision-maker. This would take too much time and eliminate the advantage of generalising the first steps. That is why it has been decided to use the same ranking method, i.e., TOPSIS, for all decision-makers going through the SDM steps.

9 Conclusions and recommendations

The aim of this research was to understand how to adapt Structured Decision Making (SDM) to aid HWTS selections in different contexts. By following the steps of the modified SDM, the understanding of trade-offs in HWTS selection is improved. In order to represent the most widely applied and tested technologies, HWTS included in this study are ceramic candle filter, ceramic pot filter, biosand filter, membrane filter, SODIS and chlorination. The developed SDM showed that only one major adaptation is required, specifically to aid in HWTS selection, which is "the estimation of consequences". The estimation of consequences is the fourth step of SDM and was found to demand differentiation between *generic* and *situation-specific* criteria. This differentiation is important, because generic criteria can be used to evaluate the set of HWTS based on literature and expert experience, while situation-specific criteria should always be investigated locally per situation. However, only by including both sets of criteria, one can create a complete overview of the trade-offs and make an informed decision.

The evaluation of weights per contexts, using the Best-Worst Method, showed a striking similarity between the (semi-)permanent settlements ('rural village' and 'urban informal slum'), compared to the three emergency contexts ('disease outbreak', 'emergency response after natural disaster' and 'refugee camp'). The weights of the three emergency contexts did not resemble each other. Nevertheless, a significance test showed that for almost all criteria, the medians between the contexts did not differ significantly from each other. The difference in preference between contexts plays an important role in HWTS selection. It shows the importance of context-based selection because different HWTS might be more suitable.

Additionally, the evaluation of the weights showed a difference in preference between the selection criteria. Among the criteria categories, the weights showed that the 'health improvement' category was the most important in the selection of HWTS, and 'accessibility' the least, according to experts. The criteria weights show clear differences within this category 'health improvement' and 'acceptability'. There was no clear difference between the criteria within the category 'accessibility'. This information helps to improve the understanding of trade-offs in the selection of HWTS.

Altogether, an adapted version of SDM is suitable to aid in HWTS selection. Going through the steps of the method has given extended insight into the trade-offs per context. The method itself and the obtained knowledge will support decision-makers in taking a structured and well-informed decision in HWTS. This is translated in an instrument, presented in the research as the selection guide, to aid decision-makers in practice with HWTS selection.

9.1. Recommendations for further research

This chapter contains the recommendations for further research. The recommendations followed from the discussed points and from the results and are presented below.

- **Specific research on the difference between contexts**
  The similarity between (semi-)permanent contexts and the difference with the emergency contexts could not be proven significant in this research. The importance of context-based decision-making thus needs further investigation. To get a better insight in potential differences between contexts, it is recommended to include a context that is clearly permanent and a context that is clearly not. It can be decided to include contexts from different emergency phases. When obtaining information from experts, it is important to precisely define these contexts. The obtained criteria set from this research can be used.
- **Specific research on difference between criteria(groups)**
  A different importance of criteria(groups) could be detected in this research through a difference in weight height. It was not tested whether this difference is significant. A deeper understanding of the importance of the criteria will not only improve the HWTS choice but may even improve future HWTS design.
- **Expand the dataset**
  The criteria weights in this research have a high standard deviation. A larger dataset can have a lowering effect on the standard deviation, making the final weights more precise. In addition, increasing the sample size will ensure that this is not a reason for a non-significant outcome. However, for certain contexts it will be relatively easier to find experts than for other contexts.
- **Evaluate the effect of using category and local weights**
  In this research, the final weights are retrieved by multiplying the category weights with the local weights. It is difficult to say whether this multiplication accurately reflects the weights that respondents would have allocated if they had made a pair comparison. It would be interesting to test this effect by applying another method in future research that allows all criteria to be compared. If another method is used in further research on the weights, it is recommended to choose one that can deal with the large number of criteria.
- **Increase the robustness of the criteria weights**
  To increase the robustness that the weights reflect the actual opinion of the experts, more research should be done on the weights by using multiple methods and a different expert group [249]. Additionally, weights can change over time [249]. Therefore, it is recommended to recalculate the weights after a couple of years.
- **Investigate the sensitivity of the ranking methods used**
  In this study, two methods for normalisation and aggregation are used for ranking the HWTS. In this study, a different ranking emerged when a different method was used. Including other ranking and normalisation methods in future research can help to investigate whether the ranking will be ordered differently.
- **Involve the HWTS user in the study**
  During this study, it was unfortunately not possible to reach out to people who are using or will use HWTS due to the pandemic COVID-19. Future research should include the experiences and opinions of the target HWTS users. The target population can specifically help to get a better understanding of the trade-offs between HWTS and what would be the reasons for purchasing a HWTS.

9.2. Recommendations for further development of the method

This study focused on the generic steps 1 to 4a. Further research could focus more on the last steps in order to create a more elaborate method.

- **Develop the suggested actions from step 4b into guidelines**
  - The action 'test source water' focused on biological contents in the water. It seems unnecessary to carry out several tests for chemical contents in every situation. But if certain complaints occur frequently locally, the source water can be specifically tested. If this reveals that chemical contents are present in the water, it is useful to include HWTS that can remedy this.
  - To simplify the action of interviews, a general topic list can be included.
  - To simplify stakeholder mapping, a general guideline of important stakeholders can be formulated with the information needed from which stakeholders.
- **Include guidance on steps 5 and 6.**
  The elaboration of how the choice is finally made (step 5) and planning the implementation and monitoring (step 6) were not considered in this study. The method can be expanded by offering guidance in these two steps to decision-makers.

Further research can improve the selection guide in the future. The recommendations are listed below:

- **Expand the selection guide**
  The selection guide can be expanded to more situations by adding HWTS and contexts. Because that can be complex, it is recommended to do this in further research instead of by the decision-maker going through the guide. First, contexts can be added by calculating the criteria weights for that context. This can be done with the BWM and an expert survey. Weights of the existing contexts do not have to be calculated again if the BWM is used. The ranking of existing contexts do not have to be carried out again, if TOPSIS is used. A created Excel with the TOPSIS method is added with this research to simplify the HWTS ranking. An Excel for the calculation of BWM can be downloaded at the website bestworstmethod.com. Secondly, when new HWTS are added, the values matrix needs to be extended with the values for the new HWTS. The ranking will also have to be recalculated, this time including the existing HWTS.
- **Add a time indication**
  It will be useful for the decision-makers to include a time indication in the selection guide or even a more detailed planning of the steps.
- **Test the guide with decision-makers**
  The potential of the selection guide can be improved when tested by the decision-makers for whom it is intended. With the help of decision-makers, it can be investigated what might be missing from the selection guide, and whether all steps have been presented clearly enough.
- **Make it an online tool**
  Eventually it could become an online tool, making it accessible worldwide.

Reference list

[1] WHO; Unicef, ‘1 in 3 people globally do not have access to safe drinking water’, **2019**. https://www.who.int/news/item/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who (accessed Oct. 26, 2020).

[2] United Nations, ‘Economic and Social Council’, *Agenda 28 April 2020*, vol. 10, no. 3, pp. 435–441, **2020**, doi: 10.1017/S0020818300007852.

[3] WHO, ‘Drinking-water’, **2019**. https://www.who.int/news-room/fact-sheets/detail/drinking-water (accessed Oct. 26, 2020).

[4] Sobsey, M. D., C. E. Stauber, L. M. Casanova, J. M. Brown, and M. A. Elliott, ‘Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World’, **2007**, doi: 10.1021/es702746n.

[5] WHO; Unicef, *Why children are still dying and what can be done*, vol. 11, no. 1. **2009**.

[6] Woldu, W., B. D. Bitew, and Z. Gizaw, ‘Socioeconomic factors associated with diarrheal diseases among under-five children of the nomadic population in northeast Ethiopia’, *Trop. Med. Health*, vol. 44, no. 1, pp. 7–14, **2016**, doi: 10.1186/s41182-016-0040-7.

[7] Dadonaite, B., H. Ritchie, and M. Roser, ‘Diarrheal diseases - Our World in Data’, **2019**. https://ourworldindata.org/diarrheal-diseases (accessed Oct. 26, 2020).

[8] Unicef, *Pneumonia and diarrhoea*. **2012**.

[9] Zwane, A. P. and M. Kremer, ‘What works in fighting diarrheal diseases in developing countries? A critical review’, *World Bank Res. Obs.*, vol. 22, no. 1, pp. 1–24, **2007**, doi: 10.1093/wbro/lkm002.

[10] Checkley, W. *et al.*, ‘Multi-country analysis of the effects of diarrhoea on childhood stunting’, *Int. J. Epidemiol.*, vol. 37, no. 4, pp. 816–830, **2008**, doi: 10.1093/ije/dyn099.

[11] Richard, S. A. *et al.*, ‘Diarrhea in early childhood: Short-Term association with weight and long-Term association with length’, *Am. J. Epidemiol.*, vol. 178, no. 7, pp. 1129–1138, **2013**, doi: 10.1093/aje/kwt094.

[12] WHO, ‘Guidelines for Drinking-water Quality’, **2017**.

[13] WHO, ‘International Network to Promote Household Water Treatment and Safe Storage’. **2004**.

[14] WHO, ‘Combating waterborne disease at the household level’, **2007**.

[15] Hutton, G. and L. Haller, ‘Estimating the costs and health benefits of water and sanitation improvements at global level’, *J. Water Health*, vol. 5, no. 4, pp. 467–480, **2004**, doi: 10.2166/wh.2007.008.

[16] Clasen, T., L. Haller, D. Walker, J. Bartram, and S. Cairncross, ‘Cost-effectiveness of water quality interventions for preventing diarrhoeal disease in developing countries’, **2007**, doi: 10.2166/wh.2007.010.

[17] CAWST, ‘Introduction to Household Water Treatment and Safe Storage’, **2011**. Accessed: Jul. 08, 2020. [Online]. Available: www.cawst.org.

[18] UNICEF, ‘Going to Scale with Household Water Treatment and Safe Storage (HWTS)’,

p. 27, **2009**.
[19] Wolf, J. *et al.*, ‘Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression’, *Trop. Med. Int. Heal.*, vol. 23, no. 5, pp. 508–525, **2018**, doi: 10.1111/tmi.13051.
[20] WHO, *Results of round II of the WHO international scheme to evaluate household water treatment technologies*. **2019**.
[21] Rosa, G., P. Kelly, and T. Clasen, ‘Consistency of use and effectiveness of household water treatment practices among urban and rural populations claiming to treat their drinking water at home: A case study in Zambia’, *Am. J. Trop. Med. Hyg.*, vol. 94, no. 2, pp. 445–455, **2016**, doi: 10.4269/ajtmh.15-0563.
[22] Sobsey, M. D., C. E. Stauber, L. M. Casanova, J. M. Brown, and M. A. Elliott, ‘Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world’, *Environ. Sci. Technol.*, vol. 42, no. 12, pp. 4261–4267, **2008**, doi: 10.1021/es702746n.
[23] Loo, S. L., A. G. Fane, W. B. Krantz, and T. T. Lim, ‘Emergency water supply: A review of potential technologies and selection criteria’, *Water Res.*, vol. 46, no. 10, pp. 3125–3151, **2012**, doi: 10.1016/j.watres.2012.03.030.
[24] Lantagne, D. and T. Clasen, ‘Point of Use Water Treatment in Emergency Response’, no. October, **2009**.
[25] Peter-Varbanets, M., C. Zurbrügg, C. Swartz, and W. Pronk, ‘Decentralized systems for potable water and the potential of membrane technology’, *Water Res.*, vol. 43, no. 2, pp. 245–265, **2009**, doi: 10.1016/j.watres.2008.10.030.
[26] Pagsuyoin, S. A., J. R. Santos, J. S. Latayan, and J. R. Barajas, ‘A multi-attribute decision-making approach to the selection of point-of-use water treatment’, *Environ. Syst. Decis.*, vol. 35, no. 4, pp. 437–452, **2015**, doi: 10.1007/s10669-015-9567-0.
[27] HIF, ‘HIF Emergency Household Water Filter Challenge: Evaluation Matrix and Report’, no. June, **2017**, [Online]. Available: www.hwts.info.
[28] Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson, ‘Structuring Environmental Management Choices’, in *Structured Decision Making: A Practical Guide to Environmental Management*, no. 2012, **2012**, pp. 1–20.
[29] Mendoza, G. A. and H. Martins, ‘Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms’, *For. Ecol. Manage.*, vol. 230, no. 1–3, pp. 1–22, **2006**, doi: 10.1016/j.foreco.2006.03.023.
[30] Belton, V. and T. Stewart, ‘Multiple criteria decision analysis: an integrated approach’, Springer Science & Business Media, **2002**.
[31] Lienert, J., L. Scholten, C. Egger, and M. Maurer, ‘Structured decision-making for sustainable water infrastructure planning and four future scenarios’, *EURO J. Decis. Process.*, vol. 3, no. 1–2, pp. 107–140, **2015**, doi: 10.1007/s40070-014-0030-0.
[32] Spuhler, D. *et al.*, ‘Developing sanitation planning options: A tool for systematic consideration of novel technologies and systems’, *J. Environ. Manage.*, vol. 271, p. 111004, **Oct. 2020**, doi: 10.1016/j.jenvman.2020.111004.
[33] Guerrero, A. M. *et al.*, ‘Using structured decision-making to set restoration objectives when multiple values and preferences exist’, *Restor. Ecol.*, vol. 25, no. 6, pp. 858–865, **2017**, doi: 10.1111/rec.12591.
[34] Cambrainha, G. M. and M. E. Fontana, ‘A multi-criteria decision making approach to balance water supply-demand strategies in water supply systems’, *Producao*, vol. 28, **2018**, doi: 10.1590/0103-6513.20170062.

[35] Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson, 'Structured Decision Making: A Practical Guide to Environmental Management', **2012**. https://books.google.nl/books?hl=en&lr=&id=bT1_LFuK6LMC&oi=fnd&pg=PR7&dq=structured+decision+making&ots=KCBOOxYRf3&sig=2lHRE7nxbId1Uu8JlHMJP_o3QRA&redir_esc=y#v=onepage&q=structured decision making&f=false (accessed Sep. 22, 2020).
[36] Gazzard, T. *et al.*, 'What is the "appropriate" fuel management regime for the Otway Ranges, Victoria, Australia? Developing a long-term fuel management strategy using the structured decision-making framework', *Int. J. Wildl. Fire*, vol. 29, no. 5, pp. 354–370, **2020**, doi: 10.1071/WF18131.
[37] Bazerman, M. H., & Moore, D. A., 'Judgment in managerial decision making', **2012**. https://books.google.nl/books?hl=en&lr=&id=6HP4DwAAQBAJ&oi=fnd&pg=PA1&dq=Bazerman,+M.+H.,+%26+Moore,+D.+A.+(2009).+Judgment+in+Managerial+Decision+Making.&ots=pWa0ONXee0&sig=UmtNFsdkmEkrFthW4CRuXVTsg2U&redir_esc=y#v=onepage&q=Bazerman%2C M. H.%2C %26 Moor (accessed Sep. 21, 2020).
[38] Matanò, A., 'MSc . Thesis - DECISION ANALYSIS SUPPORT FOR SUSTAINABLE ALLOCATION OF NEWLY-ARRIVED REFUGEES ACCORDING TO WATER SECURITY CRITERIA', **2019**.
[39] Nardo, M., M. Saisana, A. Saltelli, S. Tarantola, A. Hoffman, and E. Giovannini, *Handbook on constructing composite indicators*, no. 03. **2005**.
[40] Robinson, P. and J. Lowe, 'Literature reviews vs systematic reviews', *Aust. N. Z. J. Public Health*, vol. 39, no. 2, p. 103, **2015**, doi: 10.1111/1753-6405.12393.
[41] Mosler, H.-J., 'A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline', *Int. J. Environ. Health Res.*, vol. 22, no. 5, pp. 431–449, **2012**, doi: 10.1080/09603123.2011.650156.
[42] Michie, S., M. M. Van Stralen, and R. West, 'The behaviour change wheel: A new method for characterising and designing behaviour change interventions', **2011**. doi: 10.1186/1748-5908-6-42.
[43] Michie, S., M. M. van Stralen, and R. West, 'The COM-B Model of Behaviour', pp. 1–7, **2019**, [Online]. Available: https://social-change.co.uk/files/02.09.19_COM-B_and_changing_behaviour_.pdf.
[44] Sekaran, U. and R. Bougie, *Research methods for business: A skill building approach.*, Seventh Ed. John Wiley & Sons, **2016**.
[45] Narayanasamy, N., *Participatory rural appraisal: Principles, methods and application*. SAGE Publications India., **2009**.
[46] Mink, A., J. C. Diehl, and P. Kandachar, 'Comprehensive user insight to improve technologies for development', *Int. Dev. Plan. Rev.*, vol. 40, no. 3, pp. 299–328, **2018**, doi: 10.3828/idpr.2018.13.
[47] Handwerker, P. W., *Quick ethnography: A guide to rapid multi-method research*. Rowman Altamira, **2001**.
[48] Wood, J. L., *Methods of Social Movement Research.* **2003**.
[49] Marttunen, M., F. Haag, V. Belton, J. Mustajoki, and J. Lienert, 'Methods to inform the development of concise objectives hierarchies in multi-criteria decision analysis', *Eur. J. Oper. Res.*, vol. 277, no. 2, pp. 604–620, **Sep. 2019**, doi: 10.1016/j.ejor.2019.02.039.
[50] Keeney, R. L. and H. Raiffa, *Decisions with multiple objectives: preferences and value trade-offs*. John Wiley & Sons, **1976**.

[51] de Haan, A., ‘Probleemanalyse (TB111B)’, *TU Delft course*, **2020**. https://brightspace.tudelft.nl/d2l/le/content/279962/Home (accessed Sep. 28, 2020).
[52] Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson, ‘Understanding Objectives’, in *Struct. Decis. Mak. A Pract. Guid. to Environ. Manag. Choices*, no. 2012, **2012**, pp. 1–24.
[53] Rezaei, J., ‘Best-worst multi-criteria decision-making method’, *Omega (United Kingdom)*, vol. 53, pp. 49–57, **Jun. 2014**, doi: 10.1016/j.omega.2014.11.009.
[54] Keeney, R. L. and R. S. Gregory, ‘Selecting attributes to measure the achievement of objectives’, *Oper. Res.*, vol. 53, no. 1, pp. 1–11, **2005**, doi: 10.1287/opre.1040.0158.
[55] Özmen, M. and E. K. Aydoğan, ‘Robust multi-criteria decision making methodology for real life logistics center location problem’, *Artif. Intell. Rev.*, vol. 53, no. 1, pp. 725–751, **2020**, doi: 10.1007/s10462-019-09763-y.
[56] de Prieëlle, F., ‘ECOSYSTEM DATA GOVERNANCE AS A CRICITAL FACTOR FOR DATA PLATFORM PARTICIPATION’, **2018**.
[57] Liang, F., M. Brunelli, and J. Rezaei, ‘Consistency issues in the best worst method: Measurements and thresholds’, *Omega (United Kingdom)*, vol. 96, p. 102175, **2020**, doi: 10.1016/j.omega.2019.102175.
[58] Gupta, H. and M. K. Barua, ‘Identifying enablers of technological innovation for Indian MSMEs using best–worst multi criteria decision making method’, *Technol. Forecast. Soc. Chang.*, vol. 107, pp. 69–79, **2016**, doi: 10.1016/j.techfore.2016.03.028.
[59] Liao, H., X. Mi, Q. Yu, and L. Luo, ‘Hospital performance evaluation by a hesitant fuzzy linguistic best worst method with inconsistency repairing’, **2019**, doi: 10.1016/j.jclepro.2019.05.308.
[60] Yazdi, M., A. Nedjati, E. Zarei, and R. Abbassi, ‘A reliable risk analysis approach using an extension of best-worst method based on democratic-autocratic decision-making style’, *J. Clean. Prod.*, vol. 256, p. 120418, **2020**, doi: 10.1016/j.jclepro.2020.120418.
[61] Mohammadi, M. and J. Rezaei, ‘Bayesian best-worst method: A probabilistic group decision making model’, *Omega (United Kingdom)*, vol. 96, p. 102075, **2019**, doi: 10.1016/j.omega.2019.06.001.
[62] Rezaei, J., ‘BWM: Best Worst Method - PowerPoint slides’. .
[63] Hamalainen, R. P. and S. Alaja, ‘The threat of weighting biases in enviornmental decision analysis’, *Analysis*, no. April 2003, **2006**, [Online]. Available: http://www.e-reports.sal.tkk.fi/pdf/E12.pdf.
[64] Jacobi, S. K. and B. F. Hobbs, ‘Quantifying and Mitigating the Splitting Bias and Other Value Tree-Induced Weighting Biases’, *Decis. Anal.*, vol. 4, no. 4, pp. 194–210, **2007**, doi: 10.1287/deca.1070.0100.
[65] Scholten, L., N. Schuwirth, P. Reichert, and J. Lienert, ‘Tackling uncertainty in multi-criteria decision analysis - An application to water supply infrastructure planning’, *Eur. J. Oper. Res.*, vol. 242, no. 1, pp. 243–260, **2015**, doi: 10.1016/j.ejor.2014.09.044.
[66] Weber, M., F. Eisenführ, and D. Von Winterfeldt, ‘The Effect of Attribute Ranges on Weights in Multiattribute Utility Measurements’, *Manage. Sci.*, vol. 39, no. 8, pp. 937–943, **1988**, doi: 10.1287/mnsc.39.8.937.
[67] Kynn, M., ‘The “heuristics and biases” bias in expert elicitation’, *J. R. Stat. Soc. Ser. A Stat. Soc.*, vol. 171, no. 1, pp. 239–264, **2008**, doi: 10.1111/j.1467-985X.2007.00499.x.
[68] Ostertagová, E., O. Ostertag, and J. Kováč, ‘Methodology and application of the Kruskal-Wallis test’, *Appl. Mech. Mater.*, vol. 611, pp. 115–120, **2014**, doi: 10.4028/www.scientific.net/AMM.611.115.

[69] Kruskal, W. H. and W. A. Wallis, 'Use of Ranks in One-Criterion Variance Analysis', *J. Am. Stat. Assoc.*, vol. 47, pp. 583–621, **1952**, doi: 10.1080/01621459.1952.10483441.
[70] Peng, K. A. *et al.*, 'Revision Surgery for Vestibular Schwannomas', *J Neurol Surg B*, vol. 79, pp. 528–532, **2018**, doi: 10.1055/s-0038-1635256.
[71] Nemery, P., 'DOCTEUR EN SCIENCES de L ' INGENIEUR On the use of multicriteria ranking methods in sorting problems', *Structure*, no. November 2008, **2009**, doi: 10.13140/2.1.3854.6722.
[72] Guarini, M. R., F. Battisti, and A. Chiovitti, 'A methodology for the selection of multi-criteria decision analysis methods in real estate and land management processes', *Sustain.*, vol. 10, no. 2, **2018**, doi: 10.3390/su10020507.
[73] Hwang, C. L. and K. Yoon, 'Methods for multiple attribute decision making', Springer, Berlin, Heidelberg, **1981**.
[74] Alper, D. and C. Basdar, 'A Comparison of TOPSIS and ELECTRE Methods: An Application on the Factoring Industry', *Bus. Econ. Res. J.*, vol. 8, no. 3, pp. 627–646, **2017**.
[75] García-Cascales, M. S. and M. T. Lamata, 'On rank reversal and TOPSIS method', *Math. Comput. Model.*, vol. 56, no. 5–6, pp. 123–132, **2012**, doi: 10.1016/j.mcm.2011.12.022.
[76] Velasquez, M. and P. Hester, 'An analysis of multi-criteria decision making methods', *Int. J. Oper. Res.*, vol. 10, no. 2, pp. 56–66, **2013**.
[77] Ruchser, I. A., 'Comparing Multi Criteria Weighted Decision Methods of Simultaneous Operation al Aircraft Maintenance Process I Ncorporating M Ultiple', Delft University of Technology, **2011**.
[78] Wang, Y. M. and Y. Luo, 'On rank reversal in decision analysis', *Math. Comput. Model.*, vol. 49, no. 5–6, pp. 1221–1229, **2009**, doi: 10.1016/j.mcm.2008.06.019.
[79] Janic, M. and A. Reggiani, 'An application of the multiple criteria decision making (MCDM) analysis to the selection of a new Hub Airport', *Eur. J. Transp. Infrastruct. Res. EJTIR, 2*, no. Mcdm, **2002**, doi: 10.18757/ejtir.2002.2.2.3692.
[80] Triantaphyllou, E. and S. H. Mann, 'An Examination of the Effectiveness of Multi-Dimensional Decision-Making Methods: A Decision-Making Paradox', **1989**.
[81] Marler, R. T. and J. S. Arora, 'The weighted sum method for multi-objective optimization: New insights', *Struct. Multidiscip. Optim.*, vol. 41, no. 6, pp. 853–862, **2010**, doi: 10.1007/s00158-009-0460-7.
[82] Stanujkic, D. and E. K. Zavadskas, 'A Modified Weighted Sum Method Based on the Decision-maker's Preferred Levels of Performances', **2015**, doi: 10.24846/v24i4y201510.
[83] Kabir, W., M. O. Ahmad, and M. N. S. Swamy, 'Normalization and weighting techniques based on genuine-impostor score fusion in multi-biometric systems', *IEEE Trans. Inf. Forensics Secur.*, vol. 13, no. 8, pp. 1989–2000, **2018**, doi: 10.1109/TIFS.2018.2807790.
[84] Hamouda, M. A., W. B. Anderson, and P. M. Huck, 'Employing multi-criteria decision analysis to select sustainable point-of-use and point-of-entry water treatment systems', *Water Sci. Technol. Water Supply*, vol. 12, no. 5, pp. 637–647, **2012**, doi: 10.2166/ws.2012.035.
[85] Odokuma, E. E. and P. O. Asagba, 'Similarities and Differences between the Ranking Schemes of the WSM , TOPSIS AND VIKOR Multi Criteria', no. October, **2017**, doi: 10.26562/IRJCS.2017.OCCS10081.

[86] Brown, J. and T. Clasen, ‘High adherence is necessary to realize health gains from water quality interventions’, *PLoS One*, vol. 7, no. 5, pp. 1–9, **2012**, doi: 10.1371/journal.pone.0036735.
[87] Sonego, I. L., A. C. Huber, and H.-J. Mosler, ‘Does the Implementation of Hardware Need Software? A Longitudinal Study on Fluoride-Removal Filter Use in Ethiopia’, *Environ. Sci. Technol*, vol. 47, **2013**, doi: 10.1021/es402787s.
[88] Kincaid, D. L., ‘Social , Cultural and Behavioral Correlates of Household Water Treatment and Storage’, **2010**.
[89] WHO, ‘Results of Round I of the WHO International Scheme to Evaluate Household Water Treatment Technologies’, *Trop. Med. Int. Heal.*, vol. 106, no. 1, pp. 155–162, **2012**, doi: 10.3329/jhpn.v28i1.4521.
[90] Barstow, C. K. *et al.*, ‘Designing and piloting a program to provide water filters and improved cookstoves in Rwanda’, *PLoS One*, vol. 9, no. 3, pp. 1–12, **2014**, doi: 10.1371/journal.pone.0092403.
[91] Hunter, P. R., ‘Household water treatment in developing countries: Comparing different intervention types using meta-regression’, *Environ. Sci. Technol.*, vol. 43, no. 23, pp. 8991–8997, **2009**, doi: 10.1021/es9028217.
[92] Clarke, B. A. and A. Steele, ‘Water treatment systems for relief agencies: The on-going search for the “Silver Bullet”’, *Desalination*, vol. 248, no. 1–3, pp. 64–71, **2009**, doi: 10.1016/j.desal.2008.05.039.
[93] WHO, ‘Evaluating household water treatment options’, **2011**.
[94] Curry, K. D., M. Morgan, S. H. Peang, and S. Seang, ‘Biosand water filters for floating villages in Cambodia: safe water does not prevent recontamination’, **2015**, doi: 10.2166/washdev.2015.120.
[95] Rufener, S., D. Mäusezahl, H.-J. Mosler, and R. Weingartner, ‘Quality of Drinking-water at Source and Point-of-consumption-Drinking Cup As a High Potential Recontamination Risk: A Field Study in Bolivia’, **2010**.
[96] Centre for Disease Control and Prevention, ‘Preventing Diarrheal Disease in Developing Countries : Safe Storage of Drinking Water January 2009 The Oxfam Bucket The CDC Container Jerry Cans Modified Clay Pots’, *System*, no. January, **2009**.
[97] Unicef, ‘Household Water Treatment and Safe Storage (HWTS) in Emergency Settings’. https://www.unicef.org/innovation/household-water-treatment-and-safe-storage-hwts-emergency-settings (accessed Oct. 13, 2020).
[98] Zajonc, R. B., ‘On the Primacy of Affect’, **1984**.
[99] Siwila, S. and I. C. Brink, ‘Comparison of five point-of-use drinking water technologies using a specialized comparison framework’, *J. Water Health*, vol. 17, no. 4, pp. 568–586, **2019**, doi: 10.2166/wh.2019.041.
[100] Lantagne, D. and T. Yates, ‘Household Water Treatment and Cholera Control’, *J. Infect. Dis. HWT Cholera Control • JID*, no. 3, p. 147, **2018**, doi: 10.1093/infdis/jiy488.
[101] Soros, A., ‘Chitosan coagulation for household water treatment in developing countries’, **2015**.
[102] Butler, E. *et al.*, ‘Point of use water treatment with forward osmosis for emergency relief’, *Desalination*, vol. 312, pp. 23–30, **2013**, doi: 10.1016/j.desal.2012.12.013.
[103] Pérez-Vidal, A., J. Diaz-Gómez, J. Castellanos-Rozo, and O. L. Usaquen-Perilla, ‘Long-term evaluation of the performance of four point-of-use water filters’, *Water Res.*, vol. 98, pp. 176–182, **2016**, doi: 10.1016/j.watres.2016.04.016.
[104] Stevenson, M. M., ‘Monitoring Effective Use of Household Water Treatment and Safe

Storage Technologies in Ethiopia and Ghana by', no. June 2005, pp. 1–53, **2008**.
[105] World Health Organization (WHO), *Guidelines on sanitation and health*. **2018**.
[106] Casanova, L. M., A. Walters, A. Naghawatte, and M. D. Sobsey, 'A post-implementation evaluation of ceramic water filters distributed to tsunami-affected communities in Sri Lanka', *J. Water Health*, vol. 10, no. 2, pp. 209–220, **2012**, doi: 10.2166/wh.2012.181.
[107] Murray, A. L. *et al.*, 'Evaluation of consistent use, barriers to use, and microbiological effectiveness of three prototype household water treatment technologies in Haiti, Kenya, and Nicaragua', *Sci. Total Environ.*, vol. 718, p. 134685, **2020**, doi: 10.1016/j.scitotenv.2019.134685.
[108] Santos, J., S. A. Pagsuyoin, and J. Latayan, 'A multi-criteria decision analysis framework for evaluating point-of-use water treatment alternatives', *Clean Technol. Environ. Policy*, vol. 18, no. 5, pp. 1263–1279, **2016**, doi: 10.1007/s10098-015-1066-y.
[109] Sharma, L. M. and S. Sood, 'Reinventing the Biosand Filter: An Easy Solution for Safe Drinking Water', *IOSR J. Environ. Sci.*, vol. 10, no. 1, pp. 43–48, **2016**, doi: 10.9790/2402-10114348.
[110] UNHCR, 'Household Water Treatment and Safe Storage in Refugee Situations', *Household water treatment and safe storage*. p. 44, **2008**, [Online]. Available: www.who.int/household_water/research/technologies_intro/en/.
[111] Tamas, A., F. Wehrle, K. Wojtalla, and R. Meierhofer, 'Assessing Long-Term Sustainability of Former Eawag HWTS Projectsvia', **2011**.
[112] Hystra, 'MARKETING INNOVATIVE DEVICES FOR THE Lessons from 15 global pioneers', no. March, **2013**.
[113] Centre for Disease Control and Prevention, 'Household Water Treatment Options in Developing Countries: Solar Disinfection (SODIS)', **2008**. Accessed: Sep. 15, 2020. [Online]. Available: www.sodis.chorwww.fundacionsodis.org.
[114] Lantagne, D. and T. Clasen, 'Point-of-use water treatment in emergency response', *Waterlines*, vol. 31, no. 1–2, pp. 30–52, **2012**, doi: 10.3362/1756-3488.2012.005.
[115] van Boeijen, A. and Y. Zijlstra, *Culture Sensitive Design: A Guide to Culture in Practice*. **2020**.
[116] Banerjee, A. and E. Duflo, *Poor Economics. A Radical Rethinking of the Way to Fight Global Poverty*. **2013**.
[117] Qayyum, U., 'Book reviews: Poor Economics : Rethinking Poverty and the Ways to End it by Abhijit Banerjee and Esther Duflo', vol. 52, no. 1, **2013**.
[118] Mac Mahon, J. and L. W. Gill, 'Sustainability of novel water treatment technologies in developing countries: Lessons learned from research trials on a pilot continuous flow solar water disinfection system in rural Kenya', *Dev. Eng.*, vol. 3, pp. 47–59, **2018**, doi: 10.1016/j.deveng.2018.01.003.
[119] Grassi, S., 'Public and Private Provision under Asymmetric Information : Ability to Pay and Willingness to Pay', no. November, **2010**.
[120] Chan, L., Chan, M. & Wang, J., 'Design of Water Filter for Third World Countries', pp. 1–71, **2009**.
[121] Murphy, H. M., E. A. McBean, and K. Farahbakhsh, 'A critical evaluation of two point-of-use water treatment technologies: Can they provide water that meets WHO drinking water guidelines?', *J. Water Health*, vol. 8, no. 4, pp. 611–630, **2010**, doi: 10.2166/wh.2010.156.
[122] Van Halem, D., S. G. J. Heijman, A. I. A. Soppe, J. C. Van Dijk, and G. L. Amy, 'Ceramic

silver-impregnated pot filters for household drinking water treatment in developing countries: Material characterization and performance study', **2007**.
[123] Brown, J. and M. Sobsey, 'Use of Ceramic Water Filters in Cambodia (field note)', *F. Note*, **2007**.
[124] K Ngai, T. K., D. L. Baker, and B. E. Coff, 'Recent advances in household biosand filter design', *37th WEDC Int. Conf.*, pp. 1–7, **2014**.
[125] WSP, 'Use of BioSand Filters in Cambodia', **2010**.
[126] Kennedy, T. J., T. A. Anderson, E. Annette Hernandez, and A. N. Morse, 'Determining the operational limits of the biosand filter', **2013**, doi: 10.2166/ws.2012.075.
[127] Pooi, C. K. and H. Y. Ng, 'Review of low-cost point-of-use water treatment systems for developing communities', *npj Clean Water*, vol. 1, no. 1, **2018**, doi: 10.1038/s41545-018-0011-0.
[128] Warsinger, D. M. *et al.*, 'A review of polymeric membranes and processes for potable water reuse', *Prog. Polym. Sci.*, vol. 81, no. May, pp. 209–237, **2018**, doi: 10.1016/j.progpolymsci.2018.01.004.
[129] Smieja, J. A., 'Household Water Treatments in Developing Countries', *J. Chem. Educ*, vol. 88, pp. 549–553, **2011**, doi: 10.1021/ed100480p.
[130] Mcguigan, K. G., P. Samaiyar, M. Du Preez, R. An, and M. Conroy, 'High Compliance Randomized Controlled Field Trial of Solar Disinfection of Drinking Water and Its Impact on Childhood Diarrhea in Rural Cambodia', *Environ. Sci. Technol*, vol. 45, pp. 7862–7867, **2011**, doi: 10.1021/es201313x.
[131] Brown, D., C. Farrow, E. A. McBean, B. Gharabaghi, and J. Beauchamp, 'Advancing performance evaluation standards for household water treatment technologies', *J. Water Health*, vol. 17, no. 2, pp. 266–273, **2019**, doi: 10.2166/wh.2018.266.
[132] Andrew, R., 'An Overview of Global Standards, Protocols and Guidelines for POU and POE Microbial Reduction Claims', **2012**.
[133] WHO/UNICEF, 'A toolkit for monitoring And evaluating household water treatment And safe storage programmes', *United Nations Child. Fund*, **2012**.
[134] NSF International, 'NSF Standards for Water Treatment Systems'. http://www.nsf.org/consumer-resources/water-quality/water-filters-testing-treatment/standards-water-treatment-systems (accessed Jul. 01, 2020).
[135] Sphere, *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, vol. 1. **2018**.
[136] Isunju, J. B., K. Schwartz, M. A. Schouten, W. P. Johnson, and M. P. van Dijk, 'Socio-economic aspects of improved sanitation in slums: A review', *Public Health*, vol. 125, no. 6, pp. 368–376, **2011**, doi: 10.1016/j.puhe.2011.03.008.
[137] Bollman, R. D. and W. Reimer, 'Demographics, Employment, Income, and Networks: Differential Characteristics of Rural Populations', **2009**, doi: 10.1080/10599240902845120.
[138] PATH, 'Market Assessment of Household Water Treatment Products in Eight African Countries', **2010**, [Online]. Available: https://path.azureedge.net/media/documents/TS_safe_water_mkt_assess.pdf.
[139] Nzeadibe, T. C. and C. K. Ajaero, 'Assessment of Socio-Economic Characteristics and Quality of Life Expectations of Rural Communities in Enugu State, Nigeria', **2010**, doi: 10.1007/s11482-010-9096-4.
[140] Proctor, F. J., 'Rural economic diversification in sub-Saharan Africa', no. September, p. 24, **2014**, [Online]. Available: http://pubs.iied.org/14632IIED.

[141] Yates, T., J. Allen, M. Leandre Joseph, and D. Lantagne, 'WASH interventions in disease outbreak response', Kieran Doherty/Oxfam, **2017**.
[142] Marx, B., T. Stoker, and T. Suri, 'The economics of slums in the developing world', *J. Econ. Perspect.*, vol. 27, no. 4, pp. 187–210, **2013**, doi: 10.1257/jep.27.4.187.
[143] UN Habitat, 'Slums : Some Definitions', *State of the World's Cities 2006/7*, no. 2, pp. 1–2, **2007**.
[144] Sari, S. Y. I., D. K. Sunjaya, H. Shimizu-Furusawa, C. Watanabe, and A. S. Raksanagara, 'Water Sources Quality in Urban Slum Settlement along the Contaminated River Basin in Indonesia: Application of Quantitative Microbial Risk Assessment', **2018**, doi: 10.1155/2018/3806537.
[145] Katukiza, A. Y., M. Ronteltap, P. van der Steen, J. W. A. Foppen, and P. N. L. Lens, 'Quantification of microbial risks to human health caused by waterborne viruses and bacteria in an urban slum', *J. Appl. Microbiol.*, vol. 116, no. 2, pp. 447–463, **2014**, doi: 10.1111/jam.12368.
[146] Musoke, D., R. Ndejjo, A. A. Halage, S. Kasasa, J. C. Ssempebwa, and D. O. Carpenter, 'Drinking Water Supply, Sanitation, and Hygiene Promotion Interventions in Two Slum Communities in Central Uganda', **2018**, doi: 10.1155/2018/3710120.
[147] Burkholder, B. T. and M. J. Toole, 'Evolution of complex disasters', *Lancet*, vol. 346, no. 8981, pp. 1012–1015, **1995**, doi: 10.1016/S0140-6736(95)91694-6.
[148] Werker, E., 'Refugee camp economies', *J. Refug. Stud.*, vol. 20, no. 3, pp. 461–480, **2007**, doi: 10.1093/jrs/fem001.
[149] Breiman, R. F. *et al.*, 'Cholera outbreak in kenyan refugee camp: Risk factors for illness and importance of sanitation', *Am. J. Trop. Med. Hyg.*, vol. 80, no. 4, pp. 640–645, **2009**, doi: 10.4269/ajtmh.2009.80.640.
[150] Hershey, C. L., S. Doocy, J. Anderson, C. Haskew, P. Spiegel, and W. J. Moss, 'Incidence and risk factors for Malaria, pneumonia and diarrhea in children under 5 in UNHCR refugee camps: A retrospective study', *Confl. Health*, vol. 5, no. 1, pp. 1–11, **2011**, doi: 10.1186/1752-1505-5-24 22029694.
[151] Blanchet, K., 'Health in Humanitarian Emergencies: Principles and Practice for Public Health and Healthcare Practitioners.', *Am. J. Trop. Med. Hyg.*, vol. 99, no. 6, p. 1651, **2018**, doi: 10.4269/ajtmh.18-0839.
[152] Watson, J., M. Gayer, and M. Connolly, 'Epidemics after Natural Disasters', **2007**. Accessed: Jun. 23, 2020. [Online]. Available: www.cdc.gov/eid.
[153] IFRC, 'Complex/manmade hazards: displaced populations'. https://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/displaced-populations/ (accessed Jul. 01, 2020).
[154] Triple Quest, 'Hydraid Biosand Water Filter – Proven Technology to Address the Global Water Crisis', pp. 1–8, **2011**.
[155] Clasen, T. F., J. Brown, S. Collin, O. Suntura, and S. Cairncross, 'Reducing diarrhea through the use of household-based ceramic water filters: A randomized, controlled trial in rural Bolivia', *Am. J. Trop. Med. Hyg.*, vol. 70, no. 6, pp. 651–657, **2004**, doi: 10.4269/ajtmh.2004.70.651.
[156] Clasen, T., 'Household-Based Ceramic Water Filters for the Treatment of Drinking Water in Disaster Response: An Assessment of a Pilot Programme in the Dominican Republic', *Water Pract. Technol.*, vol. 1, no. 2, **2006**, doi: 10.2166/wpt.2006031.
[157] Lantagne, D., R. Quick, and E. D. Mintz, 'Household Water Treatment and Safe Storage in Developing Countries', p. 22, **2011**, [Online]. Available:

https://www.wilsoncenter.org/publication/household-water-treatment-and-safe-storage-options-developing-countries-review-current.
[158] Meierhofer, R., P. Rubli, J. Oremo, and A. Odhiambo, ‘Does activated silver reduce recontamination risks in the reservoirs of ceramic water filters?’, *Water (Switzerland)*, vol. 11, no. 5, pp. 1–11, **2019**, doi: 10.3390/w11051108.
[159] Ehdaie, B. *et al.*, ‘Evaluation of a Silver-Embedded Ceramic Tablet as a Primary and Secondary Point-of-Use Water Purification Technology in Limpopo Province, S. Africa’, **2017**, doi: 10.1371/journal.pone.0169502.
[160] Van Der Laan, H. *et al.*, ‘Bacteria and virus removal effectiveness of ceramic pot filters with different silver applications in a long term experiment’, **2013**, doi: 10.1016/j.watres.2013.11.010.
[161] Nazava, ‘Instruction Manual Riam’, *Int. Bus.*, pp. 1–183, **2003**.
[162] Clasen, T. and S. Boisson, ‘Household-Based Ceramic Water Filters for the Treatment of Drinking Water in Disaster Response : An Assessment of a Pilot Programme in the Dominican Republic’, vol. 1, no. 2, **2006**, doi: 10.2166/WPT.2006031.
[163] DAHME, E., L. MAJNO, A. RAI, and R. WANG, ‘Nazava water filters social impact assessment’, **2017**.
[164] Carlsen, M., K. Waddell, and S. Clara, *Nazava Water Filters ; Social Impact Assessment*. **2016**.
[165] Nazava, ‘Nazava Riam Water Filter’. https://www.nazava.com/en/shop/nazava-riam-water-filter/ (accessed Oct. 19, 2020).
[166] Sobsey, M. D., ‘Managing Water in the Home: Accelerated Health Gains from Improved Water Supply’, **2002**.
[167] Nazava, Santa Clara University, and HEC Paris, ‘Nazava impact matrix’.
[168] Mcallister, S., ‘Analysis and comparison of sustainable water filters’, *United Nations*, vol. 2005, p. 22, **2005**.
[169] van Halem, D., H. van der Laan, S. G. J. Heijman, J. C. van Dijk, and G. L. Amy, ‘Assessing the sustainability of the silver-impregnated ceramic pot filter for low-cost household drinking water treatment’, *Phys. Chem. Earth*, vol. 34, no. 1–2, pp. 36–42, **2009**, doi: 10.1016/j.pce.2008.01.005.
[170] SPOUTS of Water, ‘Purifaaya Ceramic Water Filter’, vol. 256, no. 0, pp. 1–25, **2014**.
[171] Murcott, S., ‘Implementation , Critical Factors and Challenges to Scale-Up of Household Drinking Water Treatment and Safe Storage Systems’, *Backgr. Pap. Househ. Water Treat. Safe Storage Electron. Conf. hosted by USAID/Hygiene Improv. Proj.*, no. May, pp. 31–32, **2006**.
[172] Clasen, T. *et al.*, ‘Interventions to improve water quality for preventing diarrhoea (Review)’, *Cochrane Libr.*, vol. 2015, no. 10, p. CD004794, **2015**, doi: 10.1002/14651858.CD004794.pub3.www.cochranelibrary.com.
[173] Lemons, A., A. Branz, M. Kimirei, T. Hawkins, and D. Lantagne, ‘Assessment of the quality, effectiveness, and acceptability of ceramic water filters in Tanzania’, *J. Water Sanit. Hyg. Dev.*, vol. 6, no. 2, pp. 195–204, **2016**, doi: 10.2166/washdev.2016.006.
[174] Archer, A. R., A. C. Elmore, E. Bell, and C. Rozycki, ‘Field investigation of arsenic in ceramic pot filter-treated drinking water’, *Water Sci. Technol.*, vol. 63, no. 10, pp. 2193–2198, **2011**, doi: 10.2166/wst.2011.406.
[175] Schaefer, M. V., A. Shantz, S. Fendorf, and S. C. Ying, ‘Arsenic leaching from ceramic water filters’, *Environ. Sci. Water Res. Technol.*, vol. 4, no. 2, pp. 234–240, **2018**, doi: 10.1039/c7ew00176b.

[176] Mwabi, J. K., B. B. Mamba, and M. N. B. Momba, ‘Removal of waterborne bacteria from surface water and groundwater by cost-effective household water treatment systems (HWTS): A sustainable solution for improving water quality in rural communities of Africa’, *Water SA*, vol. 39, no. 4, pp. 445–456, **2013**, doi: 10.4314/wsa.v39i4.2.
[177] Lantagne, D., ‘Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filter Report 2 : Field Investigations’, *Methods*, pp. 1–121, **2001**.
[178] Yang, H., S. Xu, D. E. Chitwood, and Y. Wang, ‘Ceramic water filter for point-of-use water treatment in developing countries: Principles, challenges and opportunities’, *Front. Environ. Sci. Eng.*, vol. 14, no. 5, pp. 1–10, **2020**, doi: 10.1007/s11783-020-1254-9.
[179] Layman, ‘Ceramic Water Filter Maintenance is Simple and Improves Filter Life and Effectiveness’. http://www.clean-water-for-laymen.com/water-filter-maintenance.html (accessed Nov. 17, 2020).
[180] Offringa, G., *Development of a Prototype Nanotechnology- Based Clay Filter Pot To Purify Water for Drinking and Cooking in Rural Homes*, no. August. **2010**.
[181] SPOUTS of Water, ‘The Purifaaya Ceramic Water Filter’. https://purifaaya.com/product/purifaaya-regular/ (accessed Oct. 23, 2020).
[182] Boisson, S., W. P. Schmidt, T. Berhanu, H. Gezahegn, and T. Clasen, ‘Randomized controlled trial in rural Ethiopia to assess a portable water treatment device’, *Environ. Sci. Technol.*, vol. 43, no. 15, pp. 5934–5939, **2009**, doi: 10.1021/es9000664.
[183] Boisson, S., M. Kiyombo, L. Sthreshley, S. Tumba, J. Makambo, and T. Clasen, ‘Field assessment of a novel household-based water filtration device: A randomised, placebo-controlled trial in the democratic Republic of Congo’, *PLoS One*, vol. 5, no. 9, pp. 1–10, **2010**, doi: 10.1371/journal.pone.0012613.
[184] Francis, M. R. *et al.*, ‘Effectiveness of membrane filtration to improve drinking water: A quasi-experimental study from rural southern India’, *Am. J. Trop. Med. Hyg.*, vol. 95, no. 5, pp. 1192–1200, **2016**, doi: 10.4269/ajtmh.15-0675.
[185] Kirby, M. A. *et al.*, ‘Effects of a large-scale distribution of water filters and natural draft rocket-style cookstoves on diarrhea and acute respiratory infection: A cluster-randomized controlled trial in Western Province, Rwanda’, *PLoS Med.*, vol. 16, no. 6, pp. 1–24, **2019**, doi: 10.1371/journal.pmed.1002812.
[186] Kirby, M. A. *et al.*, ‘Use, microbiological effectiveness and health impact of a household water filter intervention in rural Rwanda—A matched cohort study’, *Int. J. Hyg. Environ. Health*, vol. 220, no. 6, pp. 1020–1029, **2017**, doi: 10.1016/j.ijheh.2017.05.013.
[187] Kajitvichyanukul, P., N. K. Shammas, Y. Hung, L. K. Wang, and J. Ananpattarachai, ‘Membrane and Desalination Technologies’, *Membr. Desalin. Technol.*, vol. 13, **2011**, doi: 10.1007/978-1-59745-278-6.
[188] Naranjo, J. B. S. and C. P. Gerba, ‘Assessment of the LifeStraw Family Unit using the World Health Organization Guidelines for “Evaluating Household Water Treatment Options: Health-based Targets and Performance Specifications”’, *Phys. Rev. E*, p. 53, **2011**.
[189] Vestergaard Frandsen, ‘LifeStraw 2.0’.
[190] Engineering For Change, ‘LifeStraw Family 2.0’. https://www.engineeringforchange.org/solutions/product/lifestraw-family-2-0/ (accessed Oct. 23, 2020).

[191] Vestergaard, 'LifeStraw Family 2.0'. https://www.vestergaard.com/lifestraw-family-2-0/ (accessed Oct. 23, 2020).
[192] Lantagne, D., R. Meierhofer, G. Allgood, K. G. McGuigan, and R. Quick, 'Comment on "Point of use household drinking water filtration: A practical, effective solution for providing sustained access to safe drinking water in the developing world"', *Environ. Sci. Technol.*, vol. 43, no. 3, pp. 968–969, **2009**, doi: 10.1021/es802252c.
[193] Sisson, A. J., P. J. Wampler, R. R. Rediske, J. N. McNair, and D. J. Frobish, 'Long-term field performance of biosand filters in the Artibonite Valley, Haiti', *Am. J. Trop. Med. Hyg.*, vol. 88, no. 5, pp. 862–867, **2013**, doi: 10.4269/ajtmh.12-0345.
[194] Ngai, T. K. K., R. R. Shrestha, B. Dangol, M. Maharjan, and S. E. Murcott, 'Design for sustainable development - Household drinking water filter for arsenic and pathogen treatment in Nepal', *J. Environ. Sci. Heal. - Part A Toxic/Hazardous Subst. Environ. Eng.*, vol. 42, no. 12, pp. 1879–1888, **2007**, doi: 10.1080/10934520701567148.
[195] Dow Baker, C. and D. L. Baker, 'Scaling Up Household Water Treatment', *Proc. Water Environ. Fed.*, vol. 2009, no. 1, pp. 1–7, **2012**, doi: 10.2175/193864709793847627.
[196] Tellen, V., G. Nkeng, and S. Dentel, 'Improved filtration technology for pathogen reduction in rural water supplies', *Water (Switzerland)*, vol. 2, no. 2, pp. 285–306, **2010**, doi: 10.3390/w2020285.
[197] Petterson, S. R., 'Application of a QMRA Framework to Inform Selection of Drinking Water Interventions in the Developing Context', *Risk Anal.*, vol. 36, no. 2, pp. 203–214, **2016**, doi: 10.1111/risa.12452.
[198] Stauber, C. E., B. Kominek, K. R. Liang, M. K. Osman, and M. D. Sobsey, 'Evaluation of the impact of the plastic biosand filter on health and drinking water quality in rural tamale, Ghana', *Int. J. Environ. Res. Public Health*, vol. 9, no. 11, pp. 3806–3823, **2012**, doi: 10.3390/ijerph9113806.
[199] Fabiszewski De Aceituno, A. M., C. E. Stauber, A. R. Walters, R. E. Meza Sanchez, and M. D. Sobsey, 'A randomized controlled trial of the plastic-housing BioSand filter and its impact on diarrheal disease in Copan, Honduras', *Am. J. Trop. Med. Hyg.*, vol. 86, no. 6, pp. 913–921, **2012**, doi: 10.4269/ajtmh.2012.11-0066.
[200] O'Connell, B. J., D. Slawson, M. Quinn, P. Scheuerman, and O. O. Ogunleye, 'Review of biosand water filters', *Waterlines*, vol. 36, no. 3, pp. 233–242, **2017**, doi: 10.3362/1756-3488.17-00001.
[201] Fiore, M. M., K. Minnings, and L. D. Fiore, 'Assessment of biosand filter performance in rural communities in southern coastal Nicaragua: an evaluation of 199 households.', *Rural Remote Health*, vol. 10, no. 3, p. 1483, **2010**.
[202] Jenkins, M. W., S. K. Tiwari, and J. Darby, 'Bacterial, viral and turbidity removal by intermittent slow sand filtration for household use in developing countries: Experimental investigation and modeling', *Water Res.*, vol. 45, no. 18, pp. 6227–6239, **2011**, doi: 10.1016/j.watres.2011.09.022.
[203] Fewster, E., A. Mol, and C. Wiesent-Brandsma, 'The long-term sustainability of household bio-sand filtration', *People-Centred Approaches to Water Environ. Sanit. Proc. 30th WEDC Conf.*, pp. 558–561, **2004**.
[204] Wu, C. F., L. M. Piedra, L. E. Matthew, E. C. Rhodes, and T. H. Nguyen, 'Water treatment in rural guatemala: Factors associated with the use of biosand water filters', *J. Water Sanit. Hyg. Dev.*, vol. 10, no. 2, pp. 286–297, **2020**, doi: 10.2166/washdev.2020.147.
[205] Tiwari, S. S. K., W. P. Schmidt, J. Darby, Z. G. Kariuki, and M. W. Jenkins, 'Intermittent

slow sand filtration for preventing diarrhoea among children in Kenyan households using unimproved water sources: Randomized controlled trial', *Trop. Med. Int. Heal.*, vol. 14, no. 11, pp. 1374–1382, **2009**, doi: 10.1111/j.1365-3156.2009.02381.x.
[206] Cawst, 'Biosand Filter Construction Manual', *Cent. Afford. Water Sanit. Technol.*, no. August, p. 2, **2012**.
[207] Engineering For Change, 'Hydraid® BioSand Filter'. https://www.engineeringforchange.org/solutions/product/hydraid-biosand-filter/ (accessed Nov. 13, 2020).
[208] Green, V., 'HOUSEHOLD WATER TREATMENT AND SAFE STORAGE OPTIONS FOR NORTHERN REGION GHANA : CONSUMER PREFERNCE AND RELATIVE COST', pp. 1–127, **2008**.
[209] Wishing well, 'HYDRAID® - Wishing Well International FoundationWishing Well International Foundation'. http://wishingwellintl.org/hydraaid/ (accessed Oct. 20, 2020).
[210] CAWST, 'Hydraid Biosand Filter | Household Water Treatment and Safe Storage Knowledge Base'. https://www.hwts.info/products-technologies/07e65cbc/hydraid-biosand-filter/technical-information (accessed Oct. 20, 2020).
[211] Vanderzwaag, J. C., J. W. Atwater, K. H. Bartlett, and D. Baker, 'Field evaluation of long-term performance and use of biosand filters in Posoltega, Nicaragua', *Water Qual. Res. J. Canada*, vol. 44, no. 2, pp. 111–121, **2009**, doi: 10.2166/wqrj.2009.012.
[212] Eawag, *SODIS manual*. **2016**.
[213] Galli, F. and N. Smiyanov, 'MANUAL : METHODS FOR PURYFING DRINKING WATER ENGINEERS WITHOUT', **2018**.
[214] Wegelin, M., S. Canonica, K. Mechsner, T. Fleischmann, F. Pesaro, and A. Metzler, 'Solar water disinfection: Scope of the process and analysis of radiation experiments', *Aqua J. Water Supply Res. Technol.*, vol. 43, no. 4, pp. 154–169, **1994**.
[215] Heaselgrave, W. and S. Kilvington, 'The efficacy of simulated solar disinfection (SODIS) against Ascaris, Giardia, Acanthamoeba, Naegleria, Entamoeba and Cryptosporidium', *Acta Trop.*, vol. 119, no. 2–3, pp. 138–143, **2011**, doi: 10.1016/j.actatropica.2011.05.004.
[216] Boyle, M. *et al.*, 'Bactericidal Effect of Solar Water Disinfection under Real Sunlight Conditions', *Appl. Environ. Microbiol.*, vol. 74, no. 10, pp. 2997–3001, **2008**, doi: 10.1128/AEM.02415-07.
[217] Graf, J., S. Z. Togouet, N. Kemka, D. Niyitegeka, R. Meierhofer, and J. G. Pieboji, 'Health gains from solar water disinfection (SODIS): Evaluation of a water quality intervention in Yaoundé, Cameroon', *J. Water Health*, vol. 8, no. 4, pp. 779–796, **2010**, doi: 10.2166/wh.2010.003.
[218] Rose, A. *et al.*, 'Solar disinfection of water for diarrhoeal prevention in southern India', *Arch Dis Child*, vol. 91, pp. 139–141, **2006**, doi: 10.1136/adc.2005.077867.
[219] Meierhofer, R. and G. Landolt, 'Factors supporting the sustained use of solar water disinfection - Experiences from a global promotion and dissemination programme', *Desalination*, vol. 248, no. 1–3, pp. 144–151, **2009**, doi: 10.1016/j.desal.2008.05.050.
[220] Vivar, M. and M. Fuentes, 'Using solar disinfected water: On the bacterial regrowth over 1-week of water usage including direct intake after sun exposure and long-term dark storage', *Sol. Energy*, vol. 131, pp. 138–148, **2016**, doi: 10.1016/j.solener.2016.02.044.
[221] Wegelin, M. *et al.*, 'Does sunlight change the material and content of polyethylene

terephthalate (pet) bottles?', *J. Water Supply Res. Technol. - AQUA*, vol. 50, no. 3, pp. 125–133, **2001**, doi: 10.2166/aqua.2001.0012.
[222] Schmid, P., M. Kohler, R. Meierhofer, S. Luzi, and M. Wegelin, 'Does the reuse of PET bottles during solar water disinfection pose a health risk due to the migration of plasticisers and other chemicals into the water?', *Water Res.*, vol. 42, no. 20, pp. 5054–5060, **2008**, doi: 10.1016/j.watres.2008.09.025.
[223] Eawag and Helvetas, 'SODIS method'. https://www.sodis.ch/methode/index_EN.html.
[224] Megersa, M., A. Beyene, A. Ambelu, and L. Triest, 'Coupling Extracts of Plant Coagulants With Solar Disinfection Showed a Complete Inactivation of Faecal Coliforms', *Clean - Soil, Air, Water*, vol. 47, no. 1, **2019**, doi: 10.1002/clen.201700450.
[225] Aquatabs, 'About Aquatabs'. http://www.aquatabs.com/index.php?id=774 (accessed Oct. 21, 2020).
[226] Centre for Disease Control and Prevention, 'Household Water Treatment Options in Developing: Household Chlorination', **2008**. Accessed: Sep. 15, 2020. [Online]. Available: www.cdc.gov/safewater.
[227] Harshfield, E., D. Lantagne, A. Turbes, and C. Null, 'Evaluating the Sustained Health Impact of Household Chlorination of Drinking Water in Rural Haiti', *Am. J. Trop. Med. Hyg*, vol. 87, no. 5, pp. 786–795, **2012**, doi: 10.4269/ajtmh.2012.12-0010.
[228] Yates, T. M., E. Armitage, L. V. Lehmann, A. J. Branz, and D. S. Lantagne, 'Effectiveness of chlorine dispensers in emergencies: Case study results from Haiti, Sierra Leone, Democratic Republic of Congo, and Senegal', *Environ. Sci. Technol.*, vol. 49, no. 8, pp. 5115–5122, **2015**, doi: 10.1021/acs.est.5b00309.
[229] Lantagne, D. S., 'Sodium hypochlorite dosage for household and emergency water treatment', *J. / Am. Water Work. Assoc.*, vol. 100, no. 8, **2008**, doi: 10.1002/j.1551-8833.2008.tb09704.x.
[230] Lantagne, D. S., F. Cardinali, and B. C. Blount, 'Disinfection by-product formation and mitigation strategies in point-of-use chlorination with sodium dichloroisocyanurate in Tanzania', *Am. J. Trop. Med. Hyg.*, vol. 83, no. 1, pp. 135–143, **2010**, doi: 10.4269/ajtmh.2010.09-0431.
[231] Aamir Mazhar, M. *et al.*, 'Chlorination disinfection by-products in municipal drinking water e A review', **2020**, doi: 10.1016/j.jclepro.2020.123159.
[232] Gibbons, J. and S. Laha, 'Water puri®cation systems: a comparative analysis based on the occurrence of disinfection by-products', **1999**. [Online]. Available: www.elsevier.com/locate/envpol.
[233] Nieuwenhuijsen, M. J. *et al.*, 'The epidemiology and possible mechanisms of disinfection by-products in drinking water', *Trans. R. Soc. A*, vol. 367, pp. 4043–4076, **2009**, doi: 10.1098/rsta.2009.0116.
[234] Backer, L. C., D. L. Ashley, M. A. Bonin, F. L. Cardinali, S. M. Kieszak, and J. V. Wooten, 'Household exposures to drinking water disinfection by-products: Whole blood trihalomethane levels', *J. Expo. Anal. Environ. Epidemiol.*, vol. 10, no. 4, pp. 321–326, **2000**, doi: 10.1038/sj.jea.7500098.
[235] Solomon, E. T., S. Robele, H. Kloos, and B. Mengistie, 'Effect of household water treatment with chlorine on diarrhea among children under the age of five years in rural areas of Dire Dawa, eastern Ethiopia: a cluster randomized controlled trial', **2018**, doi: 10.1186/s40249-020-00680-9.
[236] Roma, E., T. Bond, and P. Jeffrey, 'Factors involved in sustained use of point-of-use

water disinfection methods: A field study from Flores Island, Indonesia', *J. Water Health*, vol. 12, no. 3, pp. 573–583, **2014**, doi: 10.2166/wh.2014.109.
[237] Medentech, 'Aquatabs handout', pp. 7–8, **2011**.
[238] Morton, A. and B. Fasolo, 'Behavioural decision theory for multi-criteria decision analysis: a guided tour ☆', *J. Oper. Res. Soc.*, vol. 60, pp. 268–275, **2008**, doi: 10.1057/palgrave.jors.2602550.
[239] PATH, 'Sparking Demand for Household Water Treatment Products: Lessons From Commercial Projects in Four Countries', **2012**.
[240] Kols, A., 'Extended User Testing of Water Treatment Devices in Andhra Pradesh', pp. 1–16, **2010**, [Online]. Available: http://www.path.org/projects/safe_water_user_testing.php.
[241] Wong, T., 'Evaluation of Household Water Treatment and Safe Storage (HWTS) Alternatives in Ghana by', p. 11, **2014**.
[242] State Health Access Data Assistance Centre, 'Why Surveying "Willingness to Pay" is Difficult', no. March, pp. 1–2, **2001**, [Online]. Available: http://www.shadac.org/.
[243] Hanington, B. and B. Martin, *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions*. Rockport Publishers, **2012**.
[244] Larsen, M. L. and A. Flensborg, 'Market creation toolbox: your guide to entering developing markets', **2011**. .
[245] Narayanasamy, N., 'Participatory rural appraisal: Principles, methods and application', SAGE Publications India, **2009**.
[246] Boeijen, A. van, *Delft design guide : design methods, delft university of technology, faculty of industrial design engineering*. **2013**.
[247] Mink, A., *Design for Well-Being An Approach for Understanding Users' Lives in Design for Development*. **2016**.
[248] Simanis, E. *et al.*, 'The Base of the Pyramid Protocol: Toward Next Generation BoP Strategy', **2008**. Accessed: Jan. 11, 2021. [Online]. Available: www.jogravely.com.
[249] Murray-Webster, R. and P. Simon, 'Making Sense of Stakeholder Mapping', **2006**. Accessed: Jan. 12, 2021. [Online]. Available: http://www.pmforum.org.
[250] Thompson, R., 'Stakeholder Analysis', **2019**.
[251] Ojomo, E., M. Elliott, L. Goodyear, M. Forson, and J. Bartram, 'Sustainability and scale-up of household water treatment and safe storage practices: Enablers and barriers to effective implementation', *Int. J. Hyg. Environ. Health*, vol. 218, no. 8, pp. 704–713, **2015**, doi: 10.1016/j.ijheh.2015.03.002.
[252] Weber, M. and K. Borcherding, 'Behavioral influences on weight judgments in multiattribute decision making', *Eur. J. Oper. Res.*, vol. 67, no. 1, pp. 1–12, **1993**, doi: 10.1016/0377-2217(93)90318-H.
[253] Jessop, A., 'Using imprecise estimates for weights', *J. Oper. Res. Soc.*, vol. 62, no. 6, pp. 1048–1055, **2011**, doi: 10.1057/jors.2010.46.
[254] Borcherding, K., T. Eppel, and D. von Winterfeldt, 'Comparison of Weighting Judgments in Multiattribute Utility Measurement', *Manage. Sci.*, vol. 37, no. 12, pp. 1603–1619, **1991**, doi: 10.1287/mnsc.37.12.1603.
[255] Langhans, S. D., P. Reichert, and N. Schuwirth, 'The method matters: A guide for indicator aggregation in ecological assessments', *Ecol. Indic.*, vol. 45, pp. 494–507, **2014**, doi: 10.1016/j.ecolind.2014.05.014.
[256] Mustajoki, J., 'Effects of imprecise weighting in hierarchical preference programming',

Eur. J. Oper. Res., vol. 218, no. 1, pp. 193–201, **2012**, doi: 10.1016/j.ejor.2011.10.033.
[257] Lilje, J. and H.-J. Mosler, 'Socio-psychological determinants for safe drinking water consumption behaviors: a multi-country review', **2017**, doi: 10.2166/washdev.2017.080.
[258] Contzen, N. and H.-J. Mosler, 'The Risks, Attitudes, Norms, Abilities, and Self-regulation (RANAS) approach to systematic behavior change', **2012**. Accessed: Jun. 17, 2020. [Online]. Available: http://www.eawag.ch/en/department/ess/main-.
[259] Daniel, D. *et al.*, 'Understanding the effect of socio-economic characteristics and psychosocial factors on household water treatment practices in rural Nepal using Bayesian Belief Networks', *Int. J. Hyg. Environ. Health*, vol. 222, no. 5, pp. 847–855, **2019**, doi: 10.1016/j.ijheh.2019.04.005.
[260] Mcdonagh, L. K. *et al.*, 'Application of the COM-B model to barriers and facilitators to chlamydia testing in general practice for young people and primary care practitioners: a systematic review', **2018**, doi: 10.1186/s13012-018-0821-y.
[261] Michie, S., L. Atkins, and H. Gainforth, 'Changing Behaviour to Improve Clinical Practice and Policy', vol. 22, pp. 1–20, **2015**.
[262] Brown, M., 'EFFECTIVENESS OF CERAMIC FILTRATION FOR DRINKING WATER TREATMENT IN CAMBODIA', **2007**.
[263] McGuigan, K. G. *et al.*, 'Batch solar disinfection inactivates oocysts of Cryptosporidium parvum and cysts of Giardia muris in drinking water', *J. Appl. Microbiol.*, vol. 101, no. 2, pp. 453–463, **2006**, doi: 10.1111/j.1365-2672.2006.02935.x.
[264] CAWST, 'LifeStraw Family 2.0'. https://www.hwts.info/products-technologies/d4c8a80b/lifestraw-family-20/technical-information (accessed Oct. 20, 2020).
[265] WHO, 'Cholera outbreak. Assessing the outbreak response and improving preparedness', **2004**.
[266] Kändler, M. *et al.*, 'Impact of land use on water quality in the upper Nisa catchment in the Czech Republic and in Germany', *Sci. Total Environ.*, vol. 586, pp. 1316–1325, **2017**.
[267] Patterson, C., A. Anderson, R. Sinha, N. Muhammad, and D. Pearson, 'Nanofiltration membranes for removal of color and pathogens in small public drinking water sources', *J. Environ. Eng. (United States)*, vol. 138, no. 1, pp. 48–57, **2012**, doi: 10.1061/(ASCE)EE.1943-7870.0000463.

Appendices

A. List of assumptions and choices

1. Introduction

- **Use SDM as a structure** (chapter 1.3 and **Error! Reference source not found.**.)
    - o SDM has been chosen because it is a process to inform decision-makers rather than a method to find the best outcome.

2. Identification of objectives and criteria

- Literature review is used to identify the objectives and criteria
    - o A **Literature review** is chosen because the goal is to provide a summary of literature on the topic of HWTS criteria (chapter 2.2.1).
    - o **Models on behavioral change** are used to help understand why people do or do not use HWTS (chapter 2.2.1 and B).
        - ▪ Chosen is to include the RANAS model, because this is a model for behavioral change especially for the WASH sector in developing countries.
        - ▪ COM-B is more general and gives a better understanding what drives long-standing behaviour and how decisions are made.
    - o **Objective Hierarchy is used to structure the information** found in literature review (chapter 3.1).

- Face-to-face interviews (chapter 2.2.2)
    - o **Semi-structured interviews** are used, to gain quantitative information in a structured way but still leave flexibility in the conversation.
    - o **Participants** have experience with the use of one or several HWTS in one or several of the contexts included in this study. When selecting the experts, the desired variation in focus area, type of function, and a limited number of respondents from the same organisation were considered.

- The set of **criteria are divided in general criteria and situation-specific criteria**. The general criteria and situation-specific criteria are of the same importance. The general criteria are addressed before the situation-specific criteria, to start of generic.

- Criteria on health improvement (chapter 3.2.1)
    - o **For the criterion 'water quality' a 4-level construction is chosen**, as this is based on the 4-level rating of the WHO research used. (chapter 3.1)
    - o The **values on water quality are based on the log10 reduction of viruses, bacteria and protozoa**, measured by the reference pathogens as described in the WHO evaluation rounds.
    - o For the **risk of by-product formation, all the leachates and disinfectant concentrations are considered** even if the concentrations are lower than the WHO health guidelines.

    - **Multiple values in the matrix are based on specific products**, as indicated in Table 4.

- Criteria on acceptability and adaptability (chapter 3.2.2)
    - The **WHO is chosen as the highest recognized authority to approve**, with a higher score if the HWTS is also proven effective in the field.
    - For ease of operation, **>10 minutes per day is chosen as time consuming**.
    - Ease of maintenance, **> 20 minutes per month is chosen as time consuming**.

- Criteria on accessibility (chapter 3.2.3)
    - **Lifecycle costs in this research include investment and operational costs**, but do not include possible discounts, subsidies, transport and costs on implementation program.
    - Lifecycle costs are measured in **$ per liters treated water**.
    - Ease of transportation, **>10 kg is chosen as too heavy to transport** and <1 kg as light weight for transportation.
    - **Supply chain requirements makes a distinction** between accessibility of an existing supply chain and setting up a supply chain. The second part is included in a different context 'prior local use'.

3. Chose alternatives

- For the HWTS included, these aspects are considered (chapter 4.1)
    - The focus is on HWTS for disinfection to reduce bacteria, viruses and protozoa.
    - The technique is already widely used in various locations around the world.
    - The technique is used in low-income settings.
    - Suitable for a household of 5 people.
    - HWTS that do not need electricity to function.
- For the membrane filter, ultrafiltration is chosen to include.
- For the contexts included, these aspects are considered (chapter 4.3)
    - The contexts must differ from one another.
    - The contexts must be located in low-income settings.
    - HWTS must have been used before in the context.
    - The context generally does not yet have a permanent way of obtaining safe and affordable drinking water.

4. Estimate preference

4.1. Value matrix (chapter 2.3.1)

- **Quantitative values** found in the literature were kept in quantitative ratio if possible as it is more precise.
- The rating system for the **constructed criteria in the value matrix is a 5-point scale** where 1 is the worst and 5 is the best rating for the HWTS.
- The value matrix indicates if values are based on **specific products**.
- For feedback on the value matrix, **semi-structured interviews with experts from the Delft University of Technology** were conducted.
- **Consistency of the values found in literature must be tracked**. The following aspects are taken into account:

    - The source of the findings.
    - The amount of literature found on the subject.
    - The consistency of the findings.
    - Whether findings have been proven in the field, in existing situations.

4.2. Weight general criteria

- Best-Worst Method (chapter 2.3.2.1 and 5.2)
    - BWM is chosen because it needs less comparisons, which is important for the large number of criteria included.
    - **Linear BWM** is used, as it can calculate unique result.
    - The consistency is checked with **the output-based consistency ratio**.
    - A **consistency ratio threshold of 0.25** is chosen.
    - The comparison was made using **category and local criteria**. This is because otherwise there would be too many criteria to compare in one step.

- Online expert survey (chapter 2.3.2.2)
    - Chosen as a way to get the input data for BWM.
    - An **online survey is chosen so that a larger group of experts could be reached**, and the experts could do the survey at the best time for them.
    - When **selecting the experts**, the desired variation in nationality, focus area, type of function, and a limited number of respondents from the same organisation were considered.
    - The survey is **designed against bias** – see chapter 2.3.2.2

4.3. Ranking alternatives (chapter 2.3.3 and 5.3)

- **Two method are used for normalization and aggregation** to compare the ranking.
- **TOPSIS is used**, because it is a method for ranking and a large number of qualitative and quantitative criteria can be included.
- **WSM is used**, because it is a widely used, straightforward approach.
- **Max-Min method is used** for normalisation for WSM.
- The **ranking results from TOPSIS is used** as the results to continue with, because it was found to be less sensitive to scale than WSM.
- The **criterion 'quantity' is not included in the ranking**. This was chosen because it is not a linear criterion. If the criterion exceeds a certain value, i.e., the minimum water demand, then a much higher value does not have a much greater advantage.

5. Evaluate trade-offs of the situation-specific criteria

- Effectiveness across water qualities is the focus on the **recommended test for turbidity**. This recommendation is chosen because it can be tested very easily and can have a big influence on the efficacy and use of the HWTS
- **Attractiveness of the product is a way to measure dignity and status** but is a simplification.

B. Behavioural change models used

The criteria with a focus on social acceptance were established with, among other things, the help of models on behavioural change. Two models used are RANAS and the COM-B model. Both will be explained in this appendix.

The RANAS model

The RANAS model consists of 5 sections: Risk, Attitude, Norm, Ability, and Self-Regulation and focuses on behavioural change in the WASH sector in developing countries [41]. The five factors of the RANAS model describe all the drivers for individuals to enhance behavioural change based on health, on the level of households [87], [257]. Figure 28 shows the elements of the RANAS model.

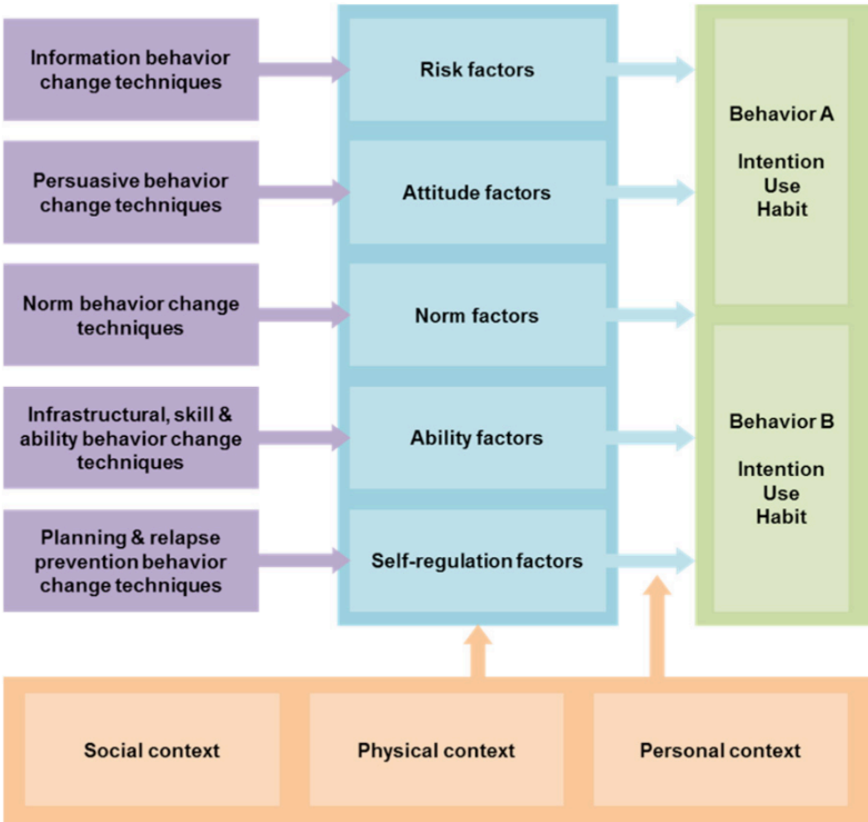


Figure 28: The RANAS model with the including elements [258].

Risk

Risk represents the individual's understanding of the health risks and the awareness of the severity and personal vulnerability [257]–[259]. Risk factors consists of perceived vulnerability, perceived severity and factual health knowledge [258]. Criteria like health knowledge and seriousness are included.

Attitude

Attitude indicates whether the individual has a positive or negative view of the new behaviour [257], [258]. Attitude includes the beliefs costs and benefits and the feelings that occur when thinking about or acting out a behaviour. Criteria like trust in the product, time to use, feelings on tase and smell are included in this part.

Norm
Norm is the "perceived social pressure towards a behaviour". It entails the factors other's behaviour, other's (dis)approval and personal importance [257], [258]. This includes criteria like social influence, feeling of obligation.

Ability
Ability stands for the trust an individual has in being able to practice a certain behaviour. Ability consists of how-to-do knowledge, confidence in performance, in continuation and in recovering [257], [258]. This includes criteria like ease of use, ease of maintenance and long term adaptation.

Self-regulation
Self-regulation stands for "person's attempts to plan and self-monitor a behaviour and to manage conflicting goals and distracting cues". Factors for self-regulation are action planning, action control, barrier planning, remembering and commitment [258].

The COM-B model

The COM-B model stands for the three components to behaviour (B): Capability (C), Opportunity (O) and Motivation (M) [42]. The COM-B model gives a better understanding what drives long-standing behaviour and how decisions are made [43]. The model is more generic, without a focus on WASH. COM-B sees behaviour as the interaction of the three components, as shown in Figure 29. COM-B is used for the Behaviour Change Wheel, another tool to design interventions for encouraging behavioural change [260], [261]. The Behaviour Change Wheel is shown in Figure 30.

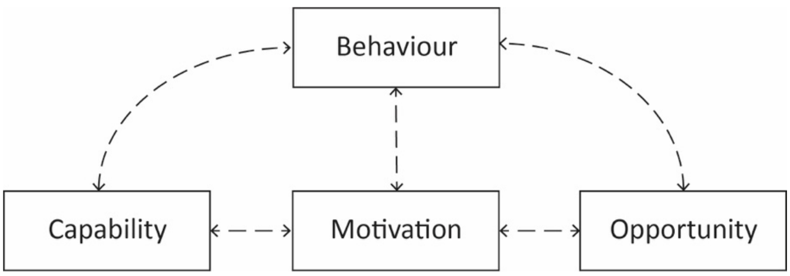


Figure 29: The COM-B model exists of the interactions between Behaviour, Capability, Motivation and Opportunity.

Capability
Capability means whether a person has the psychological and physical ability to exhibit a certain behaviour. So does a person have the knowledge and skills and the physical strength and endorsement [43].

Opportunity
Opportunity stands for the external factors that make a certain behaviour possible. This exists of the physical opportunity provided by the environment and the social opportunity provided by the social factors [43].

Motivation

Motivation stands for the internal process which makes the behaviour more important to carry out than other competing behaviours. This entails reflective motivation like evaluating past events and automatic motivation, like desires and impulses [43].

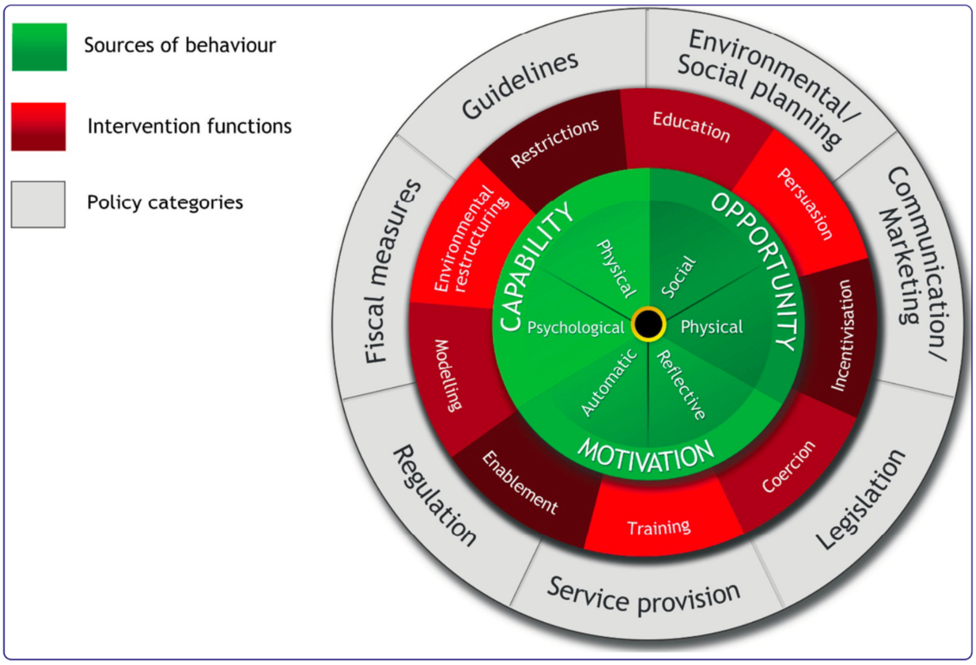


Figure 30: The Behavioral Change Wheel [42].

C. Take-aways of Face-to-face interviews with experts from group A

Table 23 contains take-aways from the face-to-face interviews conducted with expert group A. The face-to-face expert interviews are part of the method to obtain the objectives and criteria. The interviews were all held online, at different times. The interviews are numbered so that reference can be made in the main text.

Table 23:Information on the experts interviewed about the contexts included and the obtained set of criteria.

	Organisation	Type of function	NGO/ commercial	Focus locations
[A]	Forthemany	Policy maker + technical expert	Commercial	Worldwide
[B]	Simavi	Policy maker	NGO	Worldwide
[C]	The Red Cross	Technical expert	NGO	Worldwide
[D]	Connect international	Policy maker	NGO	Africa
[E]	Aqua for all	Policy maker	NGO	Africa and Asia
[F]	Nazava	Policy maker + technical expert	Commercial	Worldwide
[G]	Nazava	Policy maker + technical expert	Commercial	Ethiopia
[H]	WaterAid	Policy maker	NGO	Ethiopia
[I]	Basic water needs	Technical expert	Commercial	Worldwide
[J]	iDE	Policy maker	NGO	Ethiopia
[K]	Max Foundation	Policy maker	NGO	Bangladesh and Nepal
[L]	Unicef	Context specialist + policy maker	NGO	Worldwide

[A] Interview 03/06/2020

- There is not always one best outcome. For example in a refugee camp, you have different individuals, who may want to use another product.

[B] Interview 10/06/2020

- Materials at a slum are more often available because it is close to a large city. Provided that the right choice of materials has been considered when installing the system.
- If water also looks dirty or cloudy, the realisation that you will become ill is often higher.
- Trust in technology is also very much trust in government and local water companies.
- The dignity and status that people can get out of HWTS certainly helps. Sometimes even more than hammering away at the health benefits.
- People who have a little more to spend often choose a nicer design.
- Creating ownership is very important.

[C] Interview 10/06/2020

- Important criteria are:
  - Costs: in emergencies, many people must be reached quickly. The product cannot be too expensive as a lot of products are needed.
  - Logistics: the product must be easy to transport in order to reach these people quickly.

- Use: make sure people really use it, for example by giving more training. This can also be linked to the social criteria of acceptance.

- Status and dignity certainly have an influence on the use of the HWTS, but within emergency aid this is often less important.
- When choosing between HWTS, it will help the acceptability to use the HWTS that people already know.
- It can be a problem if different products are distributed in the same population. This does happen and can occur because there will be too few products otherwise or because different parties are present with different suppliers.

[D] Interview 10/06/2020

- It is important for users that they can drink water quickly after putting in the untreated water.
- Because it's sometimes difficult to explain why water quality is so important, and people have different priorities, selling HWTS can be difficult.
- The importance of status is not very high, especially if a better design means that the product becomes more expensive.
- Robustness of the product is always important, either because of transport or because people don't always handle the product well.

[E] Interview 11/06/2020

- Cooperation with recognized authorities is important. If they endorse the product, there is more confidence in the product. Authorities often have an active role in promotion and distribution.
- Replacing parts is a bigger problem in a rural village. It is then important that sufficient stock and spare parts are available locally.
- Importance of clean drinking water is well known to many people, also through more use of social media.
- Social status is an important element.
- Training is very important and instructions in their own language and with pictures.
- You have to ensure that people themselves are the owner of the product.
- The less maintenance is needed, the better.

[F] Interview 12/06/2020

- Delivery and maintenance are always a challenge. Especially in case of natural disasters, when the areas are not accessible.
- People know that you have to treat water before drinking it. Only people don't always know what options of products exist to do so.
- Dignity is very important for a paying customer, that they take pride in it and like to put it in the house. This is often less important in emergency situations.
- People are aware of the economic benefit of HWTS instead of alternative costs for drinking water.

[G] Interview 12/06/2020

- In rural villages it can be a problem to get spare parts as the vendors are often located in the capital.

- People prefer to buy a product through a semi-governmental organisation or corporation because they trust that more.
- The water filter is often used as a status symbol, you see that the filter is often placed in a prominent room for people to see it.
- In the design, however, the environment has to be taken into account. For example, it is important that the filter has a footing, because households in rural villages often do not have a table.
- Odour, colour and taste are important for acceptance.
- It is important that people know that drinking water has to be treated. Often, they only then start using an HWTS.

[H] Interview 17/06/2020

- Chlorine is used less in rural villages because it can go wrong there due to a lack of clarity about how much chlorine should be used for the quality of the raw water.
- It helps if others inthe social circle use the product as well.
- Important that the product is easy to use and not a lot of actions are needed.

[I] Interview 18/06/2020

- A product must be attractive, and that is crucial. When a product is attractive, it is relative.
- The ideal product is that by means of a few drawings you understand how to use the thing, and no training is needed.
- Demonstrations and training become difficult in emergency situations, as there is no time or manpower to do so.
- My experience is that people want to buy a water filter if it is clear that they or their children are getting sick of it, if water is dirty and cloudy or if it tastes dirty.
- User-friendliness and comprehensibility are very important when cleaning the product.

[J] Interview 18/06/2020

- Odour, colour, taste and the temperature of the water are important in the trust that the product works well.
- It is important that the flow rate is fast enough for a household.
- It is important that part of the labelling consists of visuals.
- What people find attractive differs per person, but this plays an important role in the choice and use of the HWTS.

[K] Interview 19/06/2020

- People understand the health problems of untreated water and they know the challenges.
- However, products must be available locally.

[L] Interview 02/07/2020

- The aim is to reach as many people as possible as quickly as possible, especially in emergency situations. Then it is good to see what is local. In addition, local production is also good for the whole market.
- Belief in how the technology works is very important, even crucial. Taste and smell can play a role in this.
- Keep listening carefully to what people like.

D. Take-aways feedback sessions with experts group B

This appendix contains take-aways from various conversations with experts from group B. All the experts from this group are from Delft University of Technology The face-to-face expert interviews are part of the method to evaluate the value matrix. The interviews were all held online, at different times. The interviews are numbered so that reference can be made in the main text.

Table 24: Information of the experts interviewed about the concept value matrix.

	Function	Organisation	Focus of interview
[M]	Associate professor	TU Delft	Membrane filter
[N]	PhD researcher	TU Delft	SODIS
[O]	Professor of Drinking Water Engineering	TU Delft and Waternet	Chlorination and biosand filter
[P]	PhD researcher	TU Delft	Ceramic candle filter and ceramic pot filter

[M] Interview 26/10/2020 – Membrane filter

- There is no residual protection in the reservoir.
- The membrane filter has no by-product.
- If there are damages to the 'straws' of a membrane filter, the consumer won't be able to see that.
- A membrane filter is not designed to significantly improve taste or smell. Because taste and smell are often caused by smaller particles, the membrane filter often can't filter it all out of the water.

[N] Interview 28/10/2020 – SODIS

- The variability in the Log10 reduction values is expected, as this depends on the time exposed to sunlight, the sunlight intensity, quality of the bottle (how scratched) and turbidity of the water.
- In reality it is possible that users do not actually drink from the bottle and still use a cup, but with the explanation of the technique it is recommended to drink directly from the bottle.
- If there are a lot of scratches on the bottle, the water may need a little longer time in the sunlight to get the same microbial log reduction. It is unclear to the user when this should be considered or even if the bottle needs to be replaced.
- In practice, it often happens that users do not drink the water immediately after it comes out of the sun, but let it cool down for a while and drink it the next day, for example.
- When SODIS is recommended, the flyers are always handed out to the users.

[O] Interview 30/10/2020 – Biosand filter and chlorination

- Because Both techniques do not have a closed storage system, the risk of recontamination does increase. People don't often clean a jerry can either. With chlorine there is residual protection which reduces the chance of regrowth and recontamination.
- By-products can only occur if the biological activity increases to such an extent that the oxygen content in the biolayer decreases sharply.

- Chlorination has a clear indicator when treatment is finished, as you can smell it in the water.
- For the biosand filter, it is not entirely clear to the user when the filter will work properly.
- For chlorination, the color gets better, but the taste is chemical.
- Maintenance for the biosand filter is relatively long.

[P] Interview 12/11/2020 – Ceramic candle and ceramic pot filter

- The storage tank can't be reached by people, making it saver against recontamination.
- Silver ions leaches in the treated water, but it does not make the water risk free for recontamination.
- Leaching of by-products is not standard for the ceramic pot filter, it depends on the clay they use. It is more a manufacturing error.
- Ceramic candle filters are more controlled as they are produced by the same manufacturer and not made locally.
- Ceramic pot filters are heavy and break easily.
- The ceramic pot filters are transported without the plastic bucket.

E.Consistency of sources in the value matrix

Table 25: Sources and consistency of the values in the value matrix.

		Ceramic candle filter *Literature used*	*Consistency rate*	**Ceramic pot filter** *Literature used*	*Consistency rate*	**Membrane filter** *Literature used*	*Consistency rate*	**Biosand filter** *Literature used*	*Consistency rate*	**Sodis** *Literature used*	*Consistency rate*	**Chlorination** *Literature used*	*Consistency rate*
Health improvement	**Quantity [L/h]**	J. Brown & Sobsey, 2007; CAWST, 2011	**Consistent, small range**	M. Brown, 2007; Casanova et al., 2012; CAWST, 2011; Ehdaie et al., 2017; Mcallister, 2005; Sobsey et al., 2008; SPOUTS of Water, 2014; van Halem et al., 2009; WHO/UNICEF, 2012	**Consistent, small range**	Producer of LifeStraw Family and Community, Boisson et al., 2010; Boisson, Schmidt, Berhanu, Gezahegn, & Clasen, 2009; WHO, 2012	**Consistent**	D. Lantagne, Meierhofer, Allgood, McGuigan, & Quick, 2009; Loo et al., 2012; Sisson et al., 2013; Sobsey et al., 2008; WHO/UNICEF, 2012; WSP, 2010	**Medium consistent, big range. Biosand filters can be made locally or filled with sand locally, being one of the reasons for a bigger range in flow rate.**	CAWST, 2011; Sobsey, 2002; Sobsey et al., 2008	**Depends on the bottle size**	Producer, CAWST, 2011; Roma, Bond, & Jeffrey, 2014; Sobsey et al., 2008	**Consistent**
	Water quality	WHO, 2019		WHO, 2019		WHO, 2012		CAWST, 2011; Petterson, 2016; Sisson et al., 2013; Sobsey et al., 2007; Tellen et al., 2010; WSP, 2010	**Medium consistent**	Expert opinion, Boyle et al., 2008; CAWST, 2011; Eawag, 2016; Galli & Smiyanov, 2018; Heaselgrave & Kilvington, 2011; McGuigan et al., 2006; Petterson, 2016; Sobsey et al., 2007; Wegelin et al., 1994	**Inconsistent, might be due to difference in hours exposed to sunlight and intensity of sunlight**	WHO, 2012	

	Risk of recontamination	CAWST, 2011; D. Lantagne et al., 2011; Pérez-Vidal et al., 2016	**Consistent**	CAWST, 2011; Ehdaie et al., 2017; D. Lantagne et al., 2011; Lemons et al., 2016; Regula Meierhofer et al., 2019	**Consistent**	CAWST, n.d.-b; D. Lantagne et al., 2011; WHO/UNICEF, 2012; WHO, 2019	**Consistent**	Curry et al., 2015; Fiore et al., 2010; D. Lantagne et al., 2011	**Medium consistent**	Expert opinion, CAWST, 2011; Centre for Disease Control and Prevention, 2008b; Eawag, 2016; D. Lantagne et al., 2011; Sobsey, 2002; Vivar & Fuentes, 2016; WHO/UNICEF, 2012; WHO, 2004, 2019	**Consistent**	CAWST, 2011; Harshfield et al., 2012; Yates et al., 2015	**Consistent**
	Risk of by-product formation	WHO, 2019, WHO, 2017, expert opinion	**Consistent**	Archer et al., 2011; D. Lantagne, 2001; Regula Meierhofer et al., 2019; Mwabi et al., 2013; Schaefer et al., 2018; Van Halem et al., 2007; van Halem et al., 2009; WHO, 2019	**Inconsistent, different findings in (field) research**	Expert opinion, Loo et al., 2012	**Consistent**	Expert opinion, Santos et al., 2016	**Consistent**	CAWST, 2011; Santos et al., 2016; Schmid et al., 2008; Sobsey, 2002; Wegelin et al., 2001	**Consistent**	Aamir Mazhar et al., 2020; Backer et al., 2000; Gibbons & Laha, 1999; D. S. Lantagne, 2008; D. S. Lantagne, Cardinali, & Blount, 2010; Nieuwenhuijsen et al., 2009; Santos et al., 2016; WHO, 2019	**Consistent**
	Reliability of product safety	WHO, 2019	**Own interpretation -clear when treatment complete**	CAWST, 2011; WHO, 2019	**Own interpretation -clear when treatment complete**	Producer, expert opinion, WHO, 2019	**Own interpretation -clear when treatment complete**	Expert opinion, Dow Baker & Baker, 2012; K Ngai et al., 2014; UNHCR, 2008	**Consistent**	Expert opinion		WHO, 2019	**Own interpretation -clear when treatment complete**
Acceptability/ adaptation	**Odour/colour / taste**	Producer, CAWST, 2011; Nazava, 2003	**Consistent**	Ehdaie et al., 2017; Van Halem et al., 2007; Yang et al., 2020	**Inconsistent, especially on the effect the first weeks**	Expert opinion, Kändler et al., 2017; Loo et al., 2012; Patterson, Anderson,	**Consistent**	CAWST, 2011; Fewster et al., 2004; D. Lantagne et al., 2011; Loo et al., 2012; Tellen et al.,	**Medium consistent**	Expert opinion, CAWST, 2011; Pagsuyoin et al., 2015; Roma et al., 2014; Sobsey, 2002	**Inconsistent**	Centre for Disease Control and Prevention, 2008a; Kincaid, 2010; D. Lantagne &	**Inconsistent**

						Sinha, Muhammad, & Pearson, 2012; WHO/UNICEF, 2012		2010; Wu et al., 2020				Clasen, 2009; Loo et al., 2012; Pagsuyoin et al., 2015; Roma et al., 2014; Solomon et al., 2018	
	Approval by authorities	DAHME, MAJNO, RAI, & WANG, 2017; WHO, 2019	**Consistent, also literature on diarrheal reduction used as reference**	WHO, 2019	**Also literature on diarrheal reduction used as reference**	Thomas Clasen et al., 2015; Naranjo & Gerba, 2011; WHO, 2012, 2019	**Consistent, also literature on diarrheal reduction used as reference**	WHO, 2011, 2012	**Consistent, also literature on diarrheal reduction used as reference**	Eawag & Helvetas, n.d.	**Also literature on diarrheal reduction used as reference**	Roma et al., 2014; Stevenson, 2008; WHO, 2012, 2019	**Consistent, also literature on diarrheal reduction used as reference**
	Labelling and instructions	Producer		Producers, Layman, n.d.	**Consistent**	Producer		Flyer, Cawst, 2012	**Compared to flyer images found, which was consistent**	Flyer, expert opinion	**Expert opinion compared to flyer images found, which was consistent**	Producer	
	Ease of operating	Galli & Smiyanov, 2018; Pagsuyoin et al., 2015; Sobsey et al., 2008	**Consistent**	Lemons et al., 2016; Pagsuyoin et al., 2015; Sobsey et al., 2008; Van Halem et al., 2007	**Consistent**	Producer, Loo et al., 2012; Sobsey, 2002; Vestergaard, n.d.; WHO/UNICEF, 2012	**Mostly consistent, 1 indicates user support needed**	D. Lantagne et al., 2011; Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey, 2002; Sobsey et al., 2008	**Consistent**	CAWST, 2011; Centre for Disease Control and Prevention, 2008b; Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey, 2002; Sobsey et al., 2008	**Consistent**	D. Lantagne et al., 2011; Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey, 2002; Sobsey et al., 2008	**Consistent**
	Maintenance needed	CAWST, 2011; T Clasen & Boisson, 2006; D. Lantagne et al., 2011; Pérez-Vidal et al., 2016	**Consistent**	Producer, J. Brown & Sobsey, 2007; CAWST, 2011; Pagsuyoin et al., 2015; Pérez-Vidal et al., 2016; Van Halem et al., 2007	**Consistent**	Producer, Loo et al., 2012; Pérez-Vidal et al., 2016	**Consistent**	K Ngai et al., 2014; Kennedy et al., 2013;Ngai et al., 2007 D. Lantagne et al., 2011; Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey et al., 2008;	**Inconsistent on ese and how time-consuming**	CAWST, 2011; Pagsuyoin et al., 2015	**Consistent**	Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey et al., 2008	**Consistent**

								Stevenson, 2008; WHO/UNICEF, 2012					
	Lifecycle costs [$/treated L]	CAWST, 2011; T. F. Clasen, Brown, Collin, Suntura, & Cairncross, 2004; Sobsey, 2002	**Consistent, medium range of the investment costs and assumption on L treated water per year**	J. Brown & Sobsey, 2007; CAWST, 2011; Galli & Smiyanov, 2018; Offringa, 2010; SPOUTS of Water, n.d.; UNHCR, 2008	**Medium consistent, big range of the investment costs and assumption on L treated water per year**	Producer	**Assumption on L treated water per year**	CAWST, 2011; Green, 2008; Sobsey et al., 2008	**Medium consistent, big range of the investment costs and depends on type of filter body and assumption L treated water/yr**	CAWST, 2011; Galli & Smiyanov, 2018; Megersa et al., 2019; R. Meierhofer & Landolt, 2009	**Medium consistent – some assumptions have been made**	Producer	**Assumption on L treated water per year for the container**
Economic feasability	**Ease of transportation**	CAWST, 2011; Loo et al., 2012; UNHCR, 2008	**Medium consistent**	CAWST, 2011; Loo et al., 2012	**Consistent**	Loo et al., 2012	**Consistent**	CAWST, 2011; D. Lantagne et al., 2011; Loo et al., 2012; Sharma & Sood, 2016; Sobsey et al., 2008; Vanderzwaag et al., 2009; WHO/UNICEF, 2012	**Consistent**	Loo et al., 2012; Sobsey, 2002	**Consistent**	D. S. Lantagne, 2008; Loo et al., 2012; Roma et al., 2014; UNHCR, 2008	**Consistent**
	Supply chain requirements	CAWST, 2011; Loo et al., 2012	**Consistent**	Loo et al., 2012; Pagsuyoin et al., 2015	**Consistent**	Expert opinion, WHO, 2012	**Consistent**	Loo et al., 2012; Pagsuyoin et al., 2015; Vanderzwaag et al., 2009	**Consistent**	CAWST, 2011; Eawag, 2016; Pagsuyoin et al., 2015; Sobsey et al., 2008	**Consistent**	CAWST, 2011; Loo et al., 2012; Pagsuyoin et al., 2015; Sobsey et al., 2008; WHO/UNICEF, 2012	**Consistent**

F. List of survey respondents, expert group C

This appendix consists of information on the experts (group C) who participated in the online survey shown in Table 26. In the case of empty fields, the participant has indicated that this information cannot be shared.

Table 26: Information on responses of online survey, expert group C.

Respondent number	Gender	Focus locations	Type of organisation ***Closed question***	Function ***Open question***	Function type ***Closed question***
1	Female	India	NGO	Water related	Director
2	Male	Worldwide	Commercial organisation	General Manager	Director
3	Male	Worldwide	Educational institute	PhD researcher	Academic researcher
4	Male	Costa Rica	Governmental organisation	R&D	Technician/engineer
5	Male	Mozambique			
6	Female	Mozambique	Commercial organisation	Hydrologist	Context expert
7	Male	Ethiopia			
8	Unknown	Unknown			Manager
9	Male	Ethiopia	Other non-profit		
10	Male	Indonesia	Commercial organisation	Director	Director
11	Female	Worldwide		Coordinator	Technician/engineer
12	Unknown	Unknown	Governmental organisation	Professor	Academic researcher
13	Female	Worldwide	Educational institute	Research Scientist	Academic researcher
14	Unknown	Unknown			
15	Male	Argentina	Educational institute	Coordinator of natural sciences area full-time teacher	Academic researcher
16	Male	South Asia and Middle East		Senior WASH Advisor	Context expert
17	Male	Costa Rica	Educational institute	Head and researcher in drinking water treatment	Academic researcher
18	Male	Worldwide	Other non-profit	Advisor	Technician/engineer
19	Female	Latin America	NGO	Senior WASH Advisor	Technician/engineer
20	Female	Africa and Asia	NGO	Senior Programme Manager	Context expert
21	Male	Ethiopia	Commercial organisation	Manager	Manager
22	Male	Brazil	NGO	Research advisor	Academic researcher

23	Female	Equador	Governmental organisation		Context expert
24	Unknown	Worldwide			
25	Female	Indonesia	NGO	WASH Specialist	Context expert
26	Male	Worldwide	Educational institute	Professor	Academic researcher
27	Male	Ethiopia	Commercial organisation	General Manager	Director
28	Unknown	Unknown			
29	Female	Worldwide			
30	Female	Worldwide		Group Leader	Academic researcher
31	Male	Indonesia, Uganda and Kenya			
32	Male	Worldwide	Governmental organisation	Research Assistant	Technician/engineer
33	Male	Kenya	Other non-profit	CEO	Director
34	Female	Uganda, Nepal, Burkina Faso, Tanzania	Educational institute	Senior Scientist	Academic researcher
35	Male	Latin America		Water Advisor	Context expert
36	Female	Worldwide	Other non-profit		Academic researcher
37	Male	Bangladesh	Educational institute	Professor	Academic researcher
38	Unknown	Kenya	NGO	WASH Project Manager	Manager
39	Male	Ethiopia	NGO		Technician/engineer

G. BWM results and consistency values

This appendix entails the data from the survey, following the BWM. The criteria weights are the average value. Besides the average value, the median and standard deviation are shown. Only data with a consistency lower than 0.25 is considered for the final weights.

Context 1: Rural village

Health improvement						
Criteria	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety	Consistency
1	0.12831241	0.509065551	0.160390516	0.041841004	0.160390516	0.132496513
2	0.038835	0.107875	0.151025	0.188781	0.513484	0.241639698
3	0.22826087	0.342391304	0.342391304	0.048913043	0.038043478	0.114130435
4	0.10170562	0.585596968	0.130764371	0.051168667	0.130764371	0.329753632
5	0.109890	0.549451	0.109890	0.175824	0.054945	0.32967033
6	0.074122	0.478544	0.197659	0.052016	0.197659	0.11443433
7	0.10994764	0.204188482	0.329842932	0.329842932	0.02617801	0.12565445
8	0.13464991	0.468581688	0.13464991	0.037701975	0.224416517	0.204667864
9	0.11363636	0.25	0.295454545	0.159090909	0.181818182	0.068181818
10	0.12844037	0.19266055	0.28440367	0.036697248	0.357798165	0.100917431
11	0.29545455	0.295454545	0.159090909	0.090909091	0.159090909	0.022727273
12	0.20140105	0.288966725	0.394045534	0.03502627	0.08056042	0.113835377
13	0.29596413	0.295964126	0.295964126	0.031390135	0.080717489	0.107623318
14	0.19337017	0.451197053	0.193370166	0.046040516	0.116022099	0.128913444
15	0.16666667	0.277777778	0.166666667	0.055555556	0.333333333	0.055555556
16	0.28571429	0.380952381	0.142857143	0.047619048	0.142857143	0.142857143
17	0.2295082	0.382513661	0.229508197	0.043715847	0.114754098	0.076502732
18	0.110333	0.392294	0.056042	0.392294	0.049037	0.281961471
19	0.434343	0.257576	0.171717	0.050505	0.085859	0.080808081
20	0.16666667	0.277777778	0.333333333	0.055555556	0.166666667	0.055555556
21	0.27108434	0.271084337	0.271084337	0.024096386	0.162650602	0.054216867
22	0.18461538	0.430769231	0.184615385	0.061538462	0.138461538	0.123076923
23	0.40438871	0.122257053	0.203761755	0.065830721	0.203761755	0.206896552
24	0.042553	0.391489	0.242553	0.161702	0.161702	0.093617021
25	0.10176884	0.57669009	0.162830143	0.116307245	0.042403683	0.237460625
26	0.09328969	0.250409165	0.466448445	0.034369885	0.155482815	0.21603928
27	0.08695652	0.326086957	0.195652174	0.195652174	0.195652174	0.065217391
28	0.08737093	0.122319301	0.448768864	0.035742653	0.305798253	0.162827641
29	0.14108911	0.430693069	0.141089109	0.235148515	0.051980198	0.274752475
30	0.26865672	0.368159204	0.134328358	0.049751244	0.179104478	0.169154229
31	0.29310345	0.379310345	0.086206897	0.103448276	0.137931034	0.120689655
32	0.11864407	0.593220339	0.118644068	0.050847458	0.118644068	0.237288136
33	0.07926479	0.418150488	0.184951177	0.040206778	0.277426766	0.136703044
34	0.0533049	0.111940299	0.52771855	0.179104478	0.12793177	0.367803838
35	0.1509434	0.283018868	0.396226415	0.056603774	0.113207547	0.169811321
36	0.03607214	0.513026052	0.100200401	0.233800935	0.116900468	0.188376754
37	0.45064378	0.210300429	0.090128755	0.038626609	0.210300429	0.180257511
Average	**0.184208**	**0.334931**	**0.227149**	**0.081866**	**0.171846**	**0.132754**
St. dev	**0.112665**	**0.126974**	**0.104182**	**0.070994**	**0.100413**	
Median	**0.158805**	**0.311026**	**0.194511**	**0.050676**	**0.159741**	

Acceptability and adaptation						
Criteria	Odour/colour/taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance	Consistency
1	0.142857143	0.057142857	0.228571429	0.285714286	0.285714286	0.05714286
2	0.131068	0.038835	0.131068	0.567961	0.131068	0.2184466
3	0.285714286	0.428571429	0.047619048	0.19047619	0.047619048	0.14285714
4	0.560252366	0.105993691	0.055520505	0.158990536	0.119242902	0.39369085
5	0.135111	0.062222	0.118222	0.566222	0.118222	0.37955556
6	0.467005	0.096447	0.050761	0.192893	0.192893	0.11167513
7	0.107142857	0.035714286	0.214285714	0.321428571	0.321428571	0.10714286
8	0.202072539	0.134715026	0.025906736	0.305699482	0.331606218	0.0984456
9	0.128205128	0.282051282	0.179487179	0.205128205	0.205128205	0.07692308
10	0.261538462	0.174358974	0.051282051	0.174358974	0.338461538	0.18461538
11	0.2	0.24	0.08	0.24	0.24	0.04
12	0.269922879	0.046272494	0.035989717	0.323907455	0.323907455	0.05398458
13	0.2	0.08	0.24	0.24	0.24	0.04
14	0.133079848	0.095057034	0.062103929	0.487959442	0.221799747	0.1774398
15	0.208955224	0.029850746	0.104477612	0.28358209	0.373134328	0.13432836
16	0.073446328	0.039548023	0.242937853	0.322033898	0.322033898	0.12429379
17	0.264483627	0.105793451	0.041981528	0.411418976	0.176322418	0.11754828
18	0.069324	0.350087	0.038128	0.464471	0.077990	0.27383016
19	0.238636	0.045455	0.079545	0.397727	0.238636	0.07954545
20	0.289719626	0.046728972	0.336448598	0.196261682	0.130841121	0.10280374
21	0.166666667	0.041666667	0.166666667	0.291666667	0.333333333	0.04166667
22	0.25	0.277777778	0.138888889	0.277777778	0.055555556	0.02777778
23	0.581395349	0.069767442	0.11627907	0.11627907	0.11627907	0.23255814
24	0.361111	0.083333	0.055556	0.250000	0.250000	0.13888889
25	0.115455101	0.131948687	0.062716351	0.102626756	0.587253105	0.3363877
26	0.185185185	0.111111111	0.333333333	0.037037037	0.333333333	0.14814815
27	0.19565217	0.19565217	0.08695652	0.32608696	0.19565217	0.06521739
28	0.099818512	0.036297641	0.119782214	0.444646098	0.299455535	0.15426497
29	0.081570997	0.021148036	0.299093656	0.299093656	0.299093656	0.10876133
30	0.176334107	0.046403712	0.13225058	0.26450116	0.380510441	0.14849188
31	0.359375	0.109375	0.09375	0.21875	0.21875	0.078125
32	0.122580645	0.058064516	0.122580645	0.574193548	0.122580645	0.28387097
33	0.078651685	0.078651685	0.056179775	0.393258427	0.393258427	0.31460674
34	0.18844836	0.107684777	0.150758688	0.509055311	0.044052863	0.24473813
35	0.1	0.133333333	0.083333333	0.283333333	0.4	0.11666667
36	0.095923261	0.172661871	0.047961631	0.107913669	0.575539568	0.28776978
37	0.396508728	0.052369077	0.211970075	0.211970075	0.127182045	0.2394015
Average	**0.224864**	**0.108749**	**0.138036**	**0.289225**	**0.239126**	**0.120397**
St. dev	**0.117280**	**0.093724**	**0.089345**	**0.114623**	**0.101651**	
Median	**0.200000**	**0.081667**	**0.118031**	**0.283458**	**0.240000**	

Figure 31:Individual BWM values for health gains and acceptability/adaptability for rural villages.

	Accessability			
Criteria	Lifecycle costs	Ease of transportation	Supply chain requirements	Consistency
1	0.290909091	0.109090909	0.6	0.27272727
2	0.058824	0.201681	0.739496	0.26890756
3	0.461538462	0.076923077	0.461538462	0.23076923
4	0.150326797	0.058823529	0.790849673	0.26143791
5	0.714286	0.175824	0.109890	0.16483516
6	0.206349	0.111111	0.682540	0.34920635
7	0.384615385	0.076923077	0.538461538	0.15384615
8	0.633333333	0.283333333	0.083333333	0.21666667
9	0.266666667	0.2	0.533333333	0.33333333
10	0.25	0.071428571	0.678571429	0.32142857
11	0.4	0.4	0.2	0
12	0.257142857	0.142857143	0.6	0.17142857
13	0.333333333	0.166666667	0.5	0.16666667
14	0.636363636	0.272727273	0.090909091	0.18181818
15	0.290909091	0.109090909	0.6	0.27272727
16	0.166666667	0.333333333	0.5	0.16666667
17	0.233333333	0.1	0.666666667	0.26666667
18	0.693182	0.090909	0.215909	0.60227273
19	0.352941	0.117647	0.529412	0.17647059
20	0.3	0.2	0.5	0.1
21	0.4	0.1	0.5	0.1
22	0.4375	0.125	0.4375	0.0625
23	0.6	0.111111111	0.288888889	0.26666667
24	0.391304	0.086957	0.521739	0.13043478
25	0.807486631	0.058823529	0.13368984	0.39572193
26	0.630769231	0.076923077	0.292307692	0.24615385
27	0.5	0.2	0.3	0.1
28	0.125	0.125	0.75	0.25
29	0.818181818	0.066666667	0.115151515	0.21818182
30	0.3	0.071428571	0.628571429	0.27142857
31	0.56	0.24	0.2	0.16
32	0.076923077	0.760683761	0.162393162	0.37606838
33	0.333333333	0.166666667	0.5	0.16666667
34	0.793333333	0.066666667	0.14	0.32666667
35	0.458333333	0.166666667	0.375	0.29166667
36	0.754545455	0.154545455	0.090909091	0.48181818
37	0.714285714	0.194805195	0.090909091	0.25974026
Average	**0.441815**	**0.171672**	**0.386512**	**0.158155**
St. dev	**0.179903**	**0.093377**	**0.195678**	
Median	**0.400000**	**0.154762**	**0.480769**	

	Main groups			
Criteria	Health improvement	Acceptability and adaptation	Economic feasibility	Consistency
1	0.428571429	0.476190476	0.095238095	0.04761905
2	0.204082	0.724490	0.071429	0.29591837
3	0.333333333	0.333333333	0.333333333	0.66666667
4	0.806060606	0.127272727	0.066666667	0.33939394
5	0.465116	0.348837	0.186047	0.58139535
6	0.076923	0.261538	0.661538	0.12307692
7	0.333333333	0.333333333	0.333333333	0
8	0.222222222	0.444444444	0.333333333	0.22222222
9	0.333333333	0.133333333	0.533333333	0.2
10	0.333333333	0.074074074	0.592592593	0.25925926
11	0.4	0.4	0.2	0
12	0.379310345	0.551724138	0.068965517	0.17241379
13	0.333333333	0.333333333	0.333333333	0
14	0.682539683	0.111111111	0.206349206	0.34920635
15	0.333333333	0.333333333	0.333333333	0
16	0.454545455	0.454545455	0.090909091	0
17	0.611111111	0.166666667	0.222222222	0.27777778
18	0.153846	0.153846	0.692308	0.23076923
19	0.222222	0.555556	0.222222	0.11111111
20	0.321428571	0.535714286	0.142857143	0.10714286
21	0.333333333	0.333333333	0.333333333	0
22	0.45	0.2	0.35	0.25
23	0.757575758	0.151515152	0.090909091	0.3030303
24	0.400000	0.200000	0.400000	0
25	0.778571429	0.071428571	0.15	0.42142857
26	0.6	0.309090909	0.090909091	0.32727273
27	0.333333333	0.333333333	0.333333333	0
28	0.276923077	0.646153846	0.076923077	0.18461538
29	0.641025641	0.128205128	0.230769231	0.51282051
30	0.361111111	0.527777778	0.111111111	0.19444444
31	0.266666667	0.166666667	0.566666667	0.23333333
32	0.777777778	0.150793651	0.071428571	0.27777778
33	0.333333333	0.095238095	0.571428571	0.23809524
34	0.130681818	0.806818182	0.0625	0.36931818
35	0.210526316	0.526315789	0.263157895	0.31578947
36	0.79020979	0.132867133	0.076923077	0.40559441
37	0.419354839	0.516129032	0.064516129	0.09677419
Average	**0.325387**	**0.362978**	**0.311274**	**0.109619**
St. dev	**0.096344**	**0.159920**	**0.197710**	
Median	**0.333333**	**0.333333**	**0.333333**	

Figure 32:Individual BWM values for accessibility and main categories, for rural villages.

Context 2: Disease outbreak

Health improvement						
Criteria	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety	Consistency
1	0.07407407	0.5	0.166666667	0.037037037	0.222222222	0.166666667
4	0.25609756	0.369918699	0.256097561	0.032520325	0.085365854	0.142276423
6	0.080645	0.392473	0.241935	0.043011	0.241935	0.091397849
10	0.10958904	0.273972603	0.401826484	0.03196347	0.182648402	0.146118721
13	0.26923077	0.269230769	0.161538462	0.030769231	0.269230769	0.053846154
18	0.30612245	0.306122449	0.12244898	0.081632653	0.183673469	0.06122449
18	0.303571	0.375000	0.053571	0.232143	0.035714	0.125
23	0.33009709	0.330097087	0.184466019	0.03236246	0.122977346	0.038834951
27	0.25641026	0.282051282	0.282051282	0.038461538	0.141025641	0.025641026
28	0.06603774	0.445754717	0.148584906	0.04245283	0.297169811	0.148584906
29	0.17137097	0.408266129	0.257056452	0.060483871	0.102822581	0.105846774
34	0.08695652	0.326086957	0.195652174	0.195652174	0.195652174	0.065217391
35	0.14666667	0.306666667	0.333333333	0.04	0.173333333	0.133333333
36	0.09868421	0.579769737	0.098684211	0.045230263	0.177631579	0.308388158
37	0.28915663	0.390361446	0.204819277	0.03373494	0.081927711	0.120481928
38	0.22222222	0.222222222	0.222222222	0.111111111	0.222222222	0
39	0.11864407	0.593220339	0.118644068	0.050847458	0.118644068	0.237288136
Average	**0.19293079**	**0.36196528**	**0.209432175**	**0.068386419**	**0.167285336**	**0.103859922**
St. dev	**0.09555592**	**0.094658375**	**0.086435746**	**0.061052288**	**0.073348175**	
Median	**0.196797**	**0.350008**	**0.200236**	**0.041226**	**0.177991**	

Acceptability and adaptation						
Criteria	Odour/colour/taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance	Consistency
1	0.034482759	0.144827586	0.337931034	0.337931034	0.144827586	0.09655172
4	0.170829744	0.097616997	0.056273328	0.538616136	0.136663796	0.14470284
6	0.142857	0.428571	0.047619	0.190476	0.190476	0.14285714
10	0.238095238	0.180952381	0.038095238	0.180952381	0.361904762	0.12380952
13	0.222222222	0.111111111	0.222222222	0.222222222	0.222222222	0
18	0.238095238	0.285714286	0.095238095	0.238095238	0.142857143	0.04761905
18	0.070994	0.070994	0.127789	0.638945	0.091278	0.56795132
23	0.076923077	0.046153846	0.138461538	0.323076923	0.415384615	0.09230769
27	0.264285714	0.042857143	0.307142857	0.307142857	0.078571429	0.05
28	0.116666667	0.1	0.05	0.233333333	0.5	0.2
29	0.230769231	0.333333333	0.153846154	0.230769231	0.051282051	0.12820513
34	0.195652174	0.195652174	0.086956522	0.326086957	0.195652174	0.06521739
35	0.058862001	0.094179202	0.052321779	0.323741007	0.47089601	0.147155
36	0.548571429	0.14	0.051428571	0.14	0.12	0.29142857
37	0.224852071	0.195266272	0.390532544	0.059171598	0.130177515	0.16568047
38	0.2	0.2	0.2	0.2	0.2	0
39	0.118644068	0.050847458	0.118644068	0.593220339	0.118644068	0.23728814
Average	**0.16888249**	**0.167138881**	**0.153018962**	**0.28698903**	**0.223970637**	**0.10942627**
St. dev	**0.073061139**	**0.111742845**	**0.114916716**	**0.135469576**	**0.143090771**	
Median	**0.195652**	**0.144828**	**0.118644**	**0.238095**	**0.190476**	

Figure 33:Individual BWM values for health and acceptability/adaptability for disease outbreak.

Accessability				
Criteria	Lifecycle costs	Ease of transportation	Supply chain requirements	Consistency
1	0.272727273	0.636363636	0.090909091	0.18181818
4	0.071428571	0.166666667	0.761904762	0.4047619
6	0.217949	0.705128	0.076923	0.16666667
10	0.3	0.071428571	0.628571429	0.27142857
13	0.2	0.3	0.5	0.1
18	0.333333333	0.333333333	0.333333333	0
18	0.147059	0.058824	0.794118	0.38235294
23	0.1	0.4	0.5	0.1
27	0.527777778	0.361111111	0.111111111	0.19444444
28	0.066666667	0.64	0.293333333	0.24
29	0.5625	0.3125	0.125	0.0625
34	0.15	0.6	0.25	0.15
35	0.25	0.25	0.5	0
36	0.666666667	0.25	0.083333333	0.33333333
37	0.673469388	0.142857143	0.183673469	0.24489796
38	0.333333333	0.333333333	0.333333333	0
39	0.076923077	0.777777778	0.145299145	0.23931624
Average	**0.289590736**	**0.44556958**	**0.264839684**	**0.12920335**
St. dev	**0.19316788**	**0.199785582**	**0.159673102**	
Median	**0.250000**	**0.361111**	**0.250000**	

Main groups				
Criteria	Health improvement	Acceptability and adaptation	Economic feasibility	Consistency
1	0.714285714	0.194805195	0.090909091	0.25974026
4	0.777777778	0.155555556	0.066666667	0.31111111
6	0.657143	0.271429	0.071429	0.15714286
10	0.361111111	0.111111111	0.527777778	0.19444444
13	0.333333333	0.333333333	0.333333333	0
18	0.4	0.4	0.2	0
18	0.721154	0.076923	0.201923	0.49038462
23	0.428571429	0.5	0.071428571	0.07142857
27	0.5	0.2	0.3	0.1
28	0.697916667	0.239583333	0.0625	0.26041667
29	0.407407407	0.518518519	0.074074074	0.11111111
34	0.4	0.5	0.1	0.1
35	0.818181818	0.090909091	0.090909091	0
36	0.783216783	0.13986014	0.076923077	0.47552448
37	0.777777778	0.145299145	0.076923077	0.23931624
38	0.333333333	0.333333333	0.333333333	0
39	0.777777778	0.138888889	0.083333333	0.19444444
Average	**0.516219737**	**0.295235166**	**0.188545097**	**0.09732397**
St. dev	**0.187233127**	**0.159488846**	**0.151056184**	
Median	**0.417989**	**0.302381**	**0.095455**	

Figure 34: Individual BWM values for accessibility and main categories, for disease outbreak.

Context 3: Urban slum

			Health improvement			
Criteria	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety	Consistency
1	0.03649635	0.109489051	0.153284672	0.153284672	0.547445255	0.218978102
4	0.04210526	0.463157895	0.126315789	0.210526316	0.157894737	0.168421053
5	0.05333333	0.566666667	0.126666667	0.126666667	0.126666667	0.193333333
6	0.13924051	0.447257384	0.185654008	0.042194093	0.185654008	0.109704641
7	0.10994764	0.204188482	0.329842932	0.329842932	0.02617801	0.12565445
8	0.20376176	0.437304075	0.122257053	0.032915361	0.203761755	0.173981191
9	0.14285714	0.142857143	0.285714286	0.142857143	0.285714286	0.142857143
10	0.08487269	0.297054418	0.454318522	0.044932601	0.118821767	0.139790315
12	0.18145957	0.272189349	0.370808679	0.039447732	0.136094675	0.17357002
14	0.25925926	0.333333333	0.111111111	0.037037037	0.259259259	0.074074074
15	0.19565217	0.2826087	0.2826087	0.04347826	0.19565217	0.108695652
16	0.20855615	0.473262032	0.20855615	0.040106952	0.069518717	0.152406417
17	0.22105263	0.368421053	0.221052632	0.042105263	0.147368421	0.073684211
18	0.27158774	0.467966574	0.066852368	0.037604457	0.155988858	0.19637883
19	0.15957447	0.372340426	0.328014184	0.044326241	0.095744681	0.106382979
20	0.15757576	0.387878788	0.236363636	0.060606061	0.157575758	0.084848485
23	0.12225705	0.404388715	0.203761755	0.065830721	0.203761755	0.206896552
24	0.04255319	0.391489362	0.242553191	0.161702128	0.161702128	0.093617021
25	0.11361142	0.62349067	0.048298573	0.100987925	0.113611416	0.285400659
26	0.0955414	0.332484076	0.385987261	0.026751592	0.159235669	0.14522293
27	0.08695652	0.326086957	0.195652174	0.195652174	0.195652174	0.065217391
28	0.15217391	0.355072464	0.22826087	0.036231884	0.22826087	0.101449275
29	0.15161725	0.570080863	0.151617251	0.084231806	0.04245283	0.188005391
30	0.33548387	0.407741935	0.122580645	0.036129032	0.098064516	0.15483871
31	0.23021583	0.374100719	0.194244604	0.071942446	0.129496403	0.158273381
33	0.14686825	0.285097192	0.414686825	0.110151188	0.043196544	0.155507559
34	0.04020101	0.557788945	0.125628141	0.150753769	0.125628141	0.195979899
35	0.1048951	0.125874126	0.41958042	0.13986014	0.20979021	0.293706294
37	0.35730337	0.387640449	0.157303371	0.030337079	0.06741573	0.114606742
38	0.09638554	0.645783133	0.096385542	0.053012048	0.108433735	0.221686747
Average	**0.15446034**	**0.380847506**	**0.218860108**	**0.087523488**	**0.158308554**	**0.144430803**
St. dev	**0.0857757**	**0.123451655**	**0.103243934**	**0.072435613**	**0.099221229**	
Median	**0.14924275**	**0.380870584**	**0.199706965**	**0.048972325**	**0.151678639**	

			Acceptability and adaptation			
Criteria	Odour/colour/taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance	Consistency
1	0.112612613	0.040540541	0.112612613	0.576576577	0.157657658	0.21171171
4	0.53805175	0.106544901	0.058599696	0.159817352	0.136986301	0.42085236
5	0.117073171	0.051219512	0.292682927	0.343902439	0.195121951	0.24146341
6	0.467391304	0.097826087	0.043478261	0.195652174	0.195652174	0.11956522
7	0.105691057	0.040650407	0.219512195	0.317073171	0.317073171	0.09756098
8	0.209677419	0.209677419	0.032258065	0.338709677	0.209677419	0.08064516
9	0.125	0.125	0.25	0.25	0.25	0.125
10	0.267716535	0.188976378	0.039370079	0.125984252	0.377952756	0.11023622
12	0.2	0.036363636	0.109090909	0.327272727	0.327272727	0.12727273
14	0.321100917	0.04587156	0.082568807	0.412844037	0.137614679	0.09174312
15	0.142857143	0.047619048	0.238095238	0.285714286	0.285714286	0.04761905
16	0.265957447	0.042553191	0.159574468	0.265957447	0.265957447	0.05319149
17	0.234899329	0.093959732	0.044742729	0.391498881	0.234899329	0.07829978
18	0.057803468	0.057803468	0.260115607	0.520231214	0.104046243	0.46242775
19	0.254545455	0.040909091	0.072727273	0.377272727	0.254545455	0.13181818
20	0.347826087	0.086956522	0.130434783	0.260869565	0.173913043	0.17391304
23	0.411764706	0.058823529	0.176470588	0.176470588	0.176470588	0.11764706
24	0.346153846	0.084615385	0.061538462	0.253846154	0.253846154	0.16153846
25	0.113611416	0.62349067	0.048298573	0.100987925	0.113611416	0.28540066
26	0.214285714	0.321428571	0.321428571	0.035714286	0.107142857	0.10714286
27	0.195652174	0.195652174	0.086956522	0.326086957	0.195652174	0.06521739
28	0.109090909	0.036363636	0.181818182	0.4	0.272727273	0.14545455
29	0.181208054	0.033557047	0.181208054	0.422818792	0.181208054	0.12080537
30	0.128971963	0.029906542	0.085981308	0.362616822	0.392523364	0.15327103
31	0.235294118	0.117647059	0.088235294	0.323529412	0.235294118	0.14705882
33	0.113372093	0.052325581	0.075581395	0.305232558	0.453488372	0.14825581
34	0.551619433	0.106275304	0.170040486	0.12145749	0.050607287	0.298583
35	0.141843972	0.113475177	0.106382979	0.425531915	0.212765957	0.31205674
37	0.1875	0.109375	0.328125	0.328125	0.046875	0.140625
38	0.592135698	0.041634541	0.115651503	0.134926754	0.115651503	0.21742483
Average	**0.23551111**	**0.089178088**	**0.141205729**	**0.301547811**	**0.232557262**	**0.12857925**
St. dev	**0.12328461**	**0.071698166**	**0.089871226**	**0.111818411**	**0.093726208**	
Median	**0.209677419**	**0.052325581**	**0.112612613**	**0.323529412**	**0.234899329**	

Figure 35: Individual BWM values for health and acceptability/adaptability for urban slums.

Accessability				
Criteria	Lifecycle costs	Ease of transportation	Supply chain requirements	Consistency
4	0.066666667	0.777777778	0.155555556	0.31111111
5	0.801136364	0.0625	0.136363636	0.42613636
6	0.666666667	0.212121212	0.121212121	0.18181818
7	0.196428571	0.0625	0.741071429	0.24107143
8	0.384615385	0.076923077	0.538461538	0.15384615
9	0.55	0.383333333	0.066666667	0.21666667
10	0.333333333	0.333333333	0.333333333	0
12	0.205357143	0.0625	0.732142857	0.29464286
14	0.5	0.1	0.4	0.3
15	0.675675676	0.189189189	0.135135135	0.27027027
16	0.575	0.1	0.325	0.075
17	0.538461538	0.153846154	0.307692308	0.07692308
18	0.222222222	0.083333333	0.694444444	0.19444444
19	0.680555556	0.111111111	0.208333333	0.56944444
20	0.525	0.1	0.375	0.225
23	0.647058824	0.117647059	0.235294118	0.05882353
24	0.206349206	0.111111111	0.682539683	0.34920635
25	0.391304348	0.086956522	0.52173913	0.13043478
26	0.805882353	0.135294118	0.058823529	0.27647059
27	0.6	0.090909091	0.309090909	0.32727273
28	0.333333333	0.222222222	0.444444444	0.11111111
29	0.071428571	0.193877551	0.734693878	0.23469388
30	0.818181818	0.090909091	0.090909091	0
31	0.618181818	0.090909091	0.290909091	0.25454545
33	0.146666667	0.066666667	0.786666667	0.38666667
34	0.25	0.375	0.375	0.125
35	0.784722222	0.0625	0.152777778	0.28472222
37	0.333333333	0.444444444	0.222222222	0.11111111
38	0.56	0.24	0.2	0.16
Unknw. 14-1	0.64	0.1	0.26	0.14
Average	**0.446464886**	**0.187580407**	**0.365954707**	**0.13533024**
St. dev	**0.196504175**	**0.121878895**	**0.210419076**	
Median	**0.458152174**	**0.135746606**	**0.329166667**	

Main groups				
Criteria	Health improvement	Acceptability and adaptation	Economic feasibility	Consistency
4	0.152777778	0.784722222	0.0625	0.28472222
5	0.79020979	0.132867133	0.076923077	0.40559441
6	0.727272727	0.181818182	0.090909091	0.54545455
7	0.071428571	0.271428571	0.657142857	0.15714286
8	0.333333333	0.333333333	0.333333333	0
9	0.162162162	0.567567568	0.27027027	0.24324324
10	0.25	0.1875	0.5625	0.3125
12	0.395833333	0.083333333	0.520833333	0.27083333
14	0.4	0.5	0.1	0.3
15	0.142857143	0.428571429	0.428571429	0.28571429
16	0.333333333	0.444444444	0.222222222	0.11111111
17	0.6	0.2	0.2	0.4
18	0.6	0.125	0.275	0.225
19	0.266666667	0.2	0.533333333	0.26666667
20	0.368421053	0.526315789	0.105263158	0.21052632
23	0.444444444	0.222222222	0.333333333	0.22222222
24	0.206349206	0.111111111	0.682539683	0.34920635
25	0.4	0.2	0.4	0
26	0.146153846	0.076923077	0.776923077	0.39230769
27	0.6	0.309090909	0.090909091	0.32727273
28	0.333333333	0.333333333	0.333333333	0
29	0.193877551	0.734693878	0.071428571	0.23469388
30	0.6	0.1	0.3	0.3
31	0.28	0.62	0.1	0.22
33	0.75	0.076923077	0.173076923	0.28846154
34	0.444444444	0.333333333	0.222222222	0.22222222
35	0.79375	0.14375	0.0625	0.35625
37	0.307692308	0.461538462	0.230769231	0.15384615
38	0.2	0.2	0.6	0.2
Unknw. 14-1	0.384615385	0.538461538	0.076923077	0.15384615
Average	**0.323805728**	**0.394111498**	**0.282082774**	**0.15692361**
St. dev	**0.131303236**	**0.178478133**	**0.174110006**	
Median	**0.333333333**	**0.333333333**	**0.27027027**	

Figure 36: Individual BWM values for accessibility and main categories, for urban slums.

Context 4: Refugee camp

Health improvement						
Criteria	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety	Consistency
1	0.11538462	0.461538462	0.192307692	0.038461538	0.192307692	0.115384615
3	0.29956585	0.299565847	0.325615051	0.039073806	0.03617945	0.026049204
5	0.4497992	0.281124498	0.140562249	0.080321285	0.048192771	0.112449799
9	0.125	0.25	0.25	0.125	0.25	0.125
14	0.35031847	0.350318471	0.095541401	0.044585987	0.159235669	0.127388535
15	0.18181818	0.272727273	0.272727273	0.090909091	0.181818182	0.090909091
21	0.27108434	0.271084337	0.271084337	0.024096386	0.162650602	0.054216867
29	0.18309859	0.415492958	0.183098592	0.183098592	0.035211268	0.133802817
30	0.42654028	0.201421801	0.120853081	0.049763033	0.201421801	0.177725118
34	0.05208333	0.109375	0.567708333	0.145833333	0.125	0.307291667
38	0.16666667	0.166666667	0.166666667	0.166666667	0.333333333	0.166666667
39	0.10098793	0.62349067	0.113611416	0.048298573	0.113611416	0.285400659
Average	**0.25692762**	**0.296994031**	**0.201845634**	**0.084197638**	**0.160035077**	**0.112959271**
St. dev	**0.12174048**	**0.090557972**	**0.075093968**	**0.056570878**	**0.097063691**	
Median	**0.22709146**	**0.276925885**	**0.187703142**	**0.065042159**	**0.172234392**	

Acceptability and adaptation						
Criteria	Odour/colour/taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance	Consistency
1	0.152173913	0.043478261	0.195652174	0.304347826	0.304347826	0.10869565
3	0.273224044	0.426229508	0.04007286	0.213114754	0.047358834	0.15300546
5	0.094017094	0.038461538	0.094017094	0.444444444	0.329059829	0.21367521
9	0.142857143	0.142857143	0.142857143	0.285714286	0.285714286	0.14285714
14	0.088607595	0.189873418	0.189873418	0.113924051	0.417721519	0.15189873
15	0.166666667	0.083333333	0.316666667	0.333333333	0.1	0.01666667
21	0.139534884	0.037209302	0.069767442	0.376744186	0.376744186	0.04186047
29	0.181208054	0.033557047	0.181208054	0.422818792	0.181208054	0.12080537
30	0.105150215	0.090128755	0.038626609	0.450643777	0.315450644	0.18025751
34	0.132783505	0.113814433	0.199175258	0.509690722	0.044536082	0.28701031
38	0.2	0.2	0.2	0.2	0.2	0
39	0.588235294	0.14379085	0.052287582	0.107843137	0.107843137	0.2745098
Average	**0.154343961**	**0.128512831**	**0.146874146**	**0.314508545**	**0.255760518**	**0.11297222**
St. dev	**0.055604823**	**0.121985468**	**0.08752041**	**0.113497084**	**0.119917553**	
Median	**0.147515528**	**0.086731044**	**0.162032598**	**0.31884058**	**0.295031056**	

Figure 37: Individual BWM values for health and acceptability/adaptability for refugee camps.

Accessability				
Criteria	Lifecycle costs	Ease of transportation	Supply chain requirements	Consistency
1	0.266666667	0.2	0.533333333	0.33333333
3	0.333333333	0.333333333	0.333333333	0.66666667
5	0.142857143	0.238095238	0.619047619	0.33333333
9	0.25	0.25	0.5	0.25
14	0.111111111	0.75308642	0.135802469	0.19753086
15	0.285714286	0.571428571	0.142857143	0
21	0.526315789	0.368421053	0.105263158	0.21052632
29	0.8	0.058823529	0.141176471	0.32941176
30	0.666666667	0.090909091	0.242424242	0.3030303
34	0.784313725	0.156862745	0.058823529	0.31372549
38	0.333333333	0.333333333	0.333333333	0
39	0.792857143	0.071428571	0.135714286	0.29285714
Average	**0.301294904**	**0.455253875**	**0.243451221**	**0.13161144**
St. dev	**0.15058607**	**0.204165678**	**0.169336524**	
Median	**0.285714286**	**0.368421053**	**0.142857143**	

Main groups				
Criteria	Health improvement	Acceptability and adaptation	Economic feasibility	Consistency
1	0.333333333	0.533333333	0.133333333	0.13333333
3	0.384615385	0.538461538	0.076923077	0.15384615
5	0.8	0.1375	0.0625	0.3
9	0.25	0.25	0.5	0.25
14	0.777777778	0.131313131	0.090909091	0.14141414
15	0.333333333	0.333333333	0.333333333	0
21	0.333333333	0.333333333	0.333333333	0
29	0.6	0.1	0.3	0.3
30	0.75	0.076923077	0.173076923	0.28846154
34	0.8	0.141176471	0.058823529	0.32941176
38	0.333333333	0.333333333	0.333333333	0
39	0.792307692	0.130769231	0.076923077	0.25384615
Average	**0.392246642**	**0.350444**	**0.257309357**	**0.09694195**
St. dev	**0.174551669**	**0.145936494**	**0.159078595**	
Median	**0.333333333**	**0.333333333**	**0.333333333**	

Figure 38: Individual BWM values for accessibility and main categories, for refugee camps.

Context 5: Emergency response after natural disaster

Health improvement						
Criteria	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety	Consistency
2	0.04477612	0.107462687	0.143283582	0.095522388	0.608955224	0.250746269
3	0.21428571	0.321428571	0.321428571	0.107142857	0.035714286	0.107142857
4	0.03910615	0.234636872	0.508379888	0.100558659	0.117318436	0.195530726
7	0.17647059	0.264705882	0.264705882	0.264705882	0.029411765	0.088235294
8	0.36328125	0.25390625	0.25390625	0.02734375	0.1015625	0.14453125
11	0.29545455	0.295454545	0.159090909	0.090909091	0.159090909	0.022727273
12	0.14342629	0.294820717	0.414342629	0.039840637	0.107569721	0.135458167
13	0.2890625	0.3203125	0.1796875	0.03125	0.1796875	0.0703125
19	0.38349515	0.247572816	0.247572816	0.038834951	0.082524272	0.111650485
21	0.18172378	0.145379024	0.531671859	0.037383178	0.10384216	0.195223261
22	0.16901408	0.394366197	0.253521127	0.126760563	0.056338028	0.112676056
23	0.41704036	0.076233184	0.049327354	0.228699552	0.228699552	0.269058296
24	0.04255319	0.391489362	0.242553191	0.161702128	0.161702128	0.093617021
25	0.14595452	0.600740349	0.046536224	0.109465891	0.097303014	0.274986779
26	0.1266055	0.412844037	0.211009174	0.03853211	0.211009174	0.220183486
31	0.27272727	0.090909091	0.090909091	0.363636364	0.181818182	0.090909091
32	0.10513834	0.614229249	0.10513834	0.055335968	0.120158103	0.22687747
35	0.26666667	0.066666667	0.333333333	0.2	0.133333333	0.133333333
36	0.03957597	0.578798587	0.133568905	0.114487633	0.133568905	0.222614841
38	0.22222222	0.222222222	0.222222222	0.111111111	0.222222222	0
39	0.04216867	0.611445783	0.105421687	0.120481928	0.120481928	0.231927711
Average	**0.18738766**	**0.320066021**	**0.254359076**	**0.112778712**	**0.125408531**	**0.133497268**
St. dev	**0.11000001**	**0.160084463**	**0.128651726**	**0.089496239**	**0.054637426**	
Median	**0.17909718**	**0.295137631**	**0.245063004**	**0.103850758**	**0.120320015**	

Acceptability and adaptation						
Criteria	Odour/colour/taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance	Consistency
2	0.107569721	0.039043825	0.15059761	0.552191235	0.15059761	0.20079681
3	0.316981132	0.483018868	0.041509434	0.101886792	0.056603774	0.19245283
4	0.421875	0.25	0.046875	0.1875	0.09375	0.328125
7	0.103448276	0.034482759	0.24137931	0.310344828	0.310344828	0.06896552
8	0.205183585	0.082073434	0.030237581	0.311015119	0.371490281	0.09935205
11	0.222222222	0.222222222	0.111111111	0.222222222	0.222222222	0
12	0.239130435	0.130434783	0.195652174	0.391304348	0.043478261	0.15217391
13	0.222222222	0.111111111	0.222222222	0.222222222	0.222222222	0
19	0.239543726	0.053231939	0.068441065	0.399239544	0.239543726	0.07984791
21	0.066115702	0.05785124	0.041322314	0.396694215	0.438016529	0.0661157
22	0.294117647	0.37254902	0.098039216	0.196078431	0.039215686	0.09803922
23	0.210526316	0.052631579	0.210526316	0.263157895	0.263157895	0.05263158
24	0.38372093	0.081395349	0.046511628	0.244186047	0.244186047	0.10465116
25	0.115384615	0.115384615	0.051282051	0.615384615	0.102564103	0.30769231
26	0.172413793	0.310344828	0.310344828	0.034482759	0.172413793	0.13793103
31	0.321428571	0.142857143	0.214285714	0.107142857	0.214285714	0.10714286
32	0.107692308	0.051282051	0.123076923	0.61025641	0.107692308	0.25128205
35	0.096774194	0.096774194	0.129032258	0.290322581	0.387096774	0.09677419
36	0.107142857	0.142857143	0.044642857	0.5625	0.142857143	0.29464286
38	0.2	0.2	0.2	0.2	0.2	0
39	0.576719577	0.052910053	0.148148148	0.111111111	0.111111111	0.31216931
Average	**0.212587405**	**0.154376393**	**0.144450799**	**0.265155693**	**0.22342971**	**0.09105467**
St. dev	**0.089417857**	**0.131818318**	**0.086062867**	**0.130727266**	**0.117550057**	
Median	**0.216374269**	**0.103942652**	**0.139814934**	**0.253671971**	**0.222222222**	

Figure 39: Individual BWM values for health and acceptability/adaptability for emergency response.

Accessability				
Criteria	Lifecycle costs	Ease of transportation	Supply chain requirements	Consistency
2	0.69047619	0.083333333	0.226190476	0.44047619
3	0.428571429	0.428571429	0.142857143	0
4	0.275	0.0625	0.6625	0.1625
7	0.058823529	0.411764706	0.529411765	0.11764706
8	0.076923077	0.679487179	0.243589744	0.29487179
11	0.3125	0.4375	0.25	0.1875
12	0.243243243	0.648648649	0.108108108	0.32432432
13	0.2	0.3	0.5	0.1
19	0.307692308	0.230769231	0.461538462	0.15384615
21	0.6	0.2	0.2	0.2
22	0.166666667	0.666666667	0.166666667	0.16666667
23	0.111111111	0.244444444	0.644444444	0.08888889
24	0.416666667	0.083333333	0.5	0.08333333
25	0.058823529	0.122994652	0.818181818	0.28877005
26	0.6	0.090909091	0.309090909	0.32727273
31	0.638888889	0.194444444	0.166666667	0.13888889
32	0.076923077	0.725274725	0.197802198	0.26373626
35	0.375	0.375	0.25	0.375
36	0.7875	0.15	0.0625	0.4125
38	0.333333333	0.333333333	0.333333333	0
39	0.144444444	0.055555556	0.8	0.35555556
Average	**0.320771161**	**0.299443966**	**0.379784873**	**0.11660592**
St. dev	**0.179236898**	**0.169451534**	**0.192175509**	
Median	**0.310096154**	**0.272222222**	**0.397435897**	

Main groups				
Criteria	Health improvement	Acceptability and adaptation	Economic feasibility	Consistency
2	0.204081633	0.071428571	0.724489796	0.29591837
3	0.384615385	0.538461538	0.076923077	0.15384615
4	0.79020979	0.132867133	0.076923077	0.40559441
7	0.333333333	0.583333333	0.083333333	0.25
8	0.4	0.4	0.2	0
11	0.4	0.4	0.2	0
12	0.541666667	0.375	0.083333333	0.20833333
13	0.333333333	0.333333333	0.333333333	0
19	0.642857143	0.285714286	0.071428571	0.21428571
21	0.333333333	0.333333333	0.333333333	0
22	0.568181818	0.340909091	0.090909091	0.11363636
23	0.682539683	0.206349206	0.111111111	0.34920635
24	0.5	0.2	0.3	0.1
25	0.760683761	0.076923077	0.162393162	0.37606838
26	0.6	0.309090909	0.090909091	0.32727273
31	0.333333333	0.166666667	0.5	0.16666667
32	0.777777778	0.150793651	0.071428571	0.27777778
35	0.375	0.375	0.25	0.375
36	0.8	0.133333333	0.066666667	0.4
38	0.333333333	0.333333333	0.333333333	0
39	0.77037037	0.162962963	0.066666667	0.37037037
Average	**0.425332307**	**0.357507076**	**0.217160617**	**0.10056402**
St. dev	**0.109582829**	**0.119114408**	**0.141614419**	
Median	**0.392307692**	**0.337121212**	**0.2**	

Figure 40: Individual BWM values for accessibility and main categories, for emergency response.

H. Results of the test of normality

In order to find out which statistical test can be used, it is necessary to check whether the data has been distributed normally. As the dataset consists of less than 30 measurement points, it cannot be assumed that the data is normally distributed. A test of normality has been performed in the program SPSS.

Category groups

Table 27: Results of the Test of Normality for the category groups.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Health improvement	.176	68	.000	.888	68	.000
Acceptability and adaptation	.131	68	.006	.962	68	.034
Economic feasibility	.159	68	.000	.885	68	.000

a. Lilliefors Significance Correction

Health improvement

Table 28: Results of the Test of Normality for the health improvement criteria.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Water quality	.065	104	.200*	.982	104	.184
Quantity	.088	104	.044	.950	104	.001
Risk of recontamination	.104	104	.007	.943	104	.000
Risk of by-products formation	.233	104	.000	.766	104	.000
Reliability product safety	.113	104	.002	.896	104	.000

a. Lilliefors Significance Correction

Acceptability/adaptation

Table 29: Results of the Test of Normality for the acceptability/adaptation criteria.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Odor/color/taste	.117	96	.002	.915	96	.000
Approval by authorities	.200	96	.000	.800	96	.000
Labelling and instructions	.117	96	.003	.919	96	.000
Ease of operating	.095	96	.034	.979	96	.133
Ease of maintenance	.054	96	.200*	.981	96	.186

a. Lilliefors Significance Correction

Accessibility

Table 30: Results of the Test of Normality for the accessibility criteria.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Lifecycle costs	.103	63	.091	.969	63	.116
Ease of transportation	.135	63	.006	.880	63	.000
Supply chain requirements	.139	63	.004	.941	63	.005

a. Lilliefors Significance Correction

I. Results of the Kruskal-Wallis test

This appendix shows the results of the Kruskal-Wallis test from the program SPSS. The grouping variable are the context they belong to. If the Kruskal-Wallis test shows significant difference between medians, the Dunn-Bonferroni test is conducted.

Category groups

Table 31: Results of the Kruskal-Wallis test for the category groups.

	Health improvement	Acceptability and adaptation	Economic feasibility
Kruskal-Wallis H	14.266	2.723	5.644
df	4	4	4
Asymp. Sig.	.006	.605	.227

Sample 1-Sam...	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
1-3	-1,669	5,952	-,281	,779	1,000
1-5	-14,183	6,689	-2,120	,034	,204
1-2	-25,667	6,526	-3,933	,000	,001
3-5	-12,514	6,827	-1,833	,067	,401
3-2	23,998	6,667	3,599	,000	,002
5-2	11,484	7,333	1,566	,117	,704

Figure 41: Results of the Dunn-Bonferroni test for the criteria category health improvement.

Health improvement

Table 32: Results of the Kruskal-Wallis test for the health improvement criteria.

	Quantity	Water quality	Risk of recontamination	Risk of by-products formation	Reliability product safety
Kruskal-Wallis H	5.878	6.562	1.301	3.873	3.776
df	4	4	4	4	4
Asymp. Sig.	.208	.161	.861	.423	.437

Acceptability/adaptation

Table 33: Results of the Kruskal-Wallis test for the acceptability/adaptation criteria.

	Odor/color/ taste	Approval by authorities	Labelling and instructions	Ease of operating	Ease of maintenance
Kruskal-Wallis H	6.363	8.966	.103	2.828	1.550
df	4	4	4	4	4
Asymp. Sig.	.174	.062	.999	.587	.818

Accessibility

Table 34: Results of the Kruskal-Wallis test for the accessibility criteria.

	Lifecycle costs	Ease of transportation	Supply chain requirements
Kruskal-Wallis H	8.158	19.381	3.573
df	3	3	3
Asymp. Sig.	.043	.000	.311

Sample 1-Sam...	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
2-5	-3,324	7,330	-,453	,650	1,000
2-3	-14,838	6,664	-2,226	,026	,156
2-1	14,940	6,523	2,290	,022	,132
5-3	11,514	6,824	1,687	,092	,549
5-1	11,617	6,686	1,737	,082	,494
3-1	,103	5,949	,017	,986	1,000

Figure 42: Results of the Dunn-Bonferroni test for the criterion Lifecycle costs.

Sample 1-Sam...	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
3-1	,442	6,519	,068	,946	1,000
3-4	-3,390	8,911	-,380	,704	1,000
3-5	-14,242	7,540	-1,889	,059	,589
3-2	22,825	7,540	3,027	,002	,025
1-4	-2,948	8,448	-,349	,727	1,000
1-5	-13,799	6,986	-1,975	,048	,482
1-2	-22,383	6,986	-3,204	,001	,014
4-5	-10,851	9,259	-1,172	,241	1,000
4-2	19,435	9,259	2,099	,036	,358
5-2	8,583	7,948	1,080	,280	1,000

Figure 43: Results of the Dunn-Bonferroni test for the criterion ease of transportation.